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Thin-Triple Windows – Now a Cost-Effective Envelope Trade-Off for High-Performance Homes

August 7, 2026

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PNNL, Alpen High Performance Products



U.S. DEPARTMENT of ENERGY BATTELLE

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Acknowledgements: Thank you to the U.S. Department of Energy for supporting this research.

We will be discussing

1. How and when major disruptive window and glass technology innovation occurs.
2. Why “thin glass” technology is quickly tracking toward a role as one of the most disruptive new innovations in recent industry history.

What is Thin Glass?

Thin glass is ultra-thin architectural glass, 0.5 to 1.3 mm thick, used in the center lite(s) of IGU configurations.



0.5 mm



Alpen’s preferred thin glass is Corning ® Enlighten™ Glass, a boro-aluminosilicate glass in 0.5 mm and 0.7 mm thicknesses, the slimmest and most durable thin glass available for architectural IGUs.



0.75 mm

Looks Pretty Similar Doesn't It?
But Things Aren't Always What They Appear



US Window Design
1700s



US Window Design
Today

The Prototypical “Energy Efficient” Window Sold in the United States Since 2000 . . . and Still in 2025



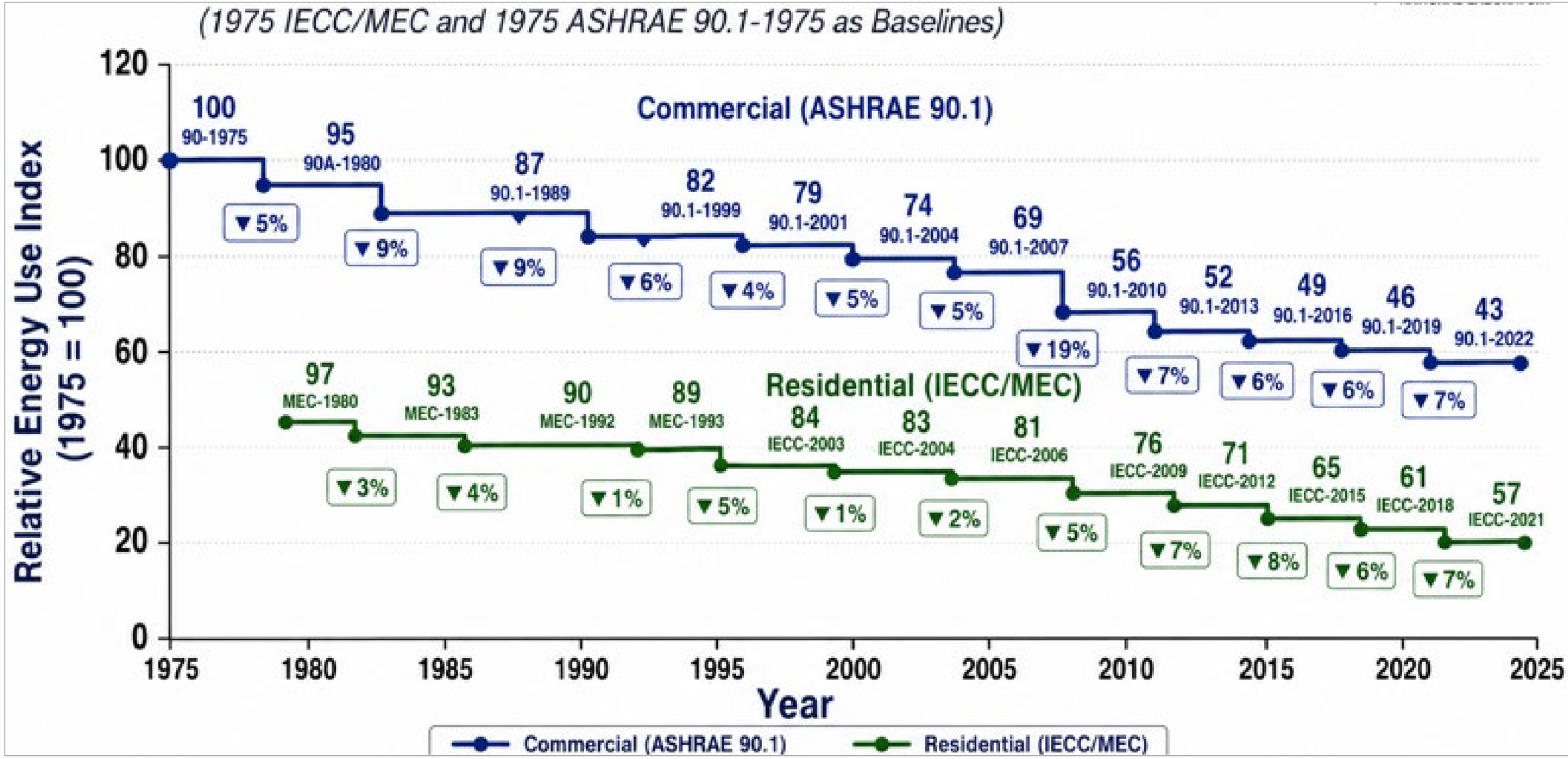
The Double-Pane Vinyl Window

Low-e Glass, Argon Gas-Filled

In U.S., two-thirds of operable windows are vertical or horizontal sliding.

How did we get to today's current status quo?
Especially with evolving building and energy codes?

Estimated Improvement in Residential and Commercial Energy Codes



Overview of Breakthrough Technologies

True Industry-Changing Breakthroughs in
Window And Glass **Technology Are Rare**

When Breakthroughs Arrive on the Scene,
They Do so Fast and are Very Impactful.

We are specifically looking at One such New Innovation
That has a Chance to Join the List – Thin Glass Technology.

But let me show you the Four major breakthroughs in the last 80 years.

We will come back to that shortly . . .

The Four Critical Industry Innovations Dominated Last 80 Years+

1. Invention of the Float Glass Process

2. Transition from Single to Dual Pane Insulated Glass Units

3. Commercialization of Low-e Coatings on Glass

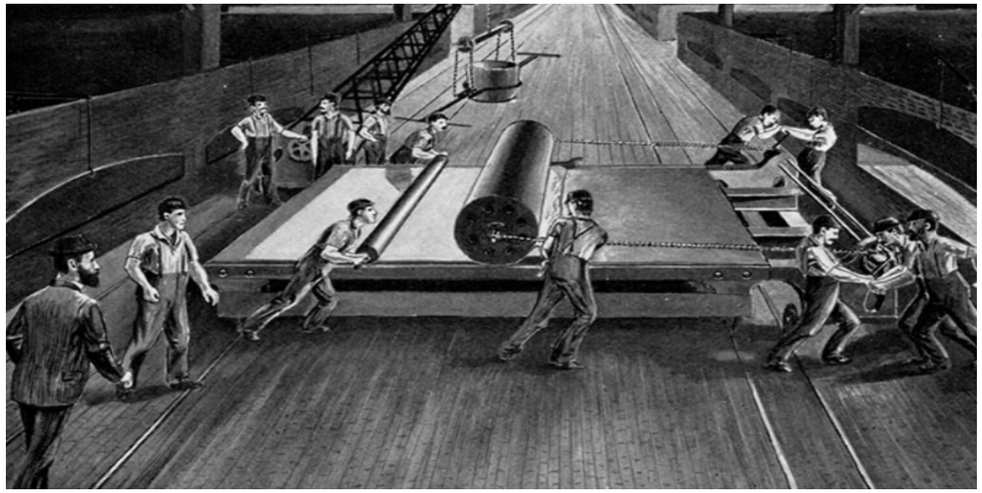
4. Rise of Vinyl Windows

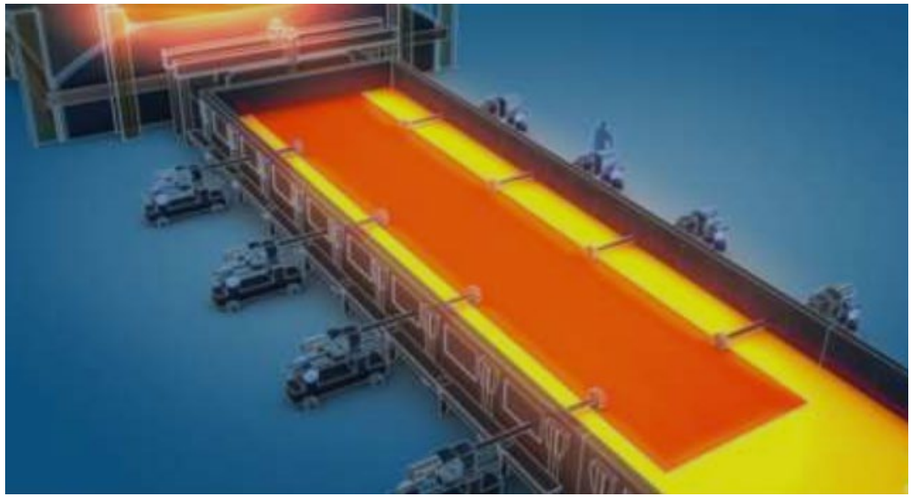
Some Critical Innovations in the Last 80 Years - Float Process

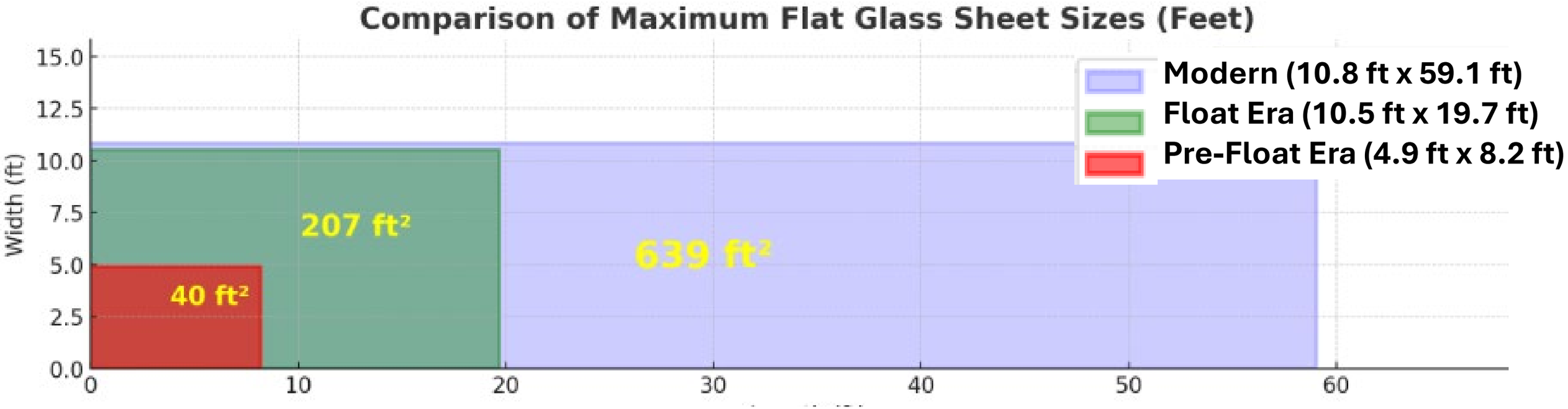


Publicly Announced 1959

Critical Innovations in the Last 80 Years - Float Glass



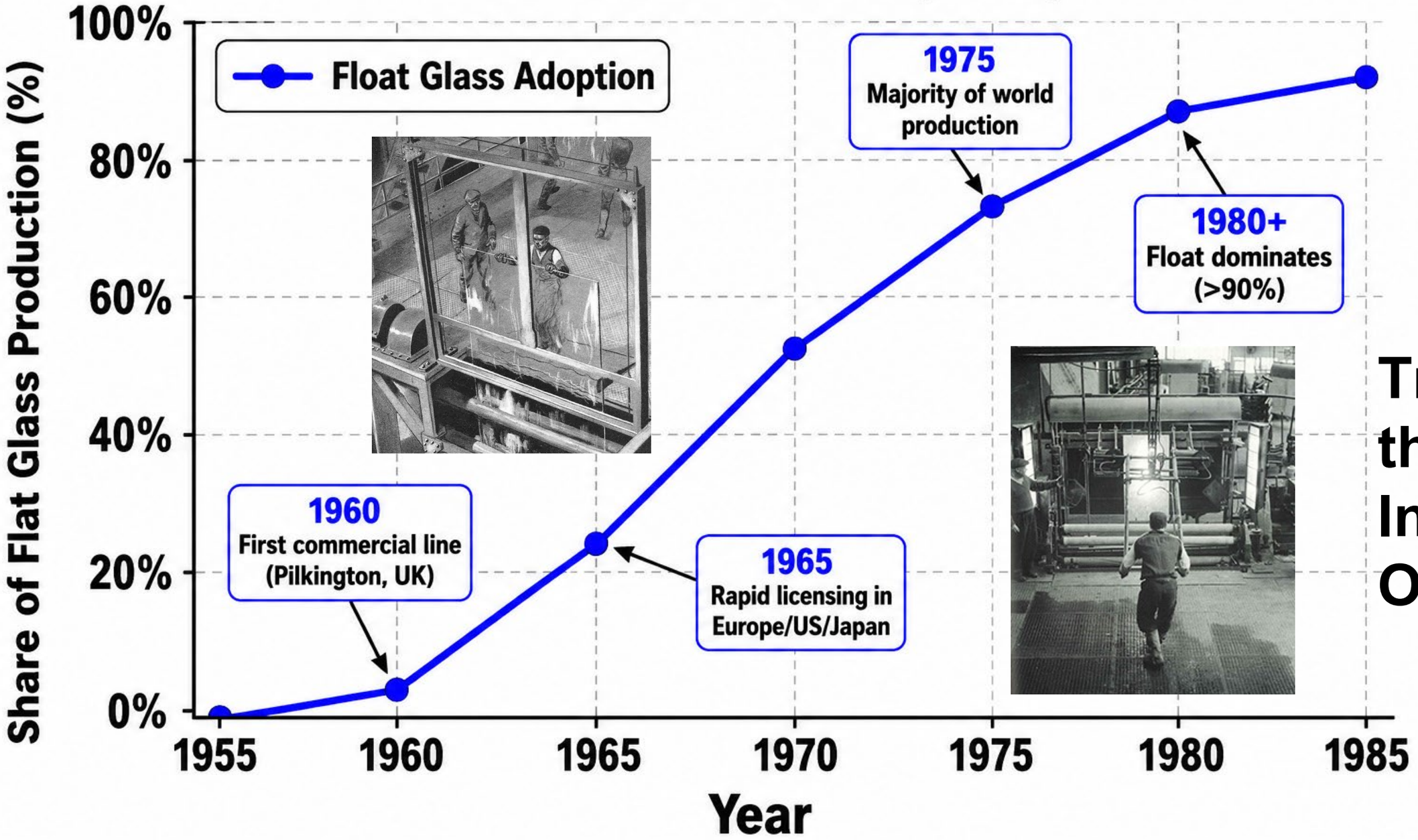




Dramatic drop in cost, increase in availability and size.

Global Adoption of Float Glass Process (1955–1985)

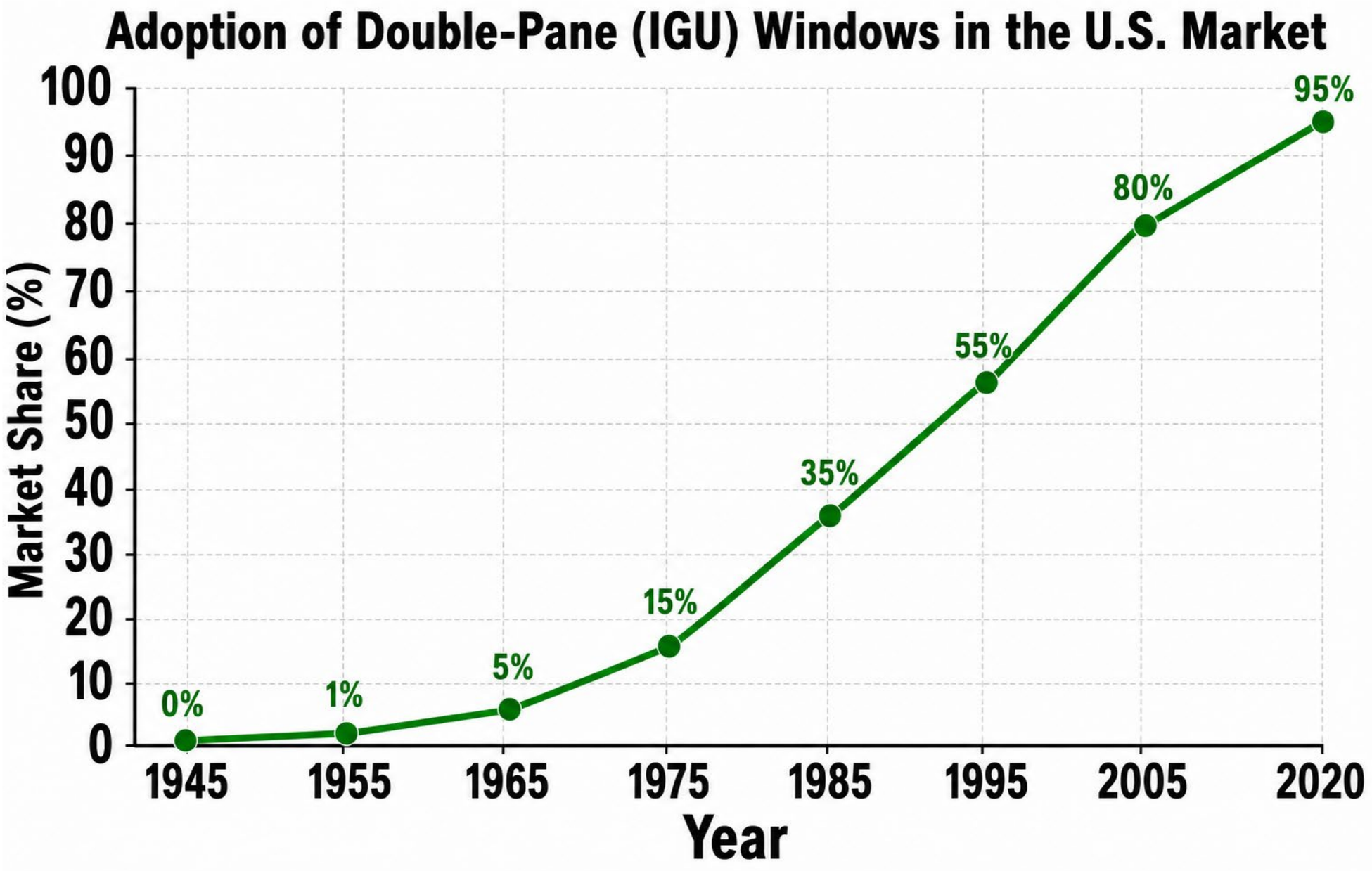
Float Glass Dominates (>90%)



Transforms the Glass Industry Overnight

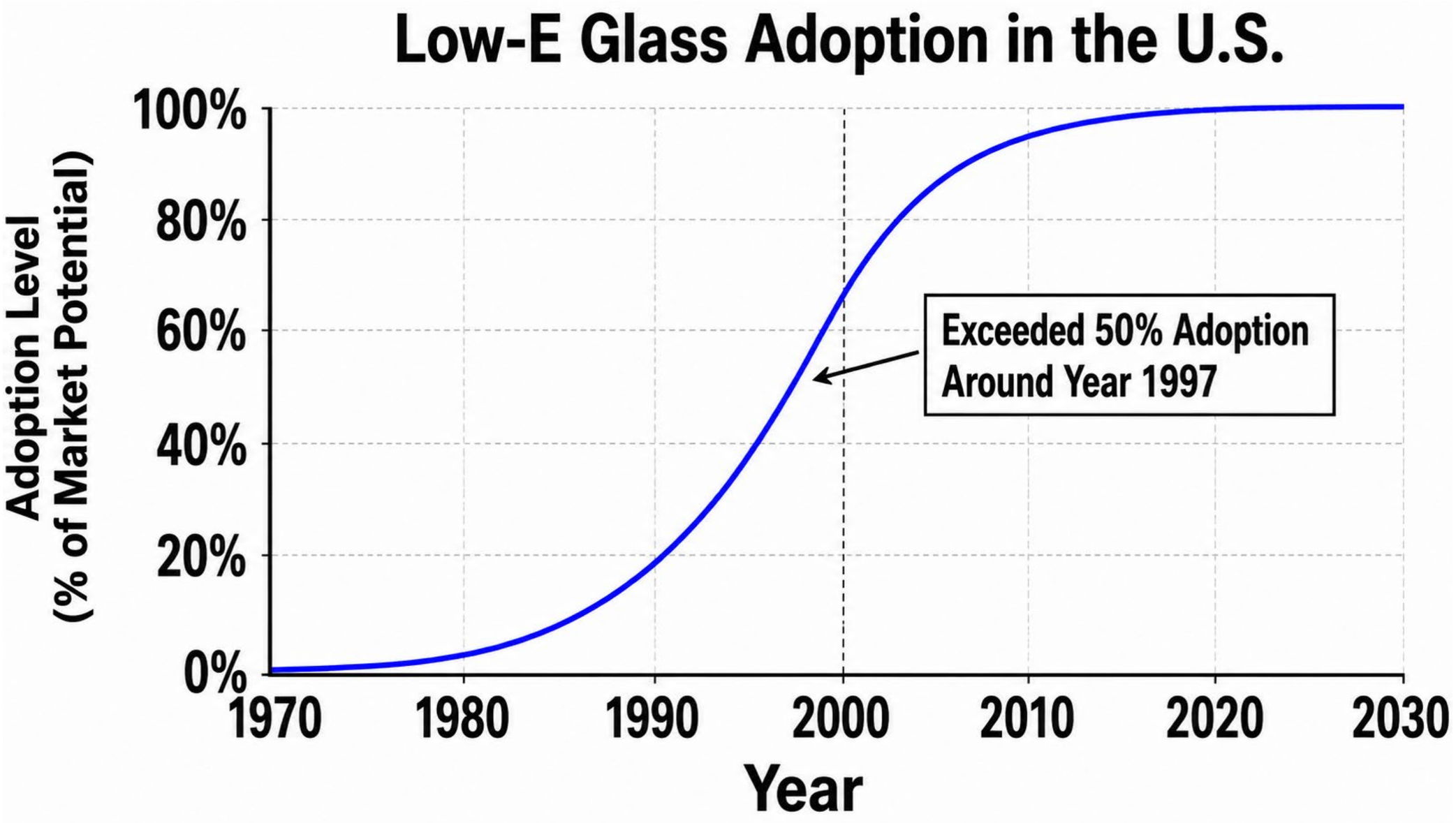
Some Critical Innovations in the Last 80 Years

Float Glass Adoption Triggers *Other Rapid Advancements*



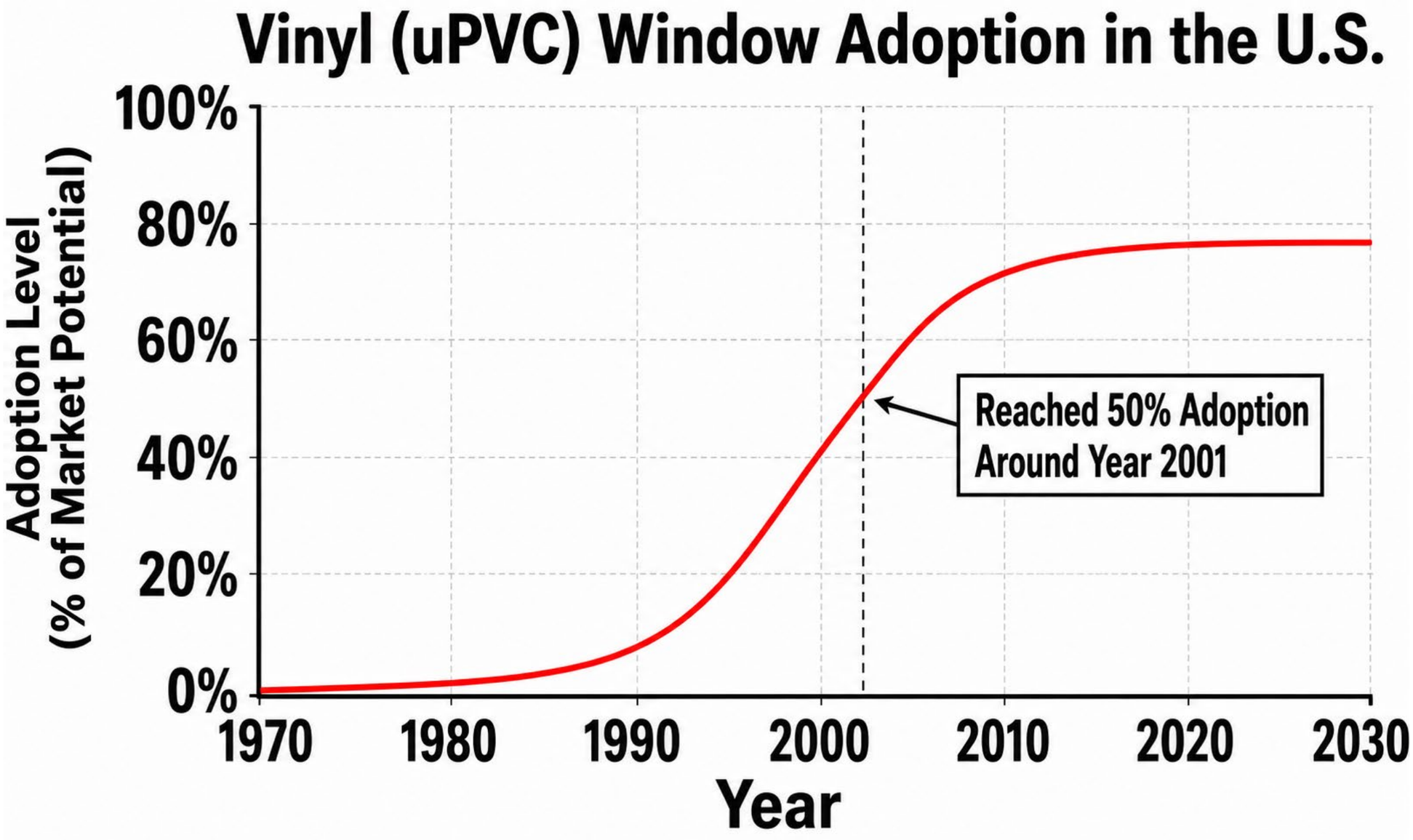
Some Critical Innovations in the Last 80 Years

Float Glass Adoption Triggers *Other Rapid Advancements*



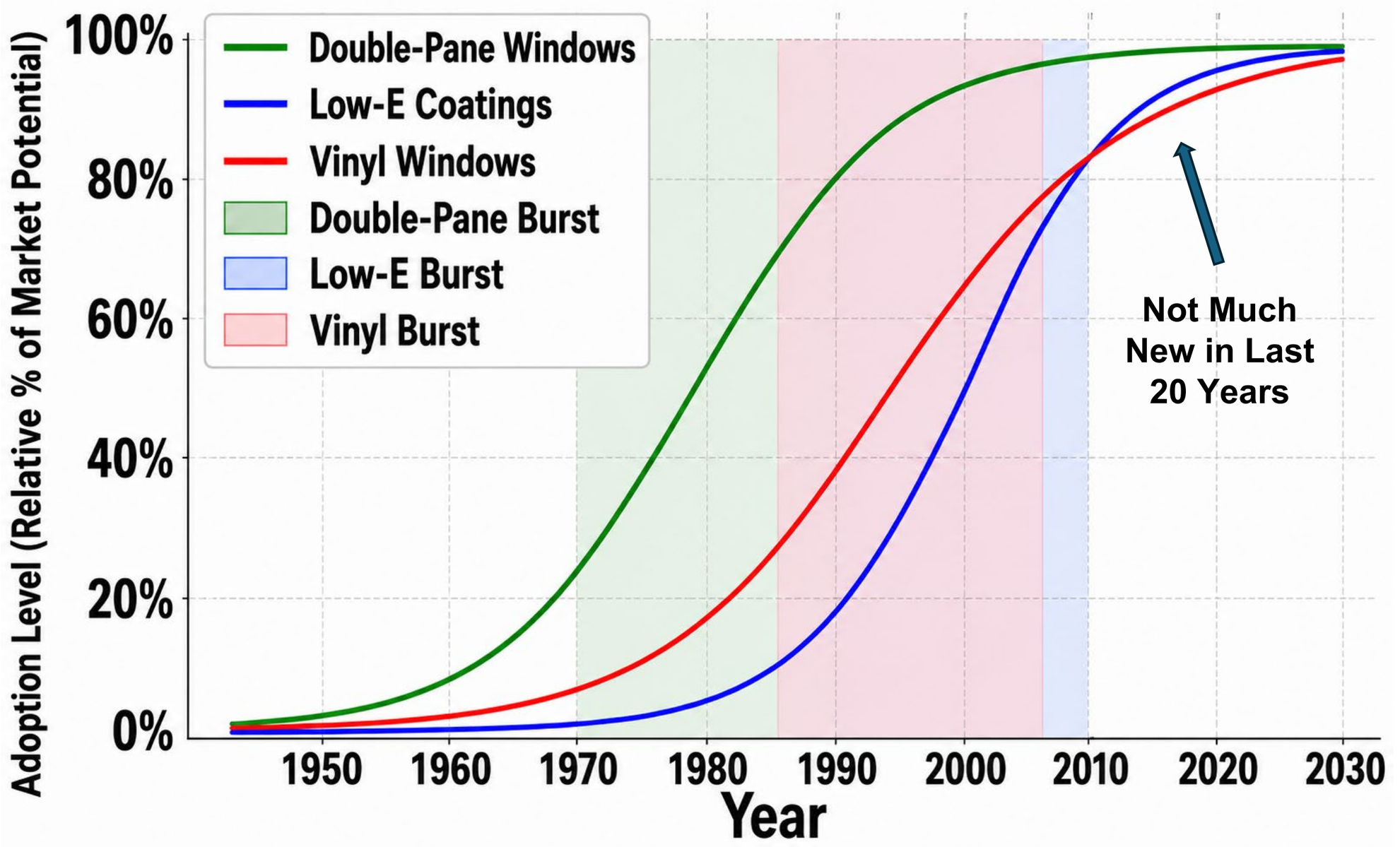
Some Critical Innovations in the Last 50 Years

Vinyl Windows – Dramatic, Fast Increase in Market Share



Dominant U.S. window frame material in market share this century

S-Curve of Innovation in the U.S. Window Industry



1. Technological Breakthroughs
2. Economic & Regulatory Shocks Accelerate Adoption
3. S-Curve of Innovation
4. Clustered Ecosystem Development
5. Market Saturation & Risk Aversion

The Most Potentially New Transformative Architectural Glass Technology in Last 50 Years

Vertical fusion glass technology

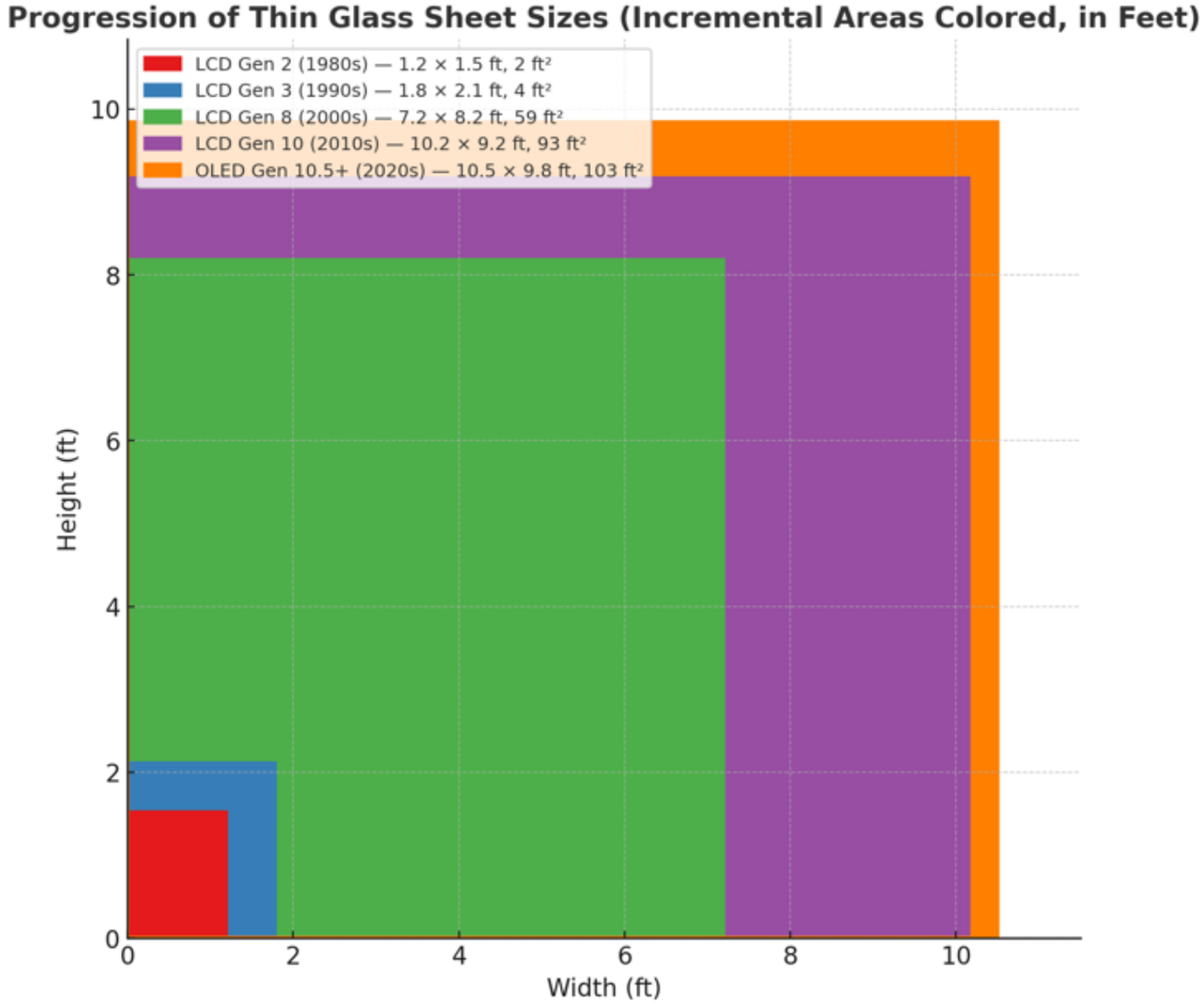
Developed by Corning and commercialized in phones and tvs.



Corning Enlighten Glass
Vertical Fusion Technology



The Most Potentially Transformative Architectural Glass Technology in the Last 50 Years





Why “Thin Glass” Technology Can Be Disruptive

1. Rapid adoption globally (multiple companies in North America, Europe, and Asia are now offering it to market):

   A. Two U.S. companies with national sales networks are selling in marketplace with accelerating sales.

   B. Largest Canadian window company formally introduced and rapidly expanding sales.

2. Five major glass equipment manufacturers now offering proven equipment lines (at least five high-speed lines in North America).

3. Solves unique U.S. “narrow sash” challenge
   - most U.S. windows restricted to 1” or less width)
   - quad thin glass design now adopted in wider glass pockets in place of “fat triple.”

4. Pricing already at or below existing market solutions and falling—
   NO “NEW SOLUTION” PREMIUM.

5. Market Proven – already over 5 million square feet in marketplace with success.

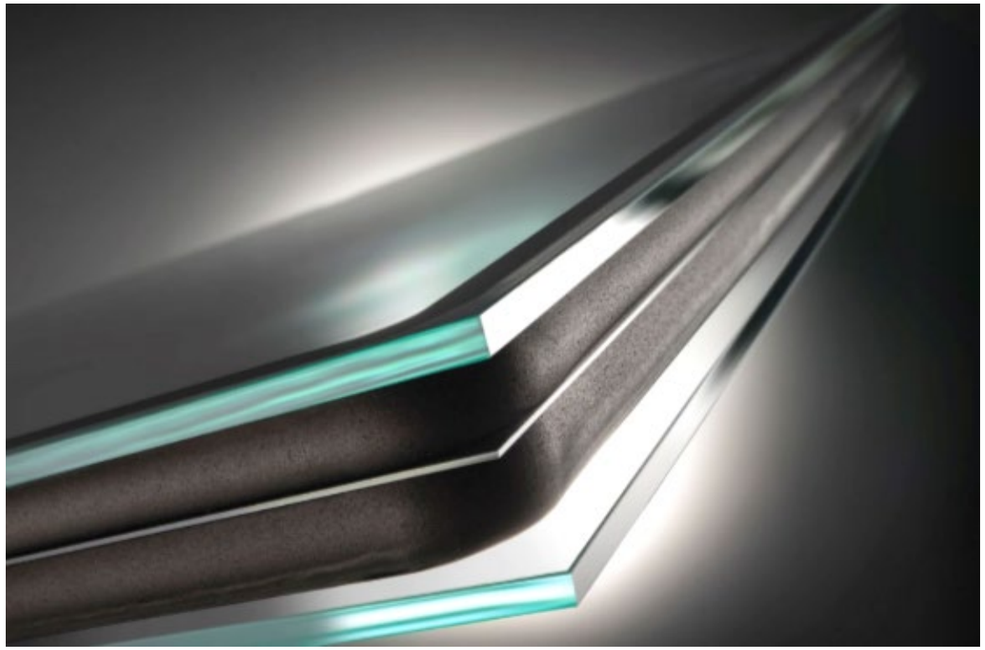
Why “Thin Glass” Technology Can Be Disruptive

Finally, big pressures in the building industry’s ability to meet evolving energy and building code requirements

and long-time incremental technology improvements have run out of steam

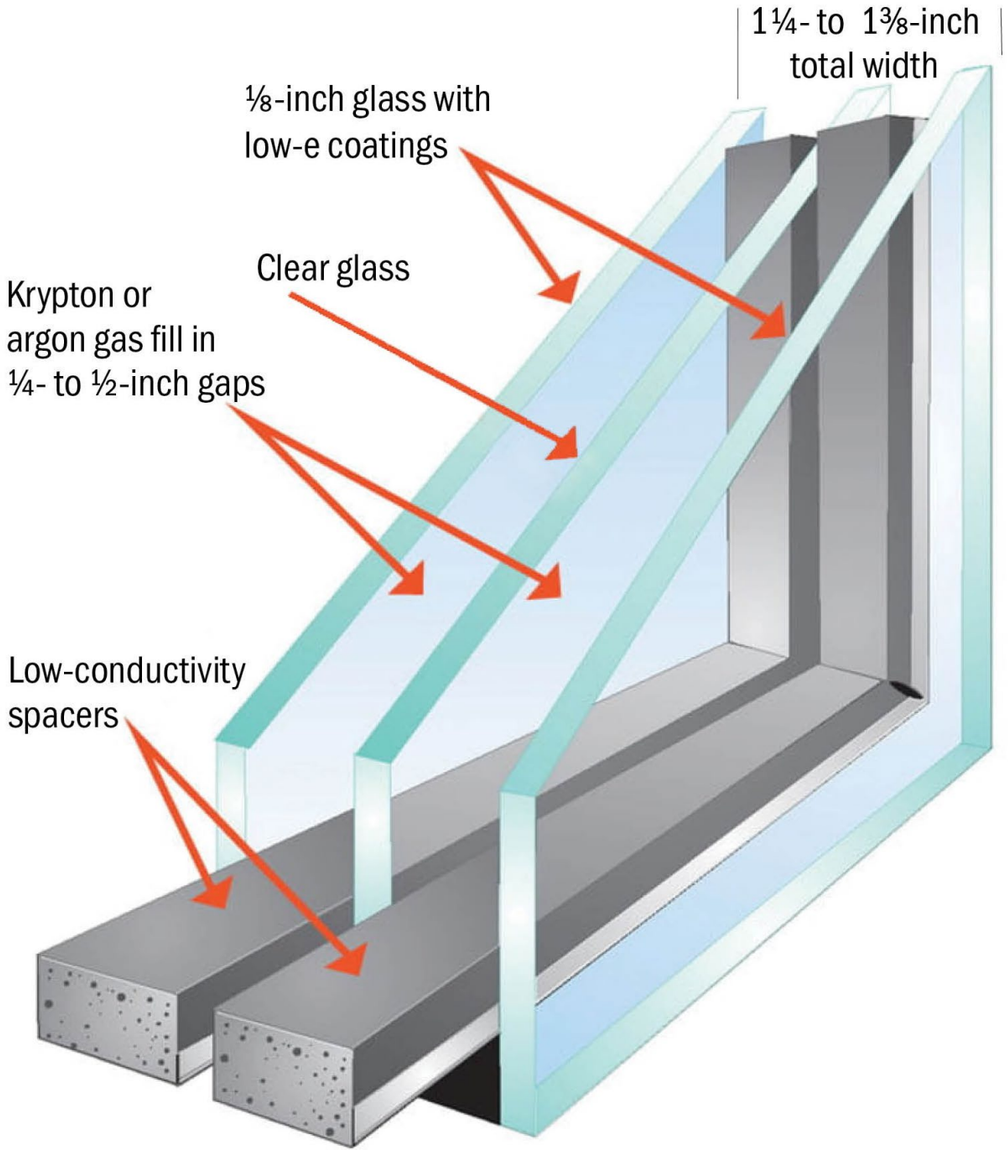
--especially low-e coatings, which are now at the natural end of technology capabilities.

“Thin glass” now offers the least expensive, scalable solution to meet new demands.

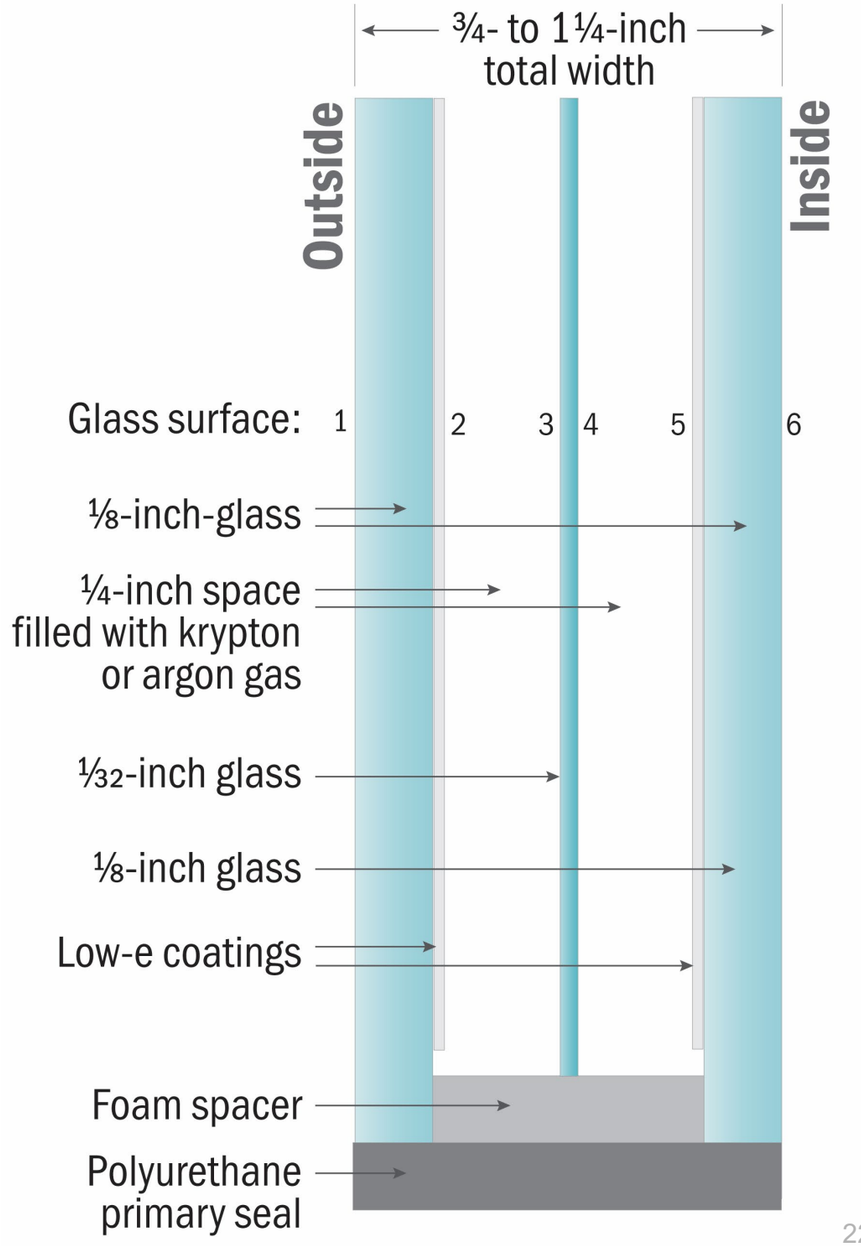


Standard Triple vs Thin Triple

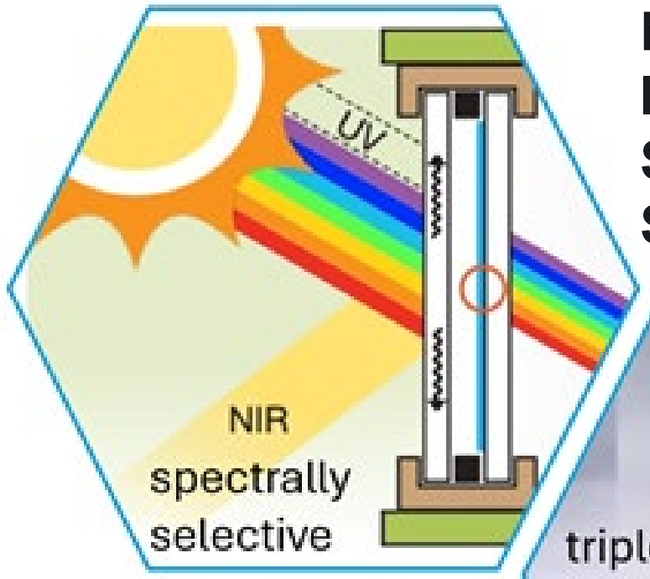
Standard Triple-Pane Window



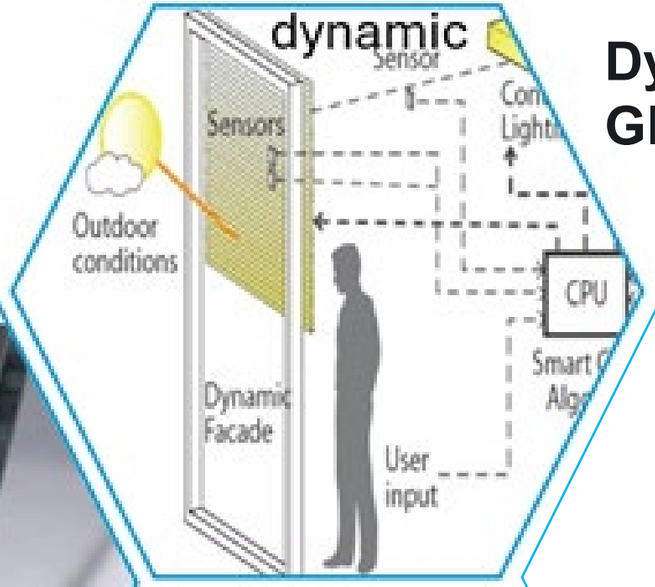
Thin Triple Window



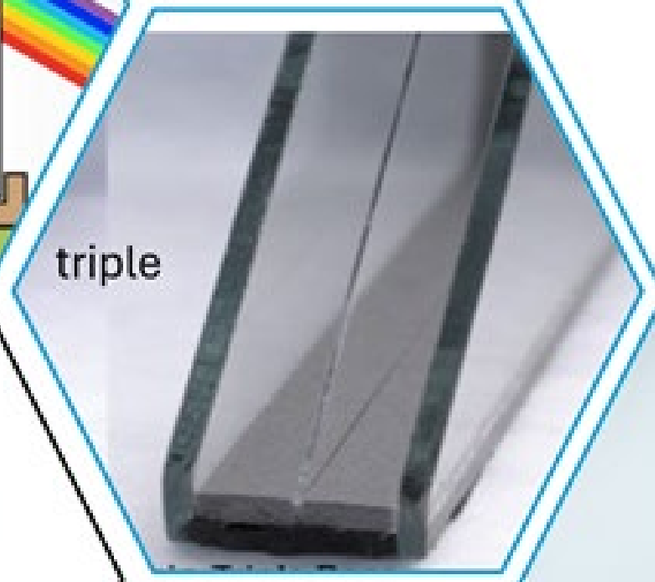
Latest Advancements in Window Technologies



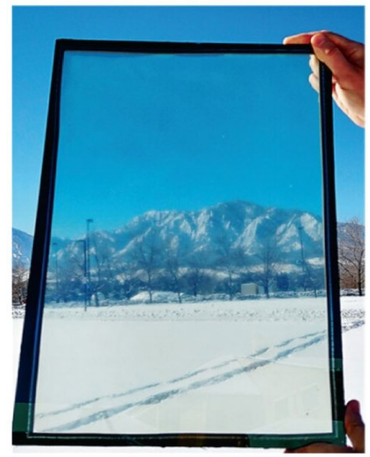
Near-Infrared Spectrally Selective



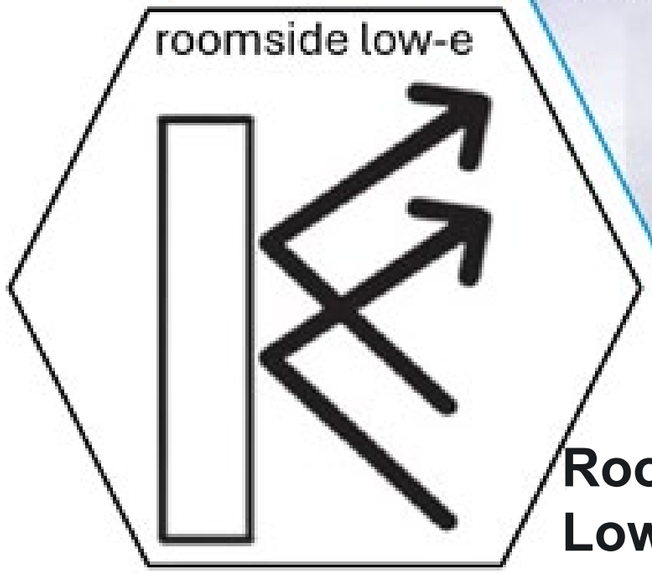
Dynamic Glazing



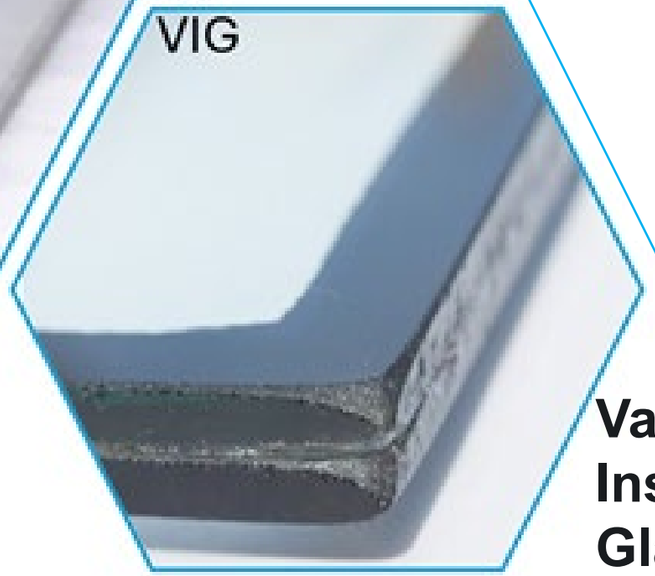
Thin Triples



Clear Aerogel

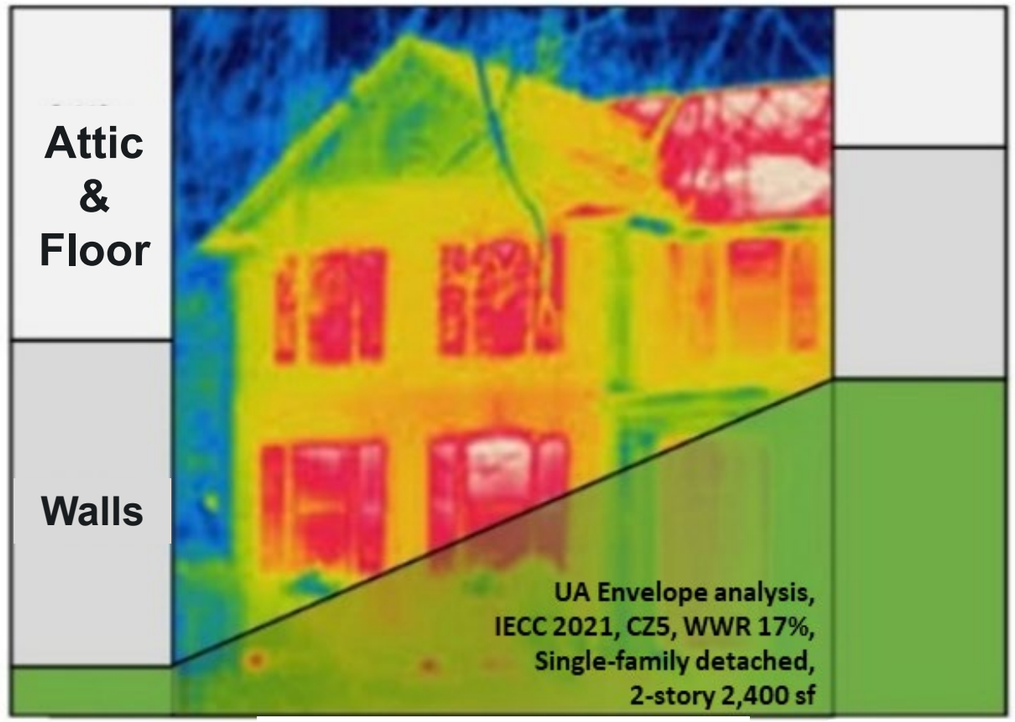


Room-side Low-E

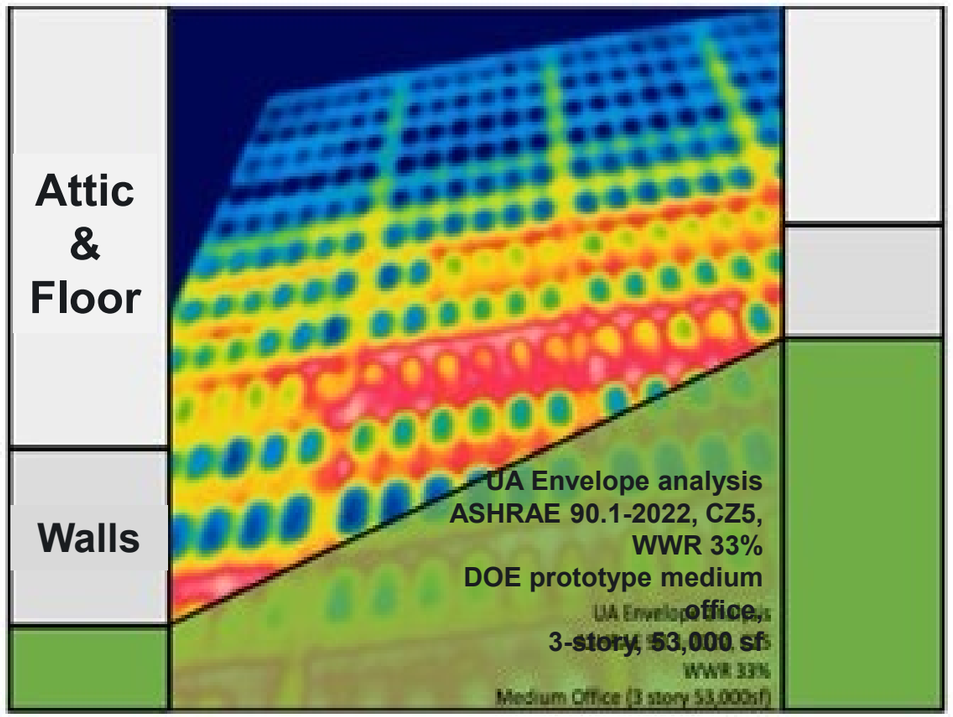


Vacuum-Insulated Glass

Why Do We Care About Windows



7% Area | Residential Windows | ? Heat loss

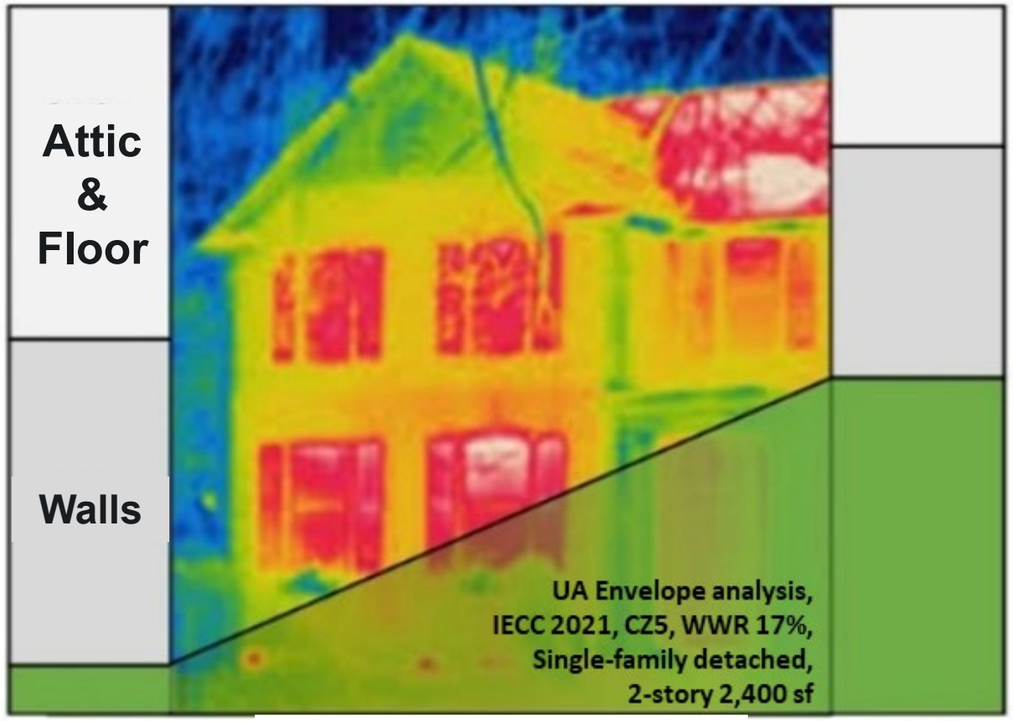


12% Area | Commercial Windows | ? Heat loss

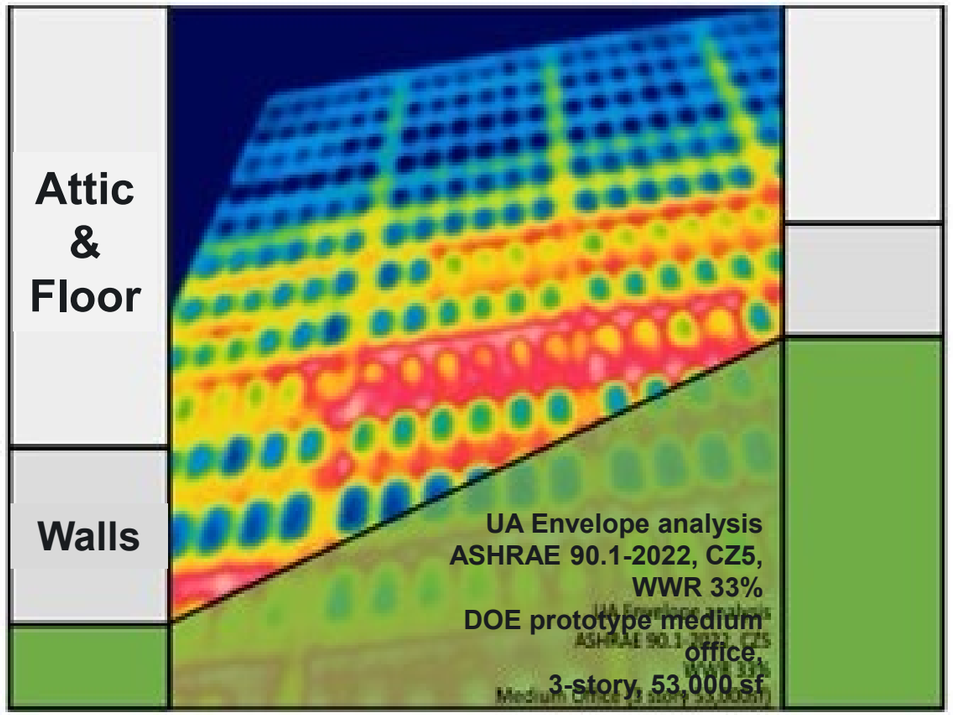
Windows account for ___of the heat loss through the building envelope in some homes and commercial buildings (Source: LBNL).

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Why Do We Care About Windows



7% Area | Residential Windows | 48% Heat loss



12% Area | Commercial Windows | 53% Heat loss

Windows account for nearly **half** of the heat loss through the building envelope in some homes and commercial buildings (Source: LBNL).

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9X More Insulation to get the same R Value with Double Panes as Triple Panes

Double Pane

Insulation: R- ?



Double-Pane Window: R-3

Whole Wall (avg): R-19.0

Triple Pane

Insulation: R-38



Triple-Pane Window: R-5

Whole Wall (avg): R-19.0

Values for typical homes, assumes building envelope consists of 15% window area, 85% wall area.

9X More Insulation to get the same R Value with Double Panes as Triple Panes

Double Pane

Insulation: R-330



Double-Pane Window: R-3

Whole Wall (avg): R-19.0

Triple Pane

Insulation: R-38



Triple-Pane Window: R-5

Whole Wall (avg): R-19.0

Values for typical homes, assumes building envelope consists of 15% window area, 85% wall area.

Trade-Off Analysis: Connecticut CZ 5

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Every tradeoff scenario beat the high-performance home target.

U-0.20 windows allowed for:

- No exterior rigid foam
- R-29 cathedral attics
- R-5 foundation insulation.

Single-Family Home A (CZ 5)						
Metrics	**Hi-Perfm Target**	**U-0.20**	**U-0.20 + <Wall ci**	**U-0.20 + <Foundation**	**U-0.20 + <Ceiling**	**U-0.20 + <Wall ci + <Foundation**
Ceiling R	60	60	60	60	29	60
Wall R (cavity)	20	20	20	20	20	20
Wall R (continuous)	5	5	0	5	5	0
Window U	0.3	0.2	0.2	0.2	0.2	0.2
Door U	0.3	0.3	0.3	0.3	0.3	0.3
Floor R	0.033	0.033	0.033	0.033	0.033	0.033
Foundation Wall R	R15	R15	R15	R5	R15	R5
Slab R, depth	R10, 4v	NA	NA	NA	NA	NA
Building UA	539.8	437.9	485.4	485.4	462.2	532.9
Savings beyond High-Performance Target	-	19%	10%	10%	14%	1.5%
Heating Load (kBtuh)	44	38	41	41	39	44
Cooling Load (kBtuh)	30	29	30	30	29	30

Trade-Off Analysis: Colorado CZ 5

Every tradeoff scenario beat the high-performance home target.

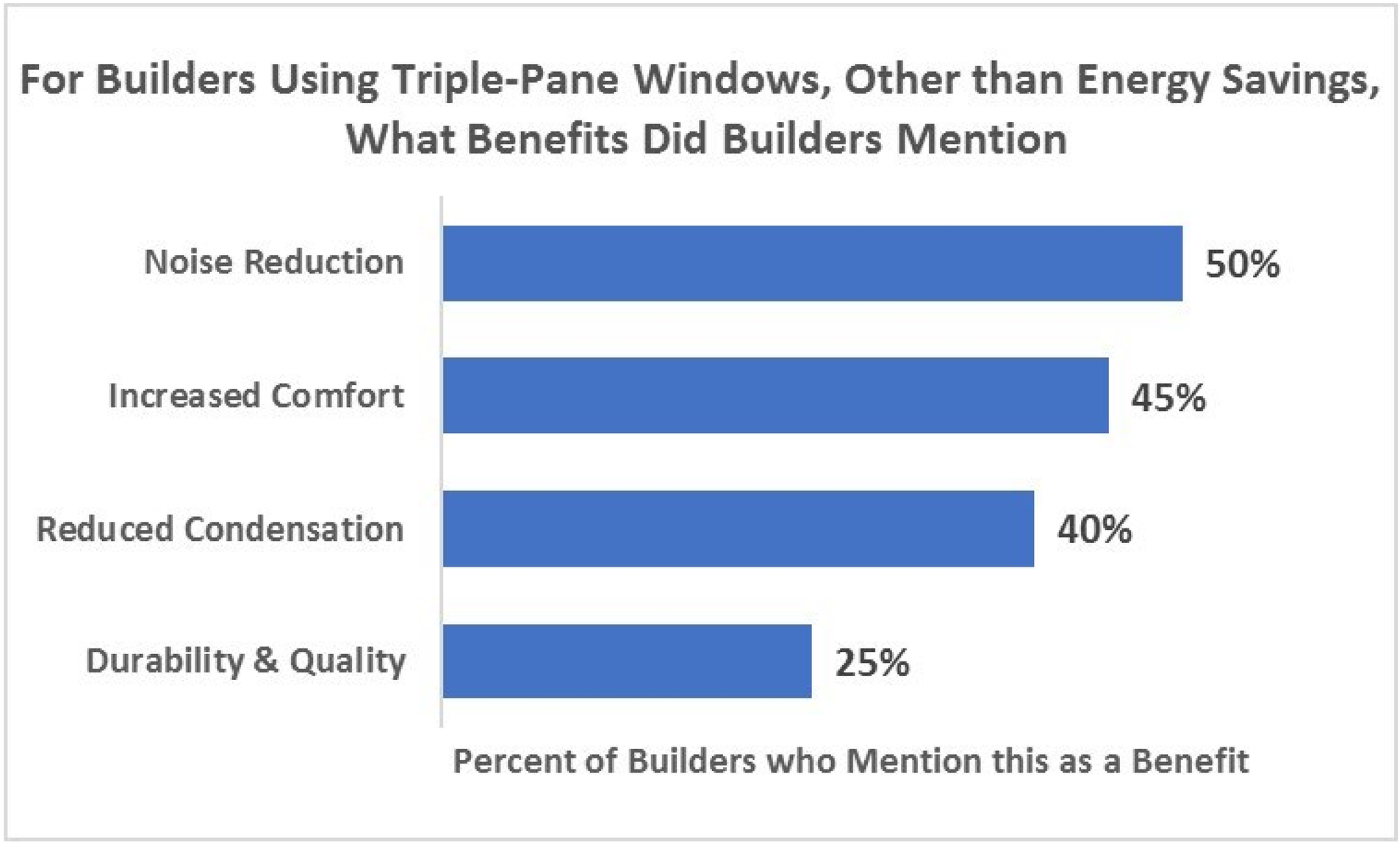
U.20 windows allowed for:

- No exterior rigid foam
- R-49 attic

Metrics	1- Single-Family, Crawlspace		2 - Townhome, Conditioned Crawlspace	
	High-Performance Target	U-0.20 + <Wall ci	High-Performance Target	U-0.20 + <Ceiling + <Wall ci
Windows	U-0.32, SHGC-0.40	U-0.20, SHGC-0.30	U-0.32, SHGC-0.40	U-0.20, SHGC-0.30
Flat Ceiling	R60	R60	R60	R49
Exterior Wall Cavity Insulation (2x6)	R20 + R5 ci	R21	R20 + R5 ci	R21
Savings beyond High-Performance Target	7%	16%	8%	16%
HERS	56	49	51	49

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Energy Trade-Offs Aren't the Only Reason to Choose High-Performance Windows



Triple Panes for Condensation Control





Helena MT Field Study, Winter 2021

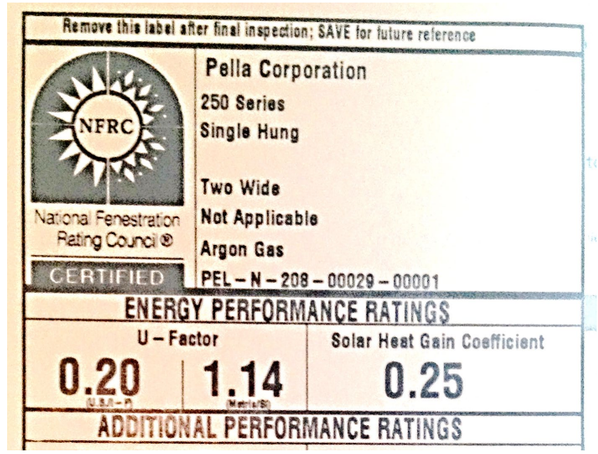
Before: Double-pane, vinyl-framed window shows condensation and ice buildup.

After: Thin triple-pane fiberglass-framed window shows zero condensation and ice.
(same location and conditions)

Condensation causes mold & rot in Habitat homes
Solution: Triple-pane windows







New 10,000ft^2 custom home in Ohio.

- An indoor pool and cold humid climate led to extensive condensation on double-pane windows.
- Owner replaced all windows with triple-panes two years later.









The home was beautiful but the double-pane windows got ugly.

Triple Panes for HVAC Reduction

Tradeoff:

Double Pane → Triple Pane

U-0.30 U-0.20

Enables

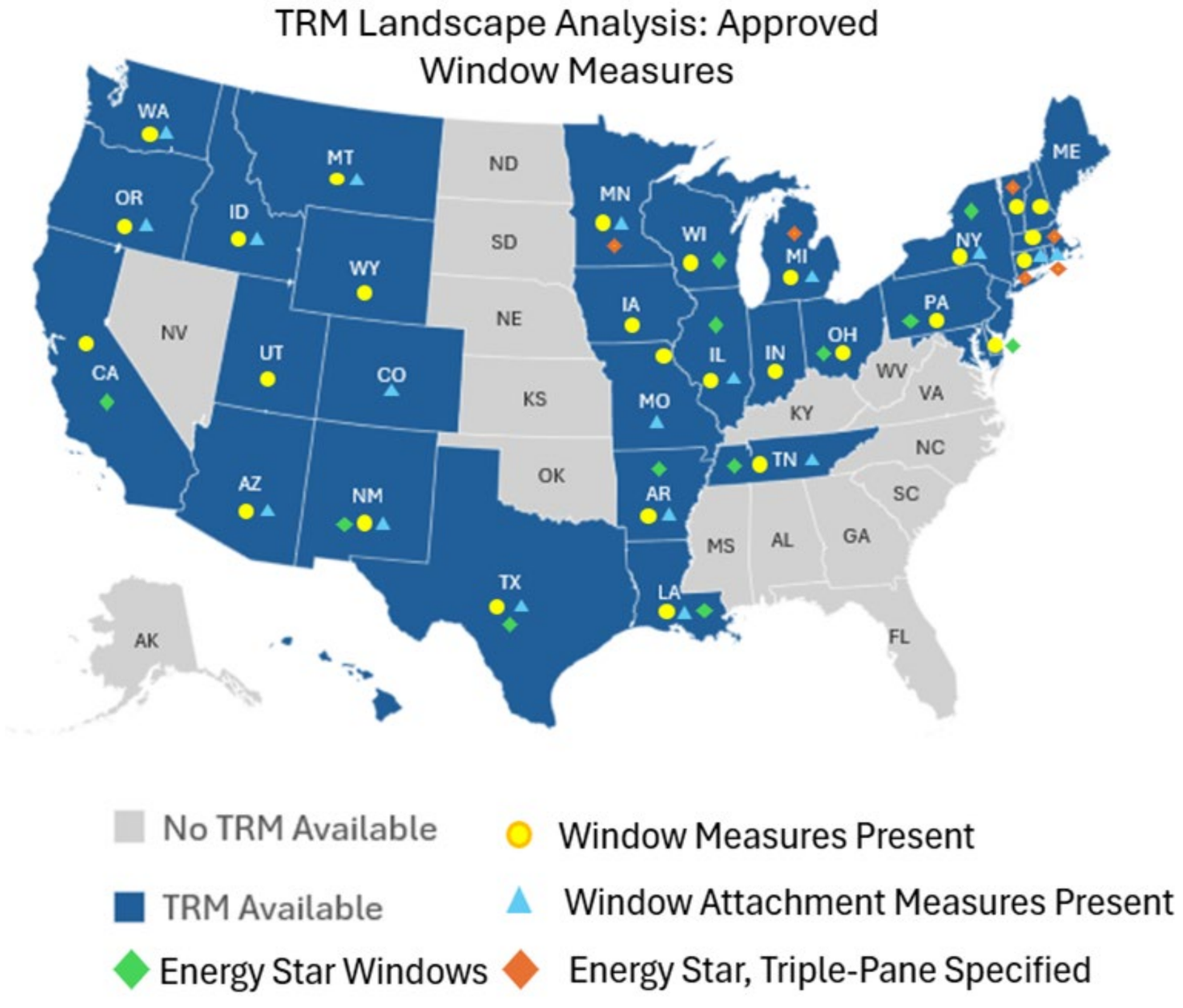
- Load reductions of 6-17%
- Shorter duct runs
- Registers on interior walls
- Smaller systems
- Minisplit vs Central HP

House	HVAC Heating Load Reduction
MI 900 ft^2	6%
MI 1,000 ft^2	17%
MI 1,100 ft^2	6%
MI 1,200 ft^2	7%
WA 1,060 ft^2	10%
WA 2,600 ft^2	12%
WA 2,635 ft^2	10%
WA 2,650 ft^2	13%
WA 2,730 ft^2	13%

Numbers provided by two DENH builders based on energy modeling of four home designs in Michigan and five home designs in Washington, as reported in Gilbride et al. 2019. *Double or Triple?* PNNL-28809.

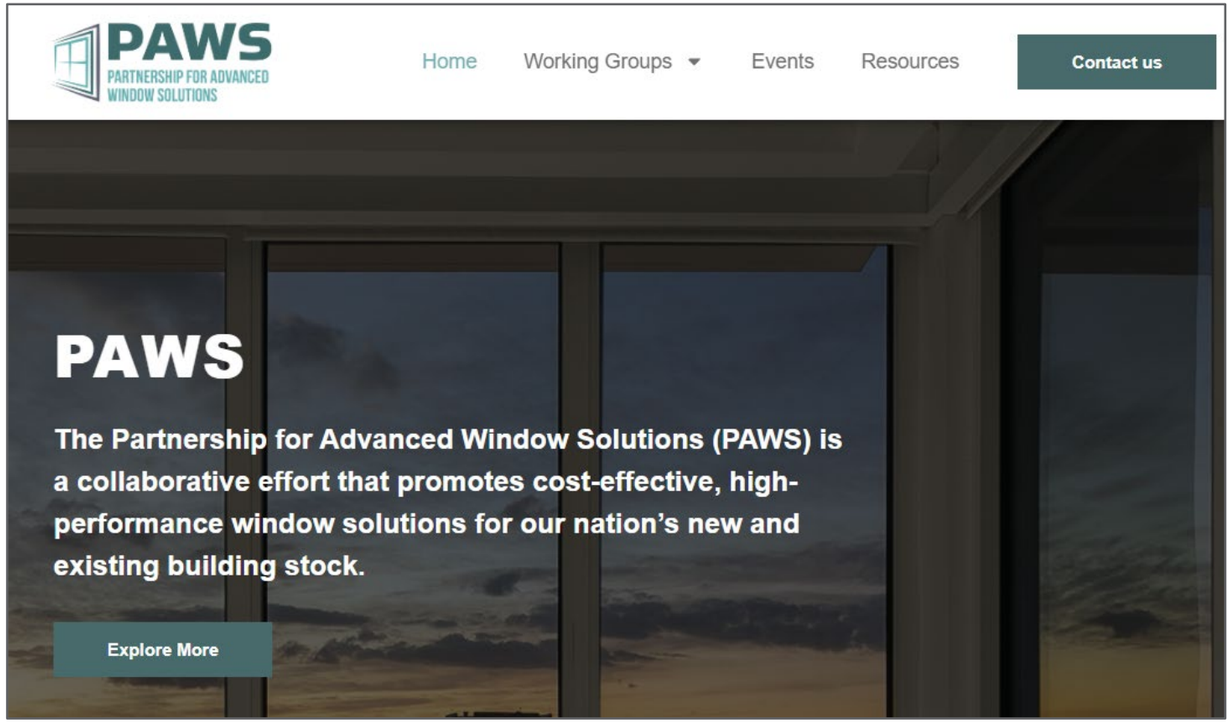
State TRMs with Window Rebates

- 27 states offer window rebates in their TRMs.
- 25 states offer rebates for primary windows.

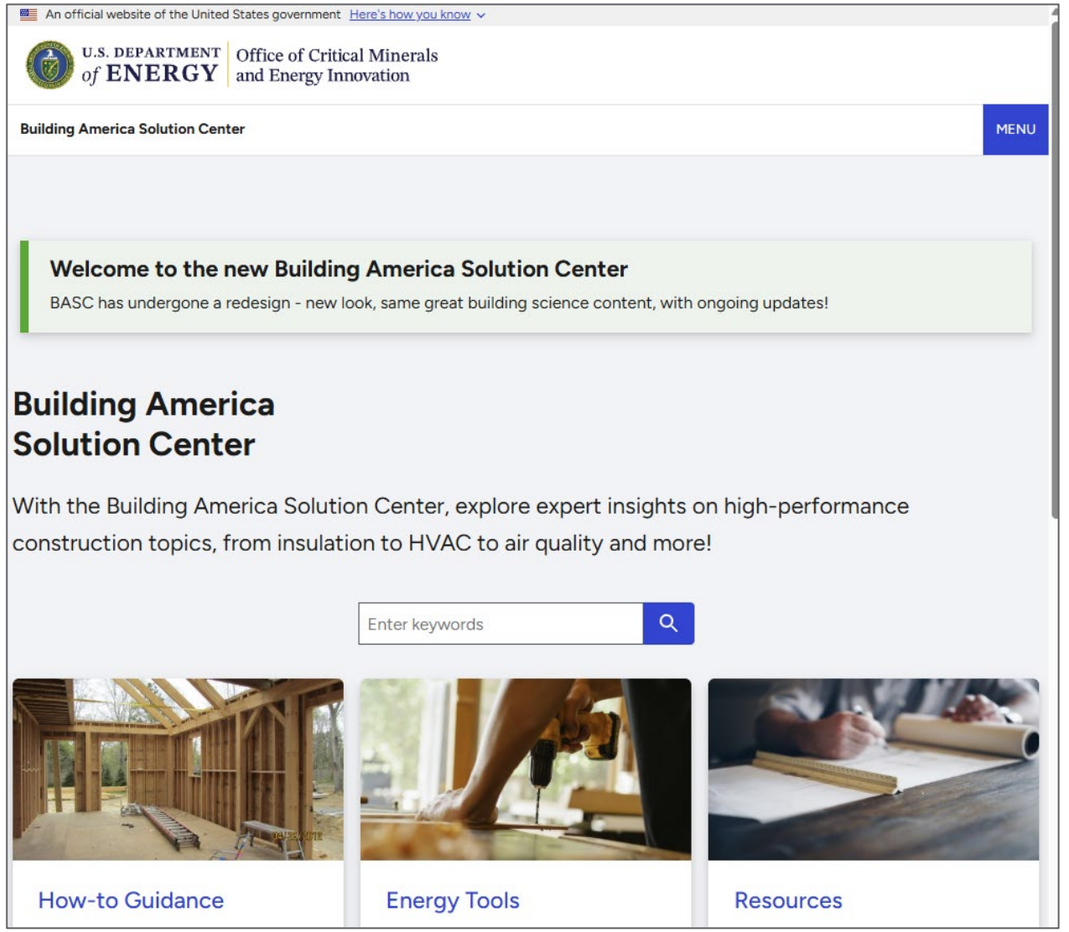


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For More Info, see…



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Thank you

