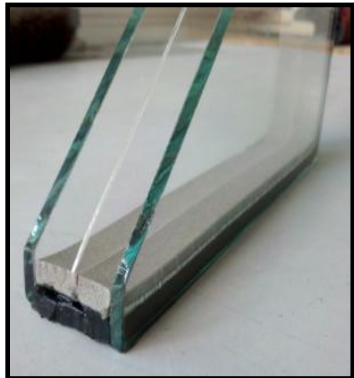


“Thin Triples”: Taking the Pain out of Triple Pane Windows



Rolf Jacobson

Research Fellow, CPHC
Center for Sustainable Building Research
University of Minnesota



Stephen Selkowitz

Retired: Leader, Windows and Envelope Materials
Department Head, Building Technologies
Lawrence Berkeley National Laboratory

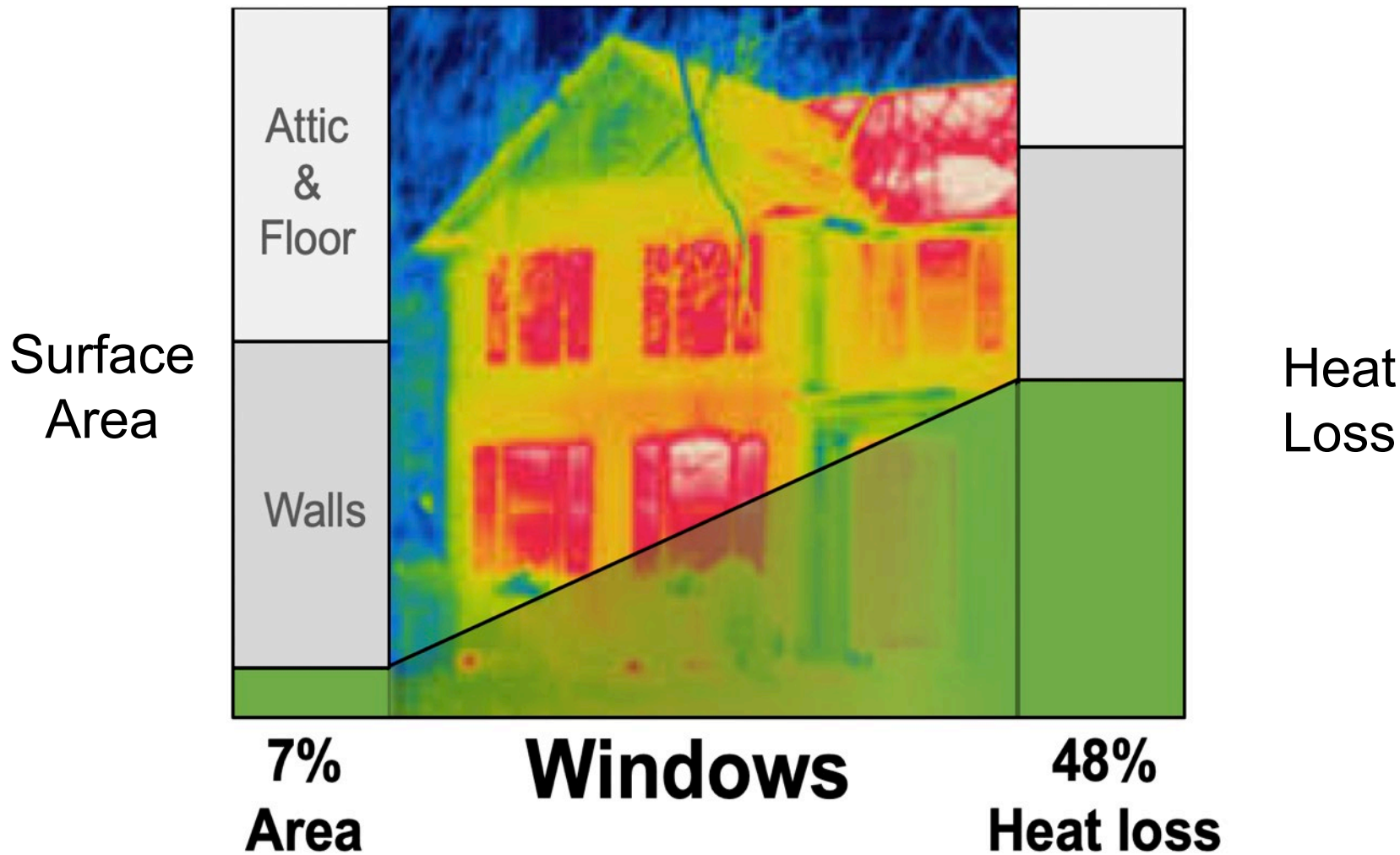


PHIUS NAPHC 2019 Washington, D.C. 12/5/2019



Outline

1. Overview of U.S. Market for Energy Efficient Windows
2. “Thin triple” strategy to “Convert” double pane windows to triples
3. Primer on PHIUS Window Requirements
4. How Thin Triples Might Support Passive House Designs



*Based on 2,000 sf 2-story house, IECC 2015

National Energy/Cost Impacts

- **Window Impacts on U.S. Energy Use ~ \$50B/yr**
 - **Energy, Electric Demand**
 - HVAC Energy: ~ 4 Q; Electric Lighting Energy: ~ 1 Q
 - Summer cooling peak, load shape, grid impacts
 - Winter Peak heating impact for electric heating
 - **Highly Insulating Windows: Large Savings Potential**
 - Residential and Commercial; Heating and Cooling
- **Longer Term 2020+ Goals**
 - “Net Zero” Buildings → Net Zero Envelope
 - Decarbonize: Gas-> Electric heating -> New Challenges
 - Resilience: survivability- no power for xx days...
 - Daylight: View, Comfort, Wellness,...

“Recent” Technology Options

Highly insulating, low heat loss glazing

Today: Typical U-value ~ 0.3 Btu/ft²-hr-F

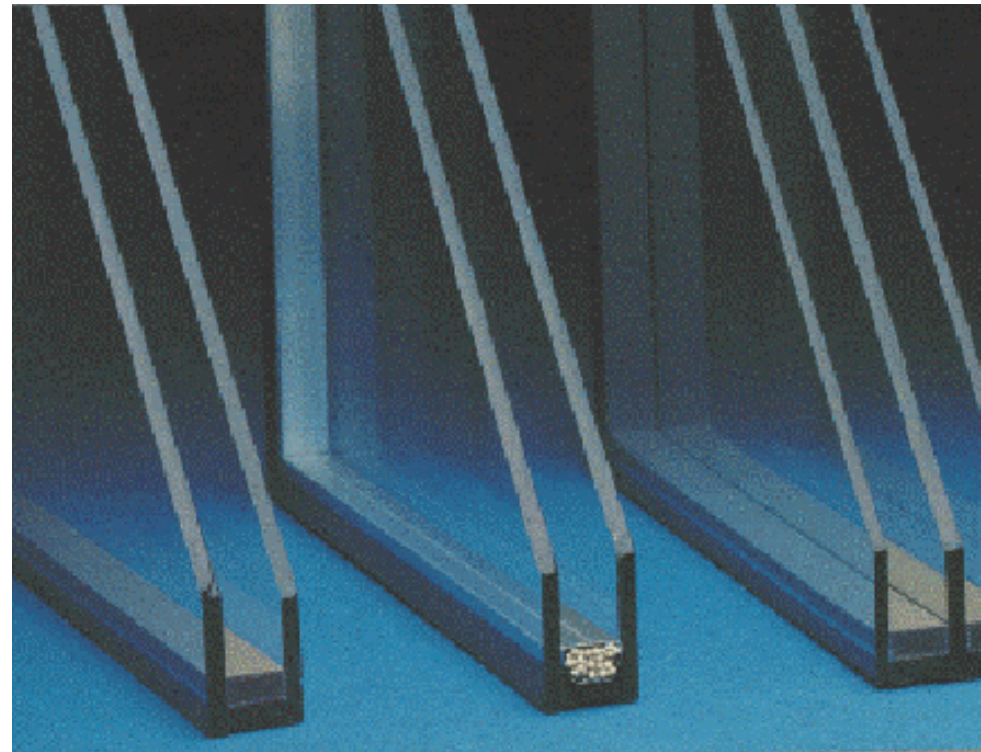
Nearer Term Objective: U-value < 0.2 Btu/ft²-hr-F

Longer Term Target: U-value < 0.1 Btu/ft²-hr-F

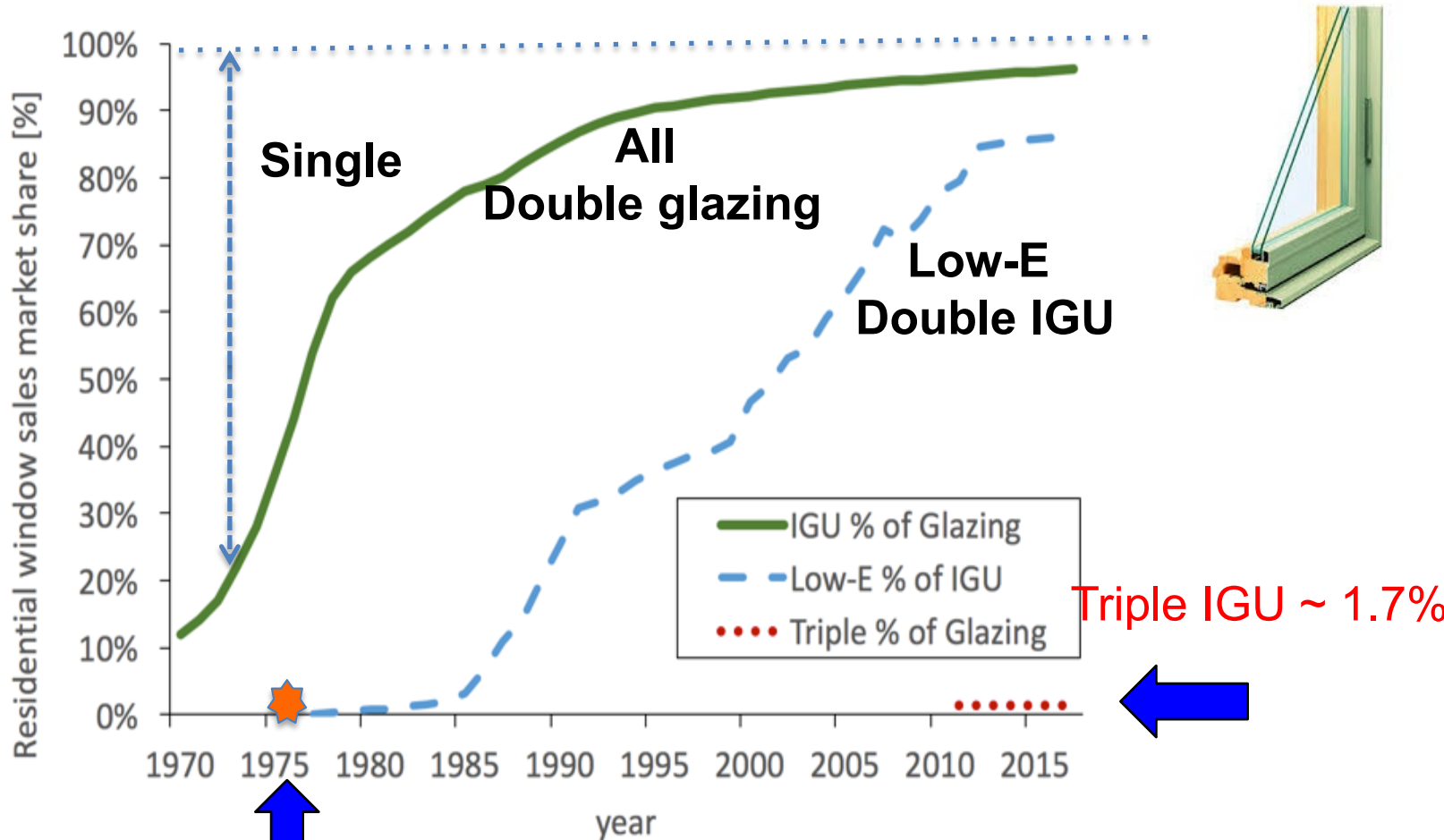
Current Approaches: 30 years

- Low-Emissivity Coatings
- Low Conductance Gas Fills
- “Warm edge” low conductance spacers
- Insulated Frame Systems

New Approaches??



Good News: We've Transformed Markets Before U.S. Residential Glazing Market Share



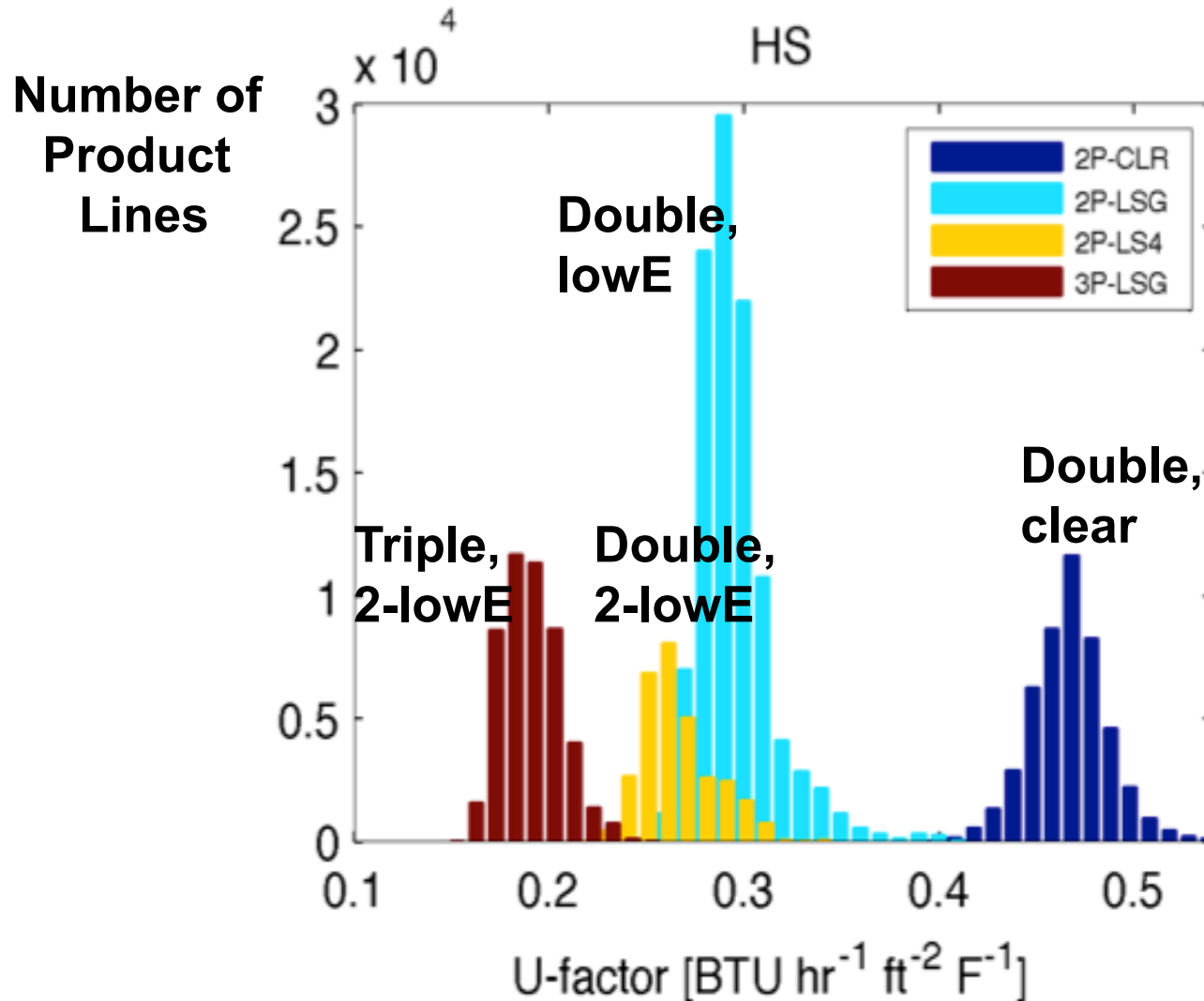
LBNL Window R&D Starts

Source: Ducker Associates

U. S. Window Market Snapshot

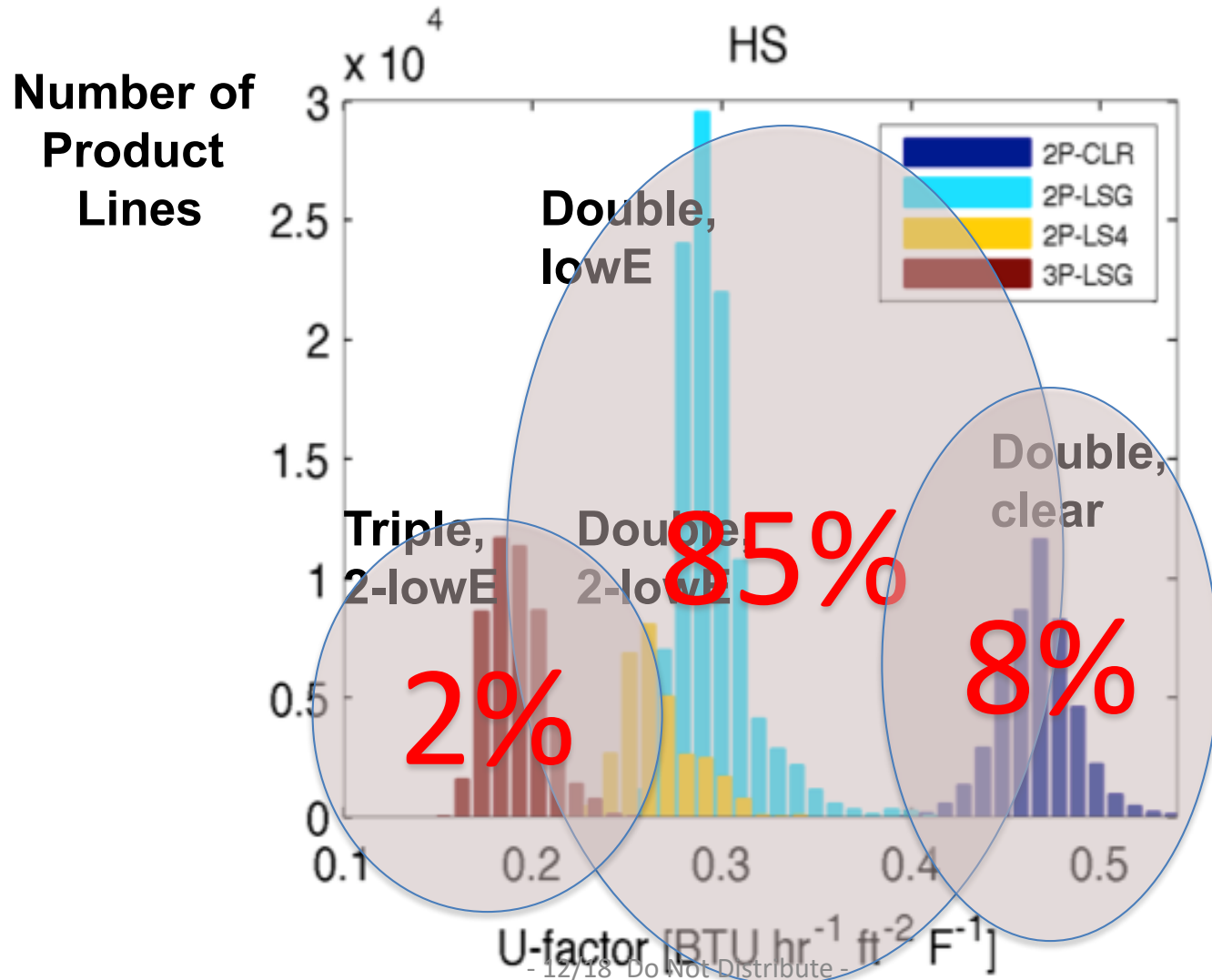
Performance distribution, **NFRC-Rated** Windows by U

Source: EPA ENERGYSTAR analysis, Horiz. sliding windows



Actual Sales are Very Different from NFRC Listings

Performance distribution, NFRC-Rated Windows by U



IGU vs Overall Window Properties

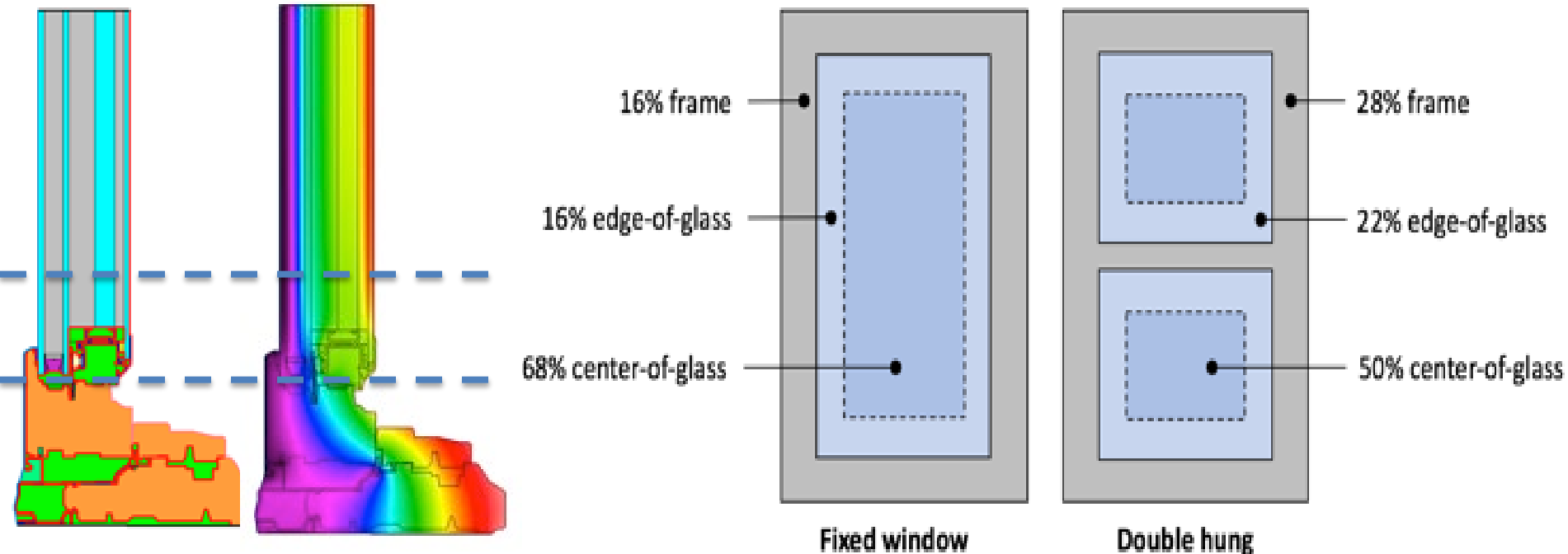
The Effect of “edge of glass” and “frame”

- **Total Window U Properties** - worse than Glazing

- SHGC: ~ 0.4 – 0.6 for cold climates; ~ 0.2 – 0.4 for hot climates

Future: dynamic glass, variable SHGC: 0.05 → 0.5

U_{window} = Area-Weighted Average of:
Center of Glass Area, Edge of Glass Area, Frame Area

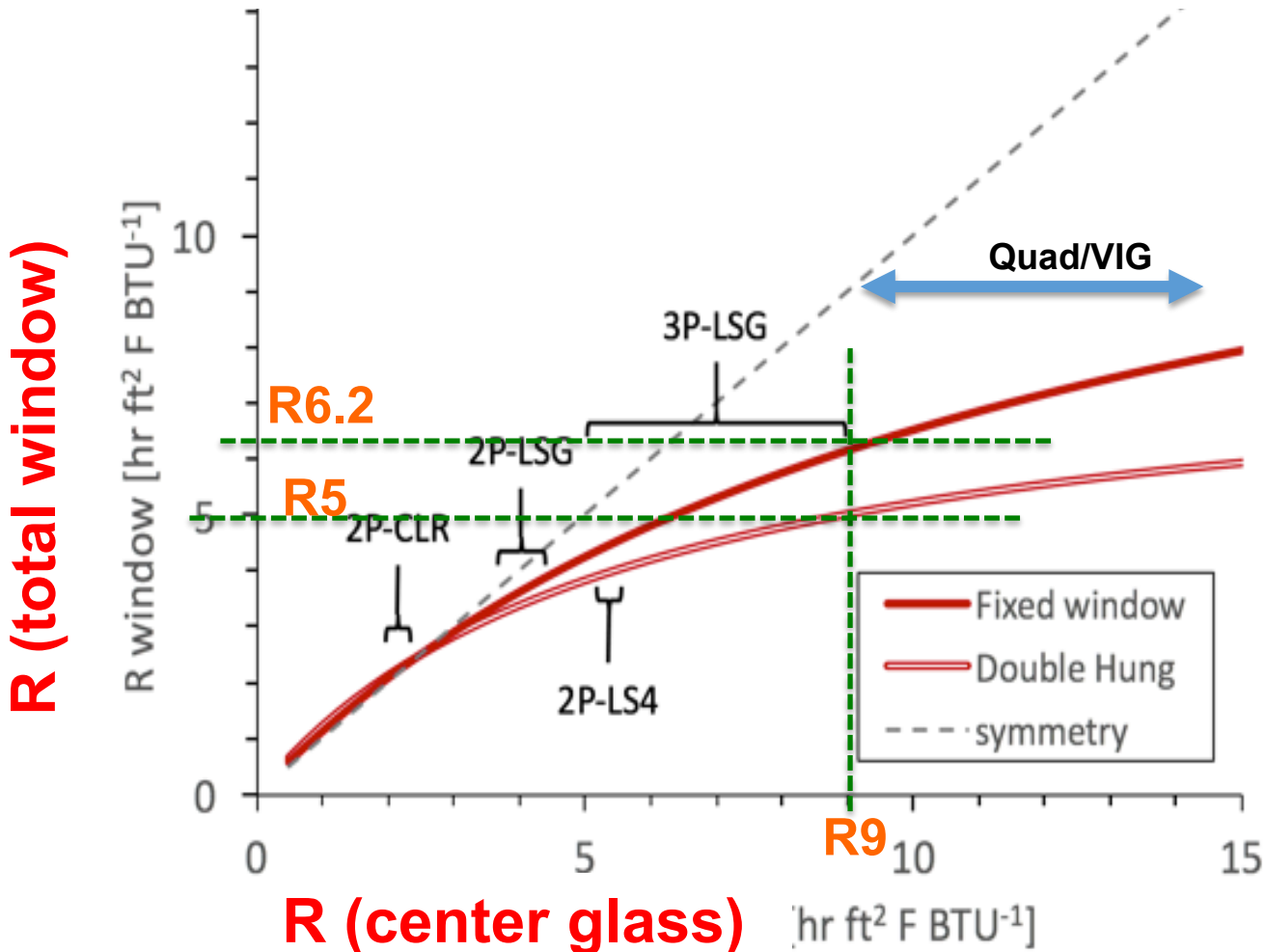


Thermally Improved Frame Needed for Efficient Windows

Efficient Glass/IGU is not enough

BUT it Gets Us Rapidly on the Path to Better Windows

Total WINDOW R vs GLAZING R: Diminishing Returns



Why Not Make Better Windows Now... ??

- **U.S. Window Manufacturers “could” redesign product lines to offer “conventional” triple glazing - but...**
 - Costly – to manufacturers to retool; → costly to end-users
 - “No Demand” now; uncertain demand at higher price point
- **Europe – Northern countries “mandate” triple glazing;**
 - **Base window easily accommodates triple IGU**
 - Offered by most suppliers – competitive market
 - Supported by codes, higher energy prices
 - Passive House windows often imported from Europe
 - But no fundamental “technical” obstacle to adoption here

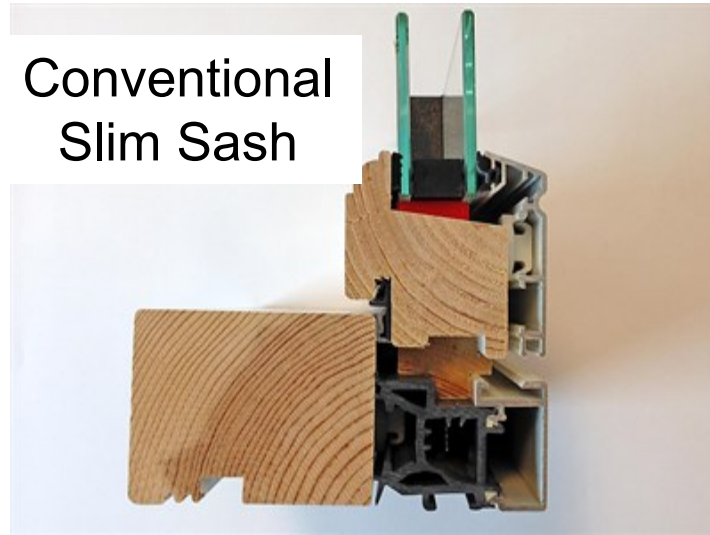
Sash/Frame and IGU Dimensions

Typical U.S. Window

~80% are sliders

Slim sash/frame

Conventional Slim Sash



Typical European Window

Most Tilt/Turn
or Fixed

Wide sash/frame

“European” Wide Sash

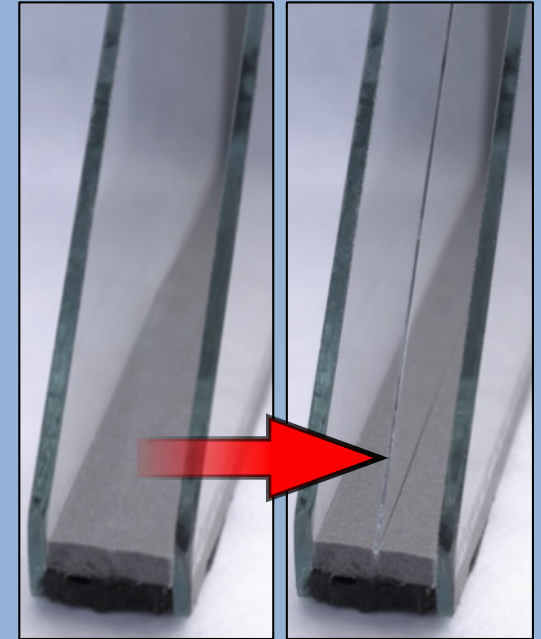




too heavy
too wide
too expensive
long ROI



Drop-in replacement
low entry **cost**
double performance
minimal weight



Double-pane Thin-triple

LBNL “Thin Triple” Concept and Strategy

Provide a low-cost, low-risk pathway to:

reduce IGU U -> ~0.10-0.14

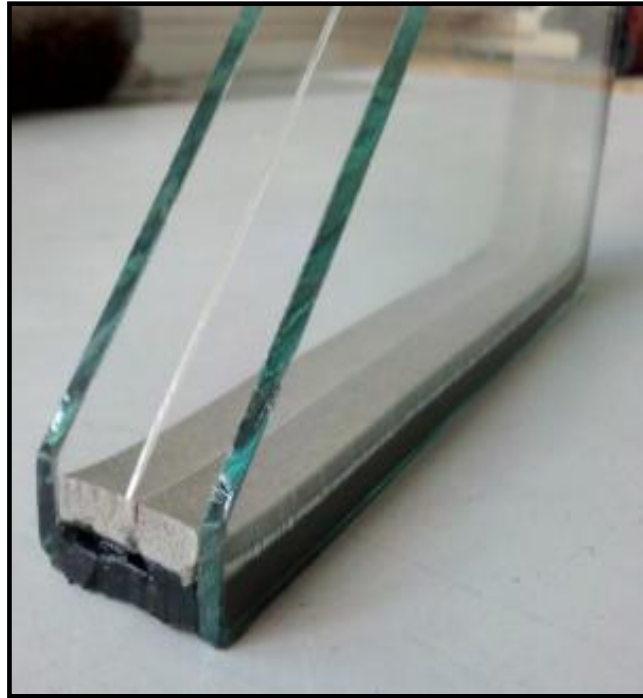
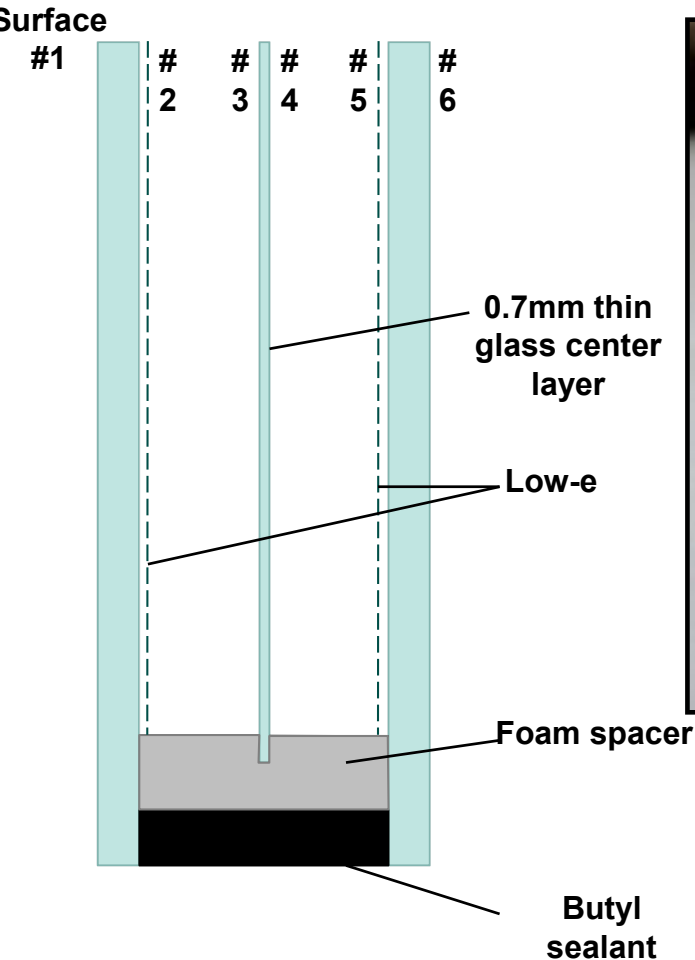
reduce window U -> ~ 0.18-0.21

...without window frame redesign

*creates a platform for future lower U
with improved frames, U -> ~ 0.10-0.16*

Drop-In “Thin Lightweight Triple”

“upgrade” all U 0.3 double glazed windows to 0.2 without redesign using new IGU with same width, weight

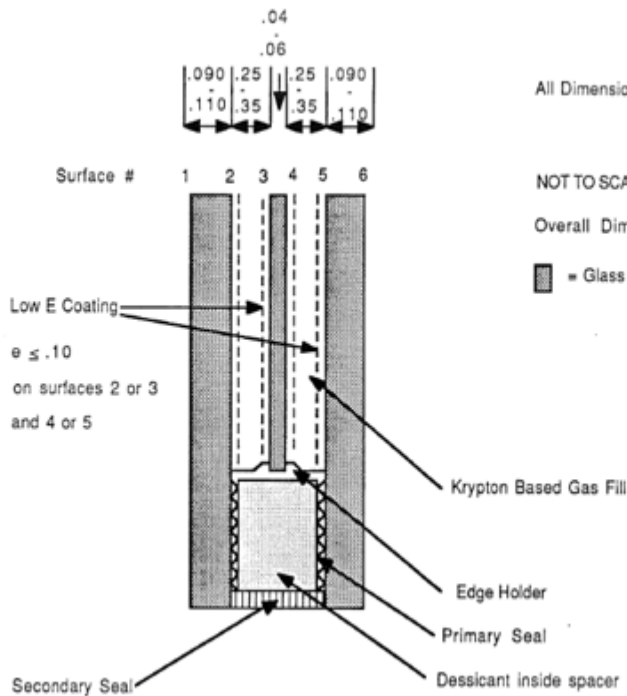


- Platform: U: ~0.1-0.12
- **Thin float glass**
 - .3, .5, .7, 1.1 mm
- Multiple suppliers
- **2 Low-E coatings**
- **Krypton gas fill**
- Non-structural center
 - 2 seals, not 4
- **Infrastructure exists**
- “Affordable”

Not a New Concept; Thin Glass, Thin Triple Concept Developed 30 yrs ago

1991 Design Patent -- >

1989 ASME paper



All Dimensions In Inches

NOT TO SCALE

Overall Dimensions: 0.75" - 1.0" in width

■ = Glass

[54] THERMAL INSULATED GLAZING UNIT

[75] Inventors: Stephen E. Selkowitz, Piedmont; Darlish K. Arasteh, Oakland, both of Calif.; John L. Hartmann, Seattle, Wash.

[73] Assignee: The United States of America as represented by the United States Department of Energy, Washington, D.C.

[21] Appl. No.: 438,539

[22] Filed: Oct. 30, 1989

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 319,871, Mar. 1, 1989, abandoned, which is a continuation of Ser. No. 178,043, Apr. 5, 1988, abandoned.

[51] Int. Cl. E06B 7/12

[52] U.S. Cl. 52/172

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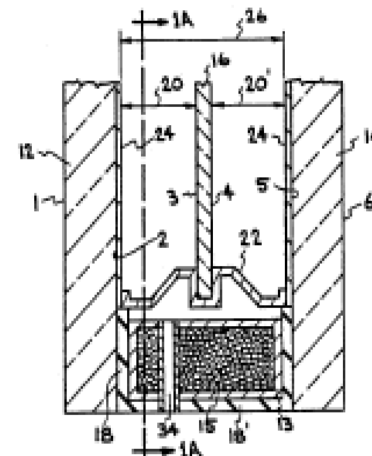
Primary Examiner—Michael J. Carrow
Attorney, Agent, or Firm—B. J. Weis, L. E. Carnahan; William R. Moser

[57] ABSTRACT

An improved insulated glazing unit is provided which can attain about R5 to about R10 thermal performance at the center of the glass while having dimensions about the same as those of a conventional double glazed insulated glazing unit. An outer glazing and inner glazing are sealed to a spacer to form a gas impermeable space. One or more rigid, non-structural glazings are attached to the inside of the spacer to divide the space between the inner and outer glazings to provide insulating gaps between glazings of from about 0.20 inches to about 0.40 inches. One or more glazing surfaces facing each thermal gap are coated with a low emissivity coating. Finally, the thermal gaps are filled with a low conductance gas such as krypton gas.

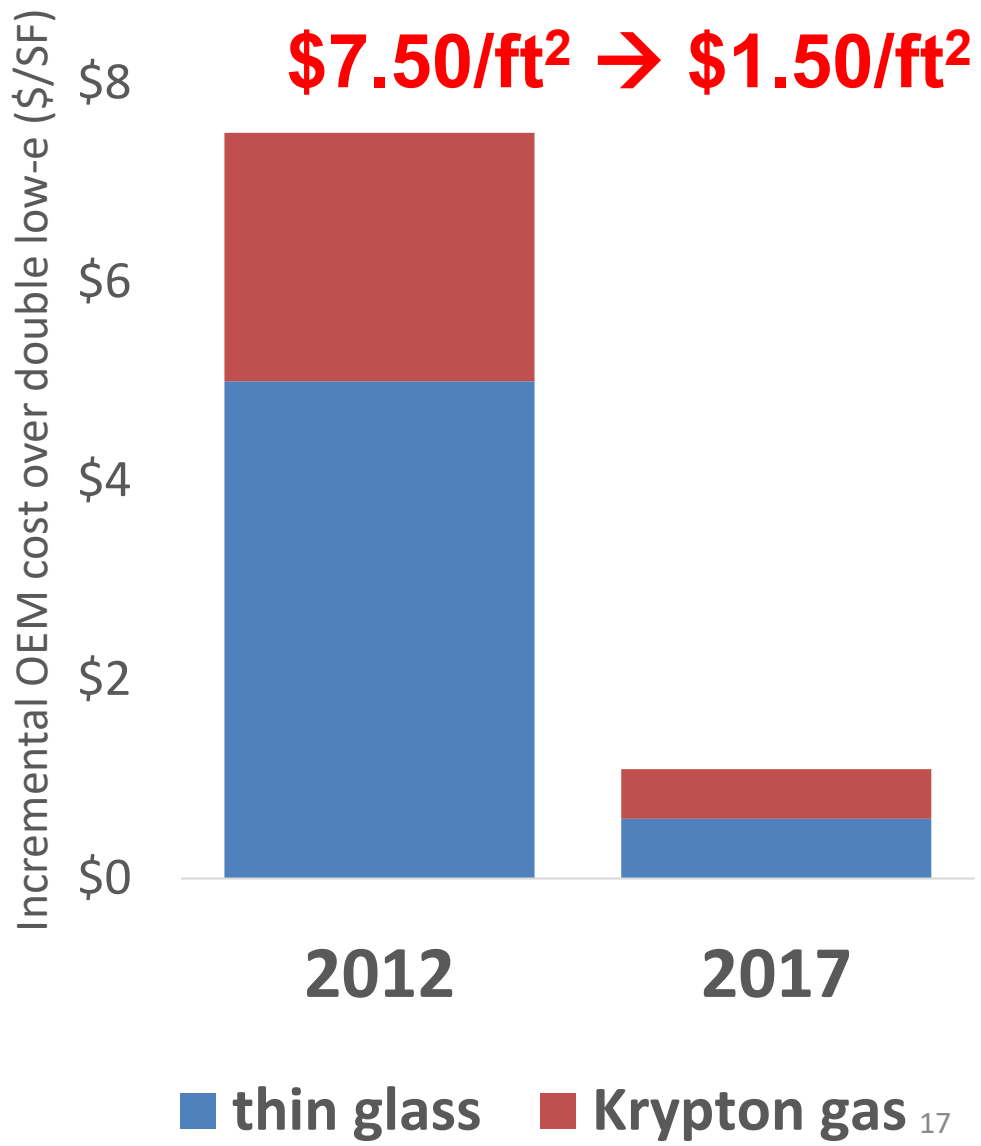
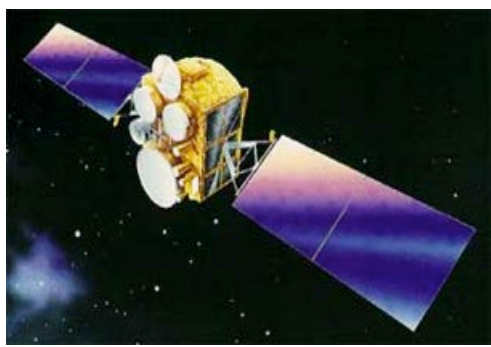
21 Claims, 2 Drawing Sheets

A statutory invention registration is not a patent. It has the enforceable attributes of a patent but does not have the enforceable attributes of a patent. No article or advertisement or the like may use the term patent, or any term suggestive of a patent, when referring to a statutory invention registration. For more specific information on the rights associated with a statutory invention registration see 35 U.S.C. 157.



80+% reductions in glass/Kr cost in 5 yrs

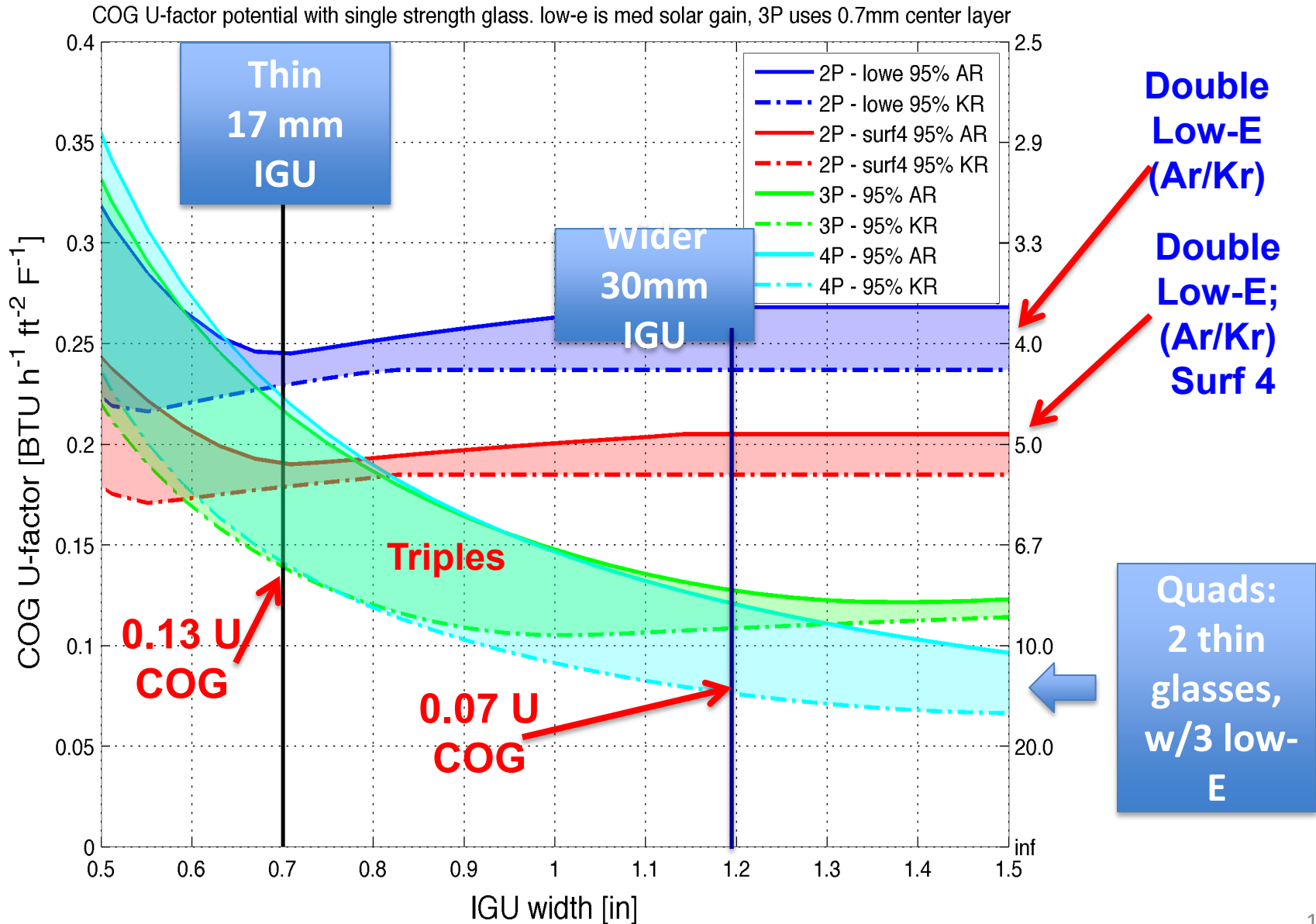
(thanks to flat screen TVs, satellite thrusters, LEDs)



Optimizing and Validating Thermal Properties

**Early Prototypes with
Window Industry Partners**

Thin Lightweight Triple → Thin Quad: R15



Emerging Technology (R8-R10 IGU)

Technical Validation

Simulation
Climate Modeling
Prototypes
Coatings

Collaborative R&D



Supply chain Partners

Thin Glass
Coatings
Gas supply
Gas fill
Spacer design
IGU fabrication



Market Scale Up (R4-R8 window)

Technical Evaluation

Laboratory Testing
Demonstrations
Utility Incentives
Codes and Standards
Net Zero advocates
ENERGYSTAR Criteria

Collaborative R&D

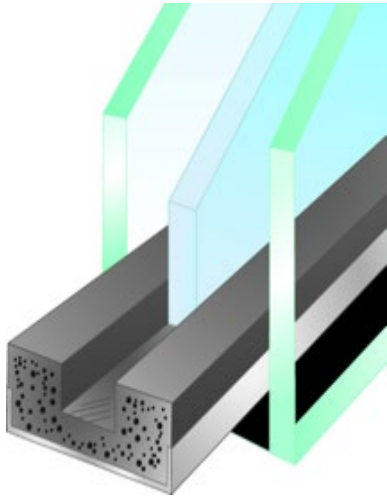


Window Partners

Andersen Windows
Alpen Windows
Market Intelligence
Supply Chain
Cost Optimization

Thin-glass spacer - Single spacer, dual seal systems (or use conventional two spacer system)

Examples: Products are already entering the market!



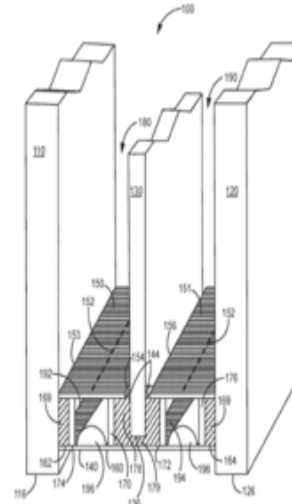
Edgetech



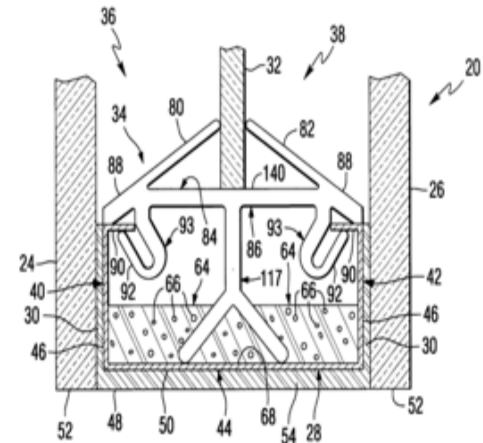
Swisspacer



SORA



Guardian: US 9,677,321 B2

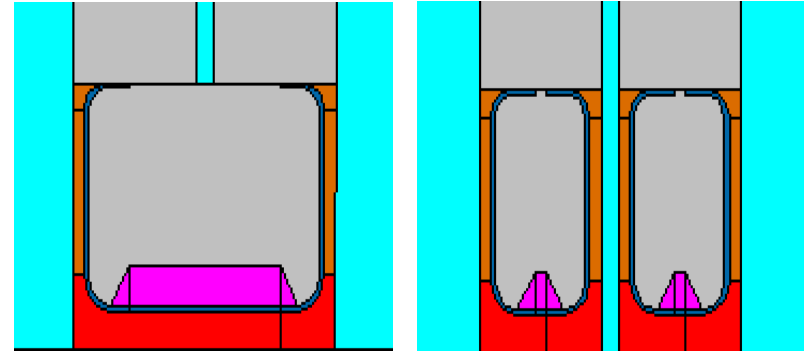


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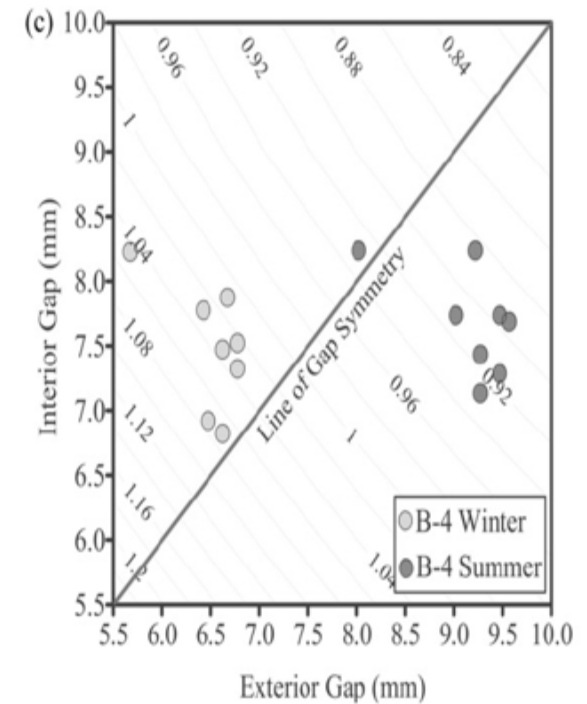
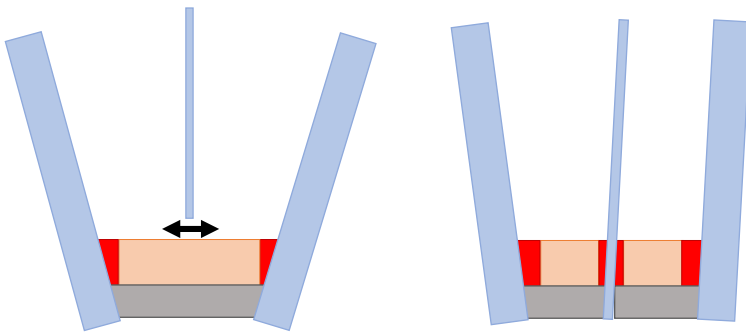
Long Term Durability/Reliability

Two sealant paths in place of four:

- Fewer sealant paths
- Removes center layer from structural load share
- Current Cyclic Durability Testing



Better pressure equalization = less optical distortion



IGU MANUFACTURING CHALLENGES

Thin-glass cutting

Thin-glass handling

Low loss Krypton gas fill

Automation: 1000 units/day



Increased U.S. Industry Interest and Collaboration

NEWS | RESEARCH | SPOUNED | EVENTS


gtm.

GREEN BUILDING

Triple-Glazed 'Super Window' Builds on Decades of Government Research

Researchers at Lawrence Berkeley National Lab have developed a more efficient drop-in replacement for the ubiquitous double-glazed windows.

JUSTIN GERDES | JULY 02, 2018



Government researchers have built a "super window" that could save \$10 billion in energy costs annually.

Researchers at Lawrence Berkeley National Laboratory are working with manufacturers to commercialize a triple-glazed "super window" that's at least twice as insulating as the most window sold in the United States today. If commercialized, the window could save \$10 billion

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'Super Windows' Could Save Billions in Energy Costs

Posted on June 14, 2018 by Trey Bernham

The Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) is working with manufacturers to bring a "super window" to market that is at least twice as insulating as 99 percent of the windows for sale today, potentially saving billions in wasted energy.

According to Berkeley Lab researchers, the "thin triple" super window design doubles the thermal performance of current Energy Star-rated double-glazed windows and is seven times more insulating than a single-glazed window. Berkeley Lab scientists have built and tested prototypes and are now working with Andersen Corp., the largest door and window manufacturer in the U.S., and separately with Alpen High-Performance Products, which specializes in energy-efficient doors and windows. Both efforts are looking to build and test enhanced prototypes suitable for large-scale manufacture.

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BuildingGreen

PRODUCT REVIEW

Thin Glass to Change High-Performance Window Market

Alpen is rolling out triple-pane products that are thinner and lighter—and will eventually be cheaper.

by Peter Yost

February 4, 2018


The good news about window performance is that the market has been transformed by the building industry moving to dual-pane, low-e, argon-filled glazing with performance around R-6, according to Lawrence Berkeley National Laboratory (LBNL). See Figure 1 in the slideshow.

The bad news is that since around 1990, the performance of the vast majority of our windows has not really changed much. See Figure 2 for a current breakdown of the market based on performance of windows rated by the National Fenestration Rating Council (NFRC).

Yes, we now have triple-pane glazing in the R-6 and beyond range, but these windows are quite heavy, expensive, and not really embraced by the U.S. market.

Enter thin glass triple glazing (TGT) technology. In Figure 3, you can see the key ways TGT is a breakthrough:

1. The "thin"—1 mm—glass is inserted in the middle of a standard dual-pane insulated glazing unit.
2. Krypton gas replaces argon in the now half-as-wide spacing of the three glass panes.



The thinnest thin glass triple-pane inserts are not only thinner but also lighter than conventional triple-pane glazing options.

Photo: Alpen

WINDOWS & DAYLIGHTING
Building Technology & Urban Systems

ABOUT US | RESEARCH | SOFTWARE TOOLS | FACILITIES | OUTREACH

Super Window Could Save Billions

Tuesday, June 05, 2018

Author: Julie Chao

About \$20 billion worth of energy leaks out of windows in the United States each winter - and that's with double-paned in majority of buildings. The Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) is now working on a "super window" that is at least twice as insulating as 99 percent of the windows for sale today and will be ready to activate

Super Window Could Save Billions in Energy Costs

Energy & Environmental News

NET-ZERO Glass From Flat-Panel TVs Makes Zero-Energy Homes More Feasible

NET-ZERO

With the latest window products, a 6-ft by 6-ft window can be as good as a 12-ft by 6-ft window. And that's with double-paned in majority of buildings. The Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) is now working on a "super window" that is at least twice as insulating as 99 percent of the windows for sale today and will be ready to activate

Zero-Energy Homes: Single Family Insights, by Sarah Cavallaro, Michael Gorman and Alan Hines, suggests that, these days, builders can utilize upgrades to building envelopes for residential homes to reduce carbon footprint. It's not just about energy performance, it's about cost. A 6-ft by 6-ft window can be as good as a 12-ft by 6-ft window. And that's with double-paned in majority of buildings. The Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) is now working on a "super window" that is at least twice as insulating as 99 percent of the windows for sale today and will be ready to activate

Thin glass triple-pane inserts are not only thinner but also lighter than conventional triple-pane glazing options.

Photo: Alpen

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The complete source for building, designing, and remodeling green homes.

Green Building News

Researchers Develop New 'Super Window'

The flatscreen TV industry advances thin glass technology, making a new type of window possible

By Scott Gibson | June 13, 2018

Thin glass triple-pane inserts are not only thinner but also lighter than conventional triple-pane glazing options.

Photo: Alpen

Alpen: Triple and Quad Thin Glass Windows



Creating More Demand:

**Market Pull and
Transformation**

Emerging Technology (R8-R10 IGU)

Technical Validation

Energy Simulation
Climate Modeling
Coatings
IGU Prototypes
Window Prototypes

Collaborative R&D



Supply chain

Partners

Thin Glass
Coatings
Gas supply
Gas fill
Spacer design
IGU fabrication



Market Scale Up (R4-R8 window)

Technical Evaluation, Promotion

Laboratory Testing
Demonstrations
Utility Incentives
Codes and Standards
Net Zero advocates
ENERGYSTAR Criteria

Collaborative R&D



Window Partners

Andersen Windows
Alpen Windows
Market Intelligence
Supply Chain
Cost Optimization

Market Drivers: Who Wants This? Needs This?

- **Building Owners**

- Energy/\$\$ Savings
- Thermal comfort
- Larger window area
- **Early Adopters**
 - **Passive House designers/buyers**
 - **Zero Net Energy Home buyers**

- **Architects/Engineers**

- Builders- first cost dominated-
 - Emerging early adopters
- Comfort/Daylight
- “Justifying” larger window area
- **HVAC system**
 - first cost savings- reduced size
 - Duct system reductions, distributed/zonal HVAC

Annual Energy Cost/Savings (6 U.S. Cities)

5 Alternative Window Designs

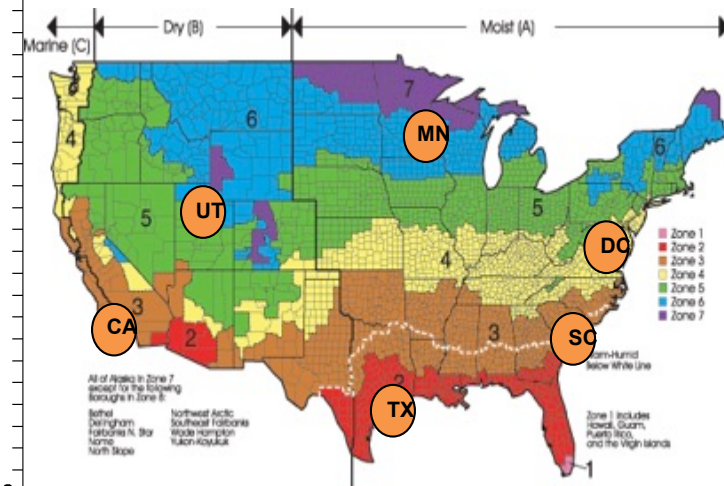
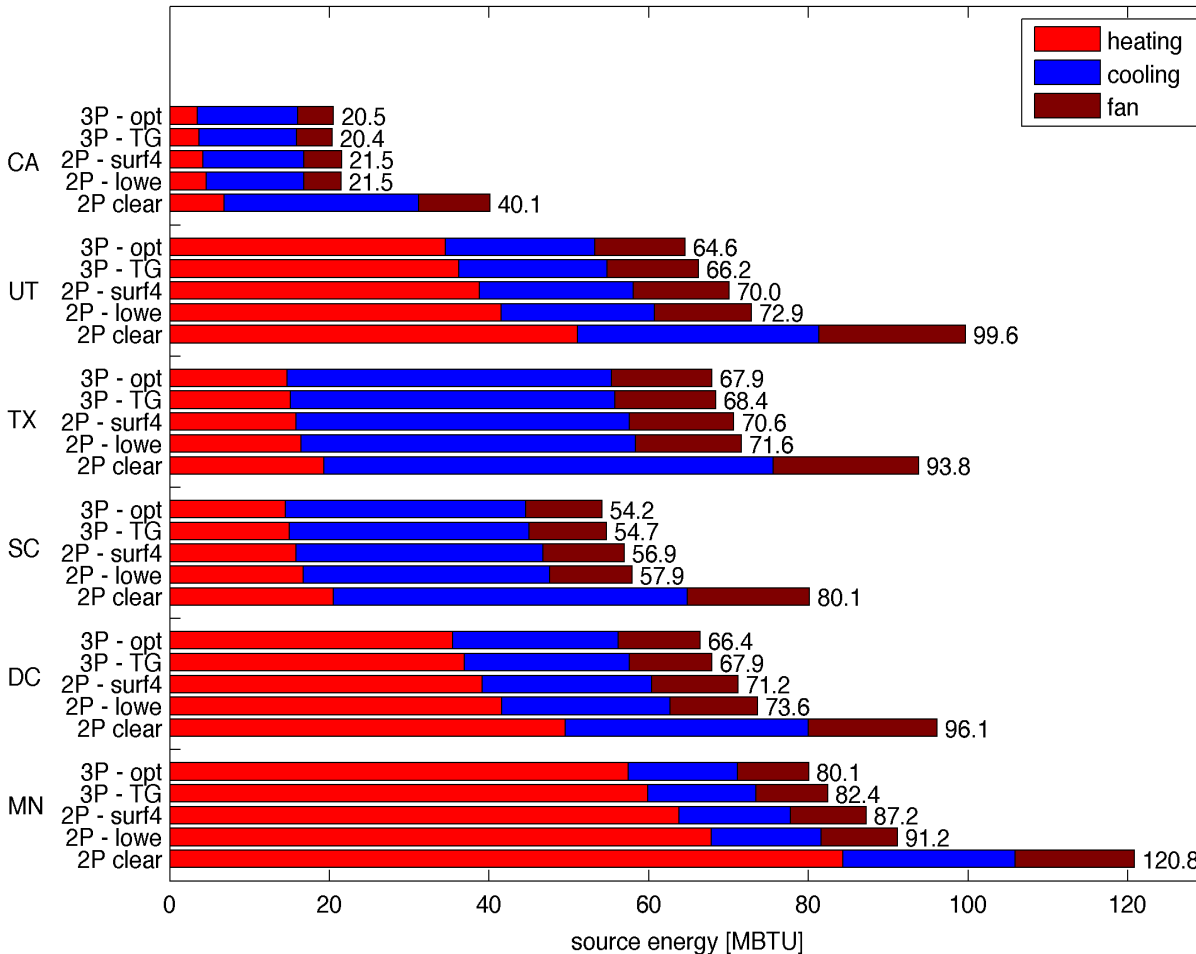
6 U.S. Climates

End use multipliers: Elec=3.167, Gas=1.084

Payback:
Varies with climate
and utility rate

Different U.S. Climate Zones

Yearly total home energy use



Mass-Market Adoption of Triple-Pane Windows

CA Demo Program:

High performance windows installed at **no incremental cost** to builder

Deployment collaborators

California Partnership for Advanced Windows (C-PAW)

Lawrence Berkeley National Lab

California Energy Commission

CONSOL

CBIA

And many more...

Development collaborators

Lawrence Berkeley National Lab

Andersen Windows

Alpen HPP

Ply-Gem

Guardian

Bystronic

Nippon Sheet Glass (NSG)

And many more...



New Master Builder Incentives Available:
THIN-GLASS TRIPLE-PANE WINDOWS

Additional incentives for installing advanced thin center glass triple-pane windows are now available for participants of the California Advanced Homes Program (CAHP) and California Multifamily New Homes (CMFNH) Program.

Thin-glass, triple-pane windows can be installed in the same window openings as double-pane windows, are significantly more energy efficient, and reduce the energy needed to maintain a comfortable temperature.



CAHP Incentives

- > High Performance Fenestration (HPF) cash bonus **doubles to \$400/home**
- > Each home receives an additional **\$6 per square foot of glazing***



CMFNH Incentives

- > High Performance Fenestration (HPF) cash bonus **doubles to \$150/unit**
- > Each unit receives an additional **\$6 per square foot of glazing***

INCENTIVE REQUIREMENTS

To qualify for these additional incentives, the programs will require:

- ✓ All buildings permit to 2016 Title 24 code
- ✓ All buildings participate in CAHP or CMFNH
- ✓ All buildings must be built in climate zones 11, 12, or 13**
- ✓ PG&E or a PG&E representative must observe the installation
- ✓ Access to incremental costs data with copies of applicable invoices (material and labor)
- ✓ Release to use collected data in case studies or marketing materials as appropriate
- ✓ Compliance with program-approved thin-glass, triple-pane window: a Krypton-filled, triple-pane window with a thin center pane of glass ($\leq 2\text{mm}$ thick), fitting into a typical double-pane window frame with an NFRC-rated U-factor ≤ 0.22 and SHGC as per Title 24 code*

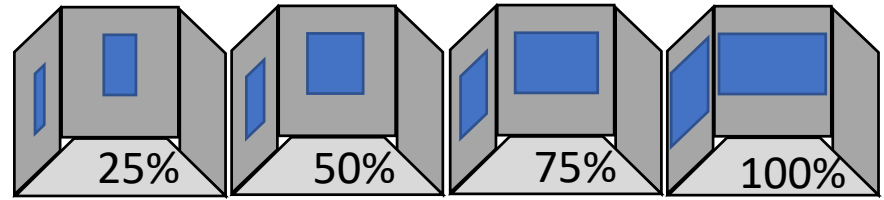
*Includes windows only. Doors, sliding glass doors, and skylights are excluded from program requirements.

**No more than ten (10) homes from any one builder in any one climate zone. Projects not meeting these requirements may be eligible but require program approval prior to enrollment.

ACT NOW: NEW INCENTIVES ARE AVAILABLE FOR A LIMITED TIME

Contact us to learn more and for assistance with sourcing
866-352-7457 | cahp@TRCcompanies.com | info@cmfnh.com

Thermal Comfort vs Window Size and Type



PPD (%)

Single Clear wood

Double Clear wood

Double Low-e vinyl

Double Low-e S4 vinyl

Triple Low-e vinyl

10

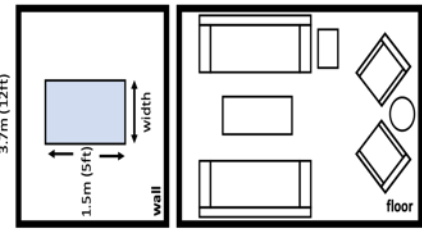
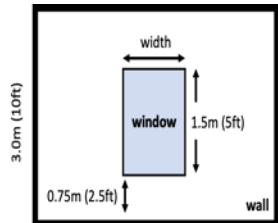
8

6

4

2

0



Minneapolis MN design day

Design Flexibility to Meet More Stringent Codes

Office Building

Make the case to **architects, engineers, and builders, early adopters**

Increase window size
Decrease perimeter HVAC

Condensation resistance
Comfort

Triple glazing eliminates need for perimeter heating coil;
Heating Coil Savings Pays for the Glass



We wouldn't need this

	Cost/ft ² Window
Upgrade Double to Triple Pane	\$5.47
Add Perimeter Heat to Double	\$53.20

Market Acceleration Programs: Creating Demand for Better Windows

- Window Manufacturers – Training, Promotion
- Education and Training – Architects, Engineers
- Voluntary Programs – ENERGY STAR
- Utility Rebates and Incentives
 - Midstream, Upstream?
- **Pilot Programs, Field Demonstration, Test Houses**

Research Project Goals and Design

Major project partners:

- 1) PNNL – pilot/field demonstration project lead
- 2) LBNL – window technology/supply chain lead
- 3) University of Minnesota – research and field testing
- 4) Funding from U.S. Dept. of Energy



Goals:

- 1) Increase uptake of the technology in the US market
- 2) Perform field testing to validate energy, comfort, condensation, and sound performance

Research Project Goals and Design

1) Technology uptake – Developing a “Push-Pull” Strategy

a) Supply Push

- LBNL leads efforts with manufacturers
- LBNL facilitates testing and provision of glass and IGU information for IGDB (International Glazing Database) and NFRC + Energy Star certification

b) Demand Pull

- PNNL leads validation studies and outreach efforts (conferences, webinars, in-the-field demonstrations, etc) to encourage implementation of higher performance residential windows

c) Window manufacturer involvement to date

- Alpen windows: thin triple IGU development and supply
- Kensington (Pennsylvania): frame and window assembly
- Paradigm (Maine): frame and window assembly
- Looking for additional window manufacturers



Field Test/Demonstration Project Goals and Design

2) Validation testing

a) 8 to 16 new residential or retrofit projects in different climates around US.

- Retrofit projects (before and after monitoring)
- New construction projects
- Looking for additional “case study” projects

b) Validating performance from occupant’s perspective:

- HVAC savings (energy consumption, peak loads)
- condensation performance
- acoustic performance
- comfort improvement
- subjective occupant experience

c) Validating performance from installer/builder perspective:

- window costs compared to double glaze options
- ease of installation/labor
- supply chain (availability)

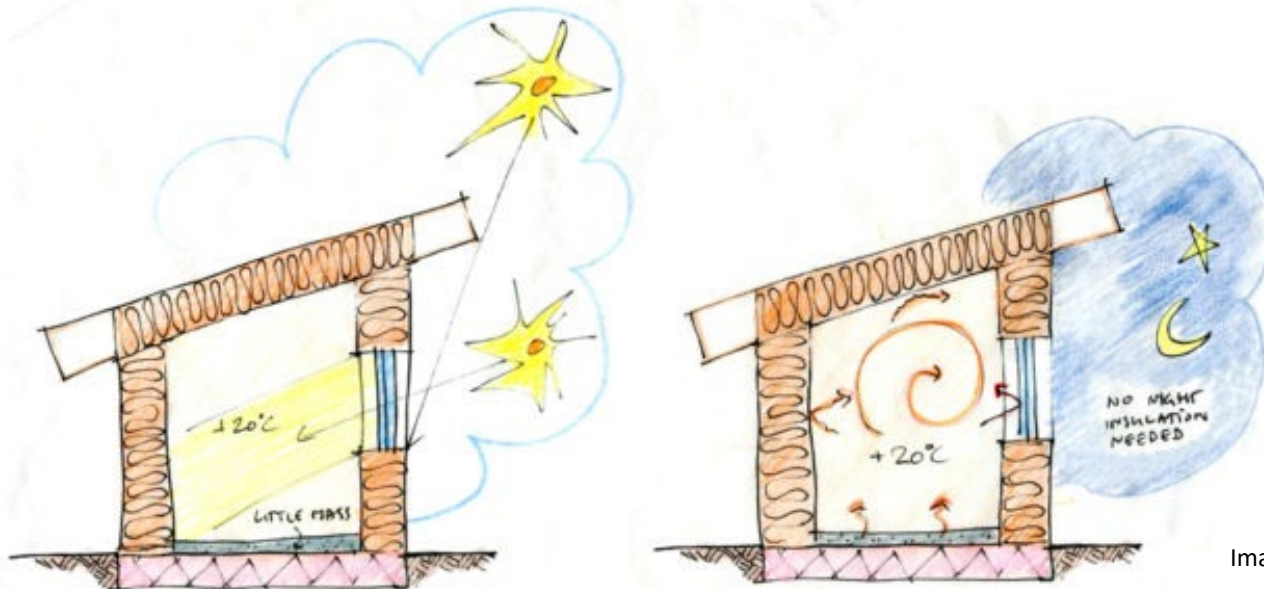
Habitat for Humanity field test project - Minneapolis, MN



Passive House Designers are Key Potential Partners

1. Passive House designs require high performance, low U windows
2. Product availability is limited today and costly
3. New low U window products are needed but manufacturers want to see the demand before investing in new low U products

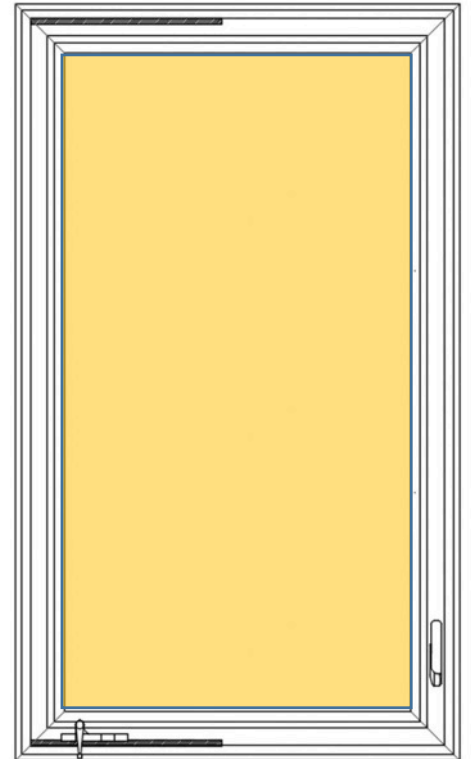
We are exploring how new thin triple IGUs can enhance window product offerings to meet needs for Passive House Projects



PHIUS window requirements

PHIUS measures window performance differently than NFRC:

U_g = U-value of glass (value for center of glass)

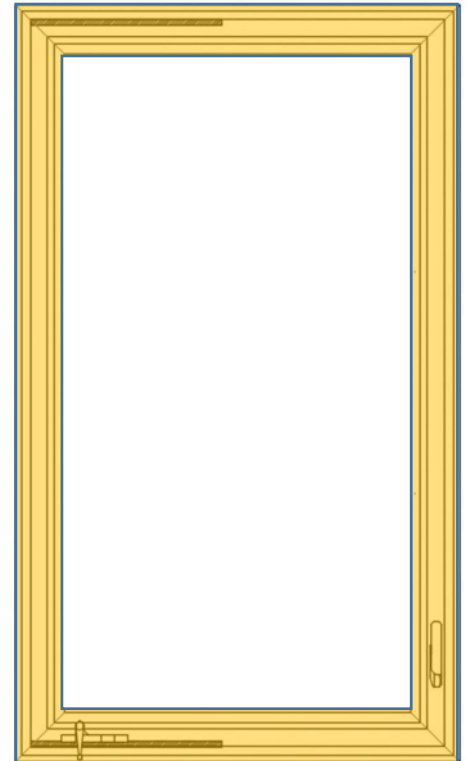


PHIUS window requirements

PHIUS measures window performance differently than NFRC:

U_g = U-value of glass

U_f = U-value of frame



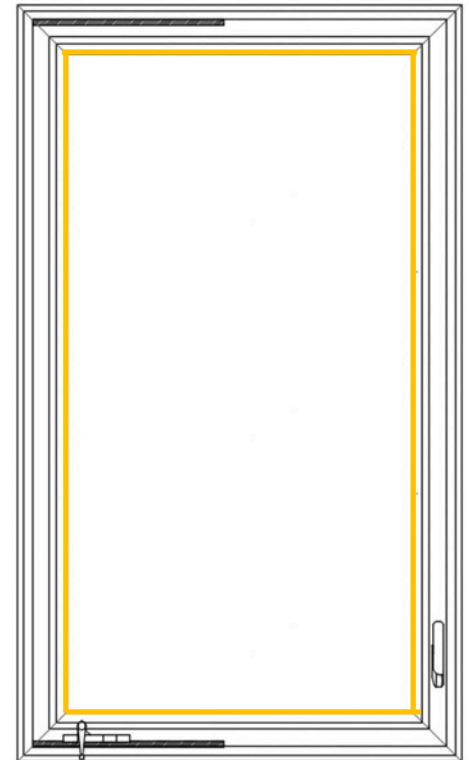
PHIUS window requirements

PHIUS measures window performance differently than NFRC:

U_g = U-value of glass

U_f = U-value of frame

Ψ_{spacer} = heat loss through spacer
(accounts for edge-of-glass effects)



PHIUS window requirements

PHIUS measures window performance differently than NFRC:

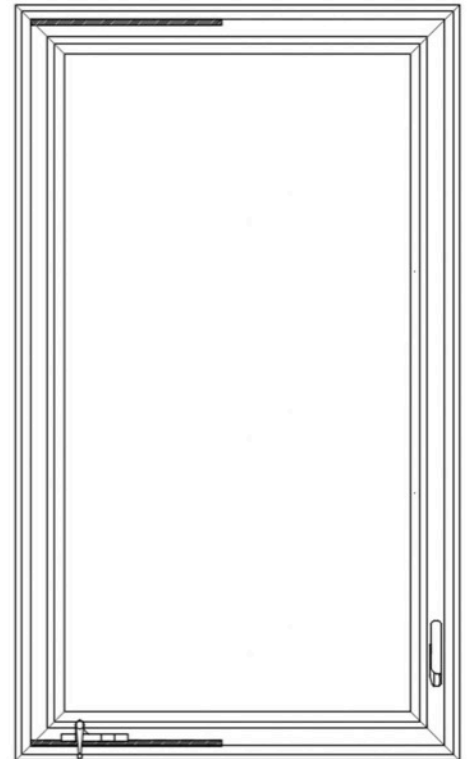
U_g = U-value of glass

U_f = U-value of frame

Ψ_{spacer} = heat loss through spacer
(accounts for edge-of-glass effects)

$$U_w = \frac{U_g \times A_g + U_f \times A_f + \Psi_{\text{spacer}} \times L_{\text{spacer}}}{A_g + A_f}$$

Window U-value is used to compare window performance.



PHIUS window requirements

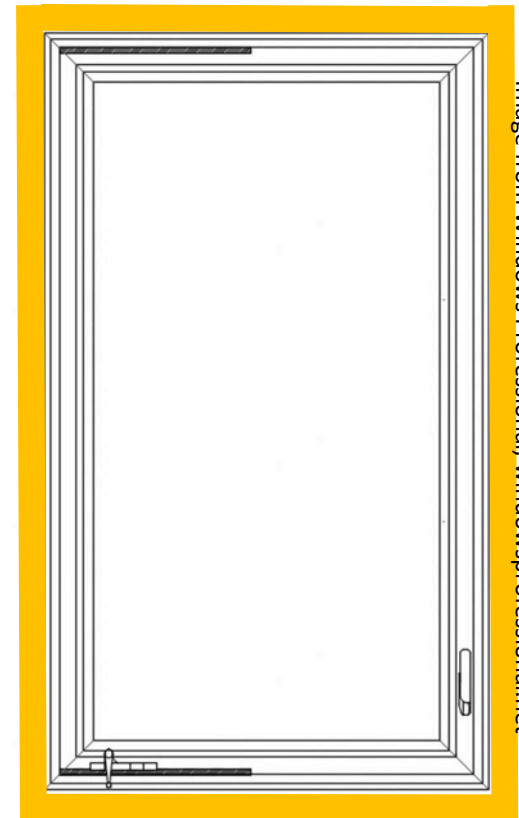
PHIUS measures window performance differently than NFRC:

U_g = U-value of glass

U_f = U-value of frame

Ψ_{spacer} = heat loss through spacer
(accounts for edge-of-glass effects)

Ψ_{install} = heat loss through joint between frame and wall
(accounts for installation effects)



PHIUS window requirements

PHIUS measures window performance differently than NFRC:

U_g = U-value of glass

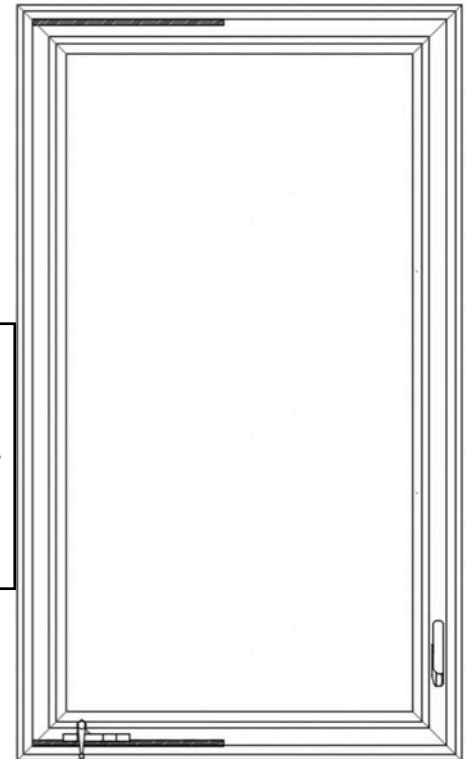
U_f = U-value of frame

Ψ_{spacer} = heat loss through spacer
(accounts for edge-of-glass effects)

Ψ_{install} = heat loss through joint between frame and wall
(accounts for installation effects)

$$U_{w \text{ installed}} = \frac{U_g \times A_g + U_f \times A_f + \Psi_{\text{spacer}} \times L_{\text{spacer}} + \Psi_{\text{install}} \times L_{\text{install}}}{A_g + A_f}$$

Installed window U-value is used to calculate window heat loss in the energy model.



PHIUS window requirements

PHIUS climate zone **recommendations:**

$$U_{w \text{ installed}}$$

$$U_g$$

ASHRAE/IECC/DOE North American Climate Zone	Overall installed window U-value Btu/h.ft ² .F	Center-of-glass U-value Btu/h.ft ² .F	SHGC - South	SHGC - North, East, West
8	≤0.11	≤0.10	≥0.50	Any
7	≤0.12	≤0.11	≥0.50	Any
6	≤0.13	≤0.12	≥0.50	Any
5	≤0.14	≤0.13	≥0.50	Any
4	≤0.15	≤0.14	≥0.50	≤0.40
Marine North	≤0.16	≤0.15	≥0.50	≤0.40
Marine South	≤0.22	≤0.20	≤0.50	≤0.30
3	≤0.18	≤0.16	≤0.50	≤0.30
2 West	≤0.18	≤0.16	≤0.30	≤0.30
2 East	≤0.20	≤0.18	≤0.30	≤0.30

PHIUS window requirements

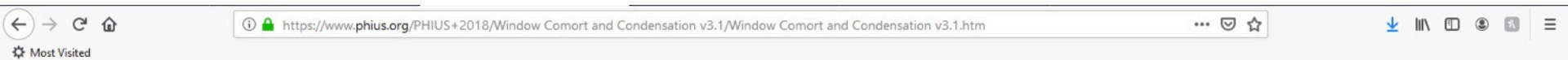
PHIUS climate zone **recommendations**: The recommended performance for even the warmest climate zones is well beyond what double-glazed windows can provide.

ASHRAE/IECC/DOE North American Climate Zone	Overall installed window U-value Btu/h.ft ² .F	Center-of-glass U-value Btu/h.ft ² .F	SHGC - South	SHGC - North, East, West
8	≤0.11	≤0.10	≥0.50	Any
7	≤0.12	≤0.11	≥0.50	Any
6	≤0.13	≤0.12	≥0.50	Any
5	≤0.14	≤0.13	≥0.50	Any
4	≤0.15	≤0.14	≥0.50	≤0.40
Marine North	≤0.16	≤0.15	≥0.50	≤0.40
Marine South	≤0.22	≤0.20	≤0.50	≤0.30
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2 West	≤0.18	≤0.16	≤0.30	≤0.30
2 East	≤0.20	≤0.18	≤0.30	≤0.30

PHIUS window requirements

While window *energy* performance values are recommendations, PHIUS does have hard requirements for window condensation and comfort performance.

PHIUS has created a calculator to assist in determining compliance.



PHIUS WINDOW COMFORT & CONDENSATION RISK ASSESSMENT

Project Name

Project #

State

City

ASHRAE 99% Design Temperature [°F]

<http://ashrae-meteo.info/>

PHIUS+ Climate Data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambient Temp (°F)	36.3	34.3	43.2	67.4	63.7	75.6	81.0	78.6	67.3	59.7	46.9	43.5
Dewpoint (°F)	23.4	20.3	27.7	42.6	53.2	63.3	65.5	63.7	60.6	49.6	39.7	32.7

CONDENSATION RISK

ISO 13788 Calculation for Low Thermal Inertia Elements

Is this a Heating Climate?	TRUE
Use simple method for indoor humidity?	TRUE
High occupancy?	TRUE
U-value of window frame/glass [BTU/hr.ft².F]	0.48
Safety Factor	15%

Interior Surface Temperature of window frame/glass [°F]	48.5
Risk of condensation on interior surface acceptable?	YES
Critical fRsi	0.64
Critical Month	FEB
Critical CRF Rating	64

COMFORT REQUIREMENTS

Applies to all projects.

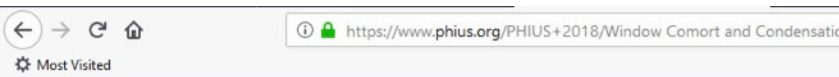
Windows >10' in height and above have the same required U-value.

Window Vertical Height (ft) - Use slider	5.0
Required Whole Window U-value [BTU/hr.ft².F]	0.31



PHIUS window requirements

Condensation Risk: In general, the easier of the two requirements to meet.
Must be met for both frame and glass, U_f and U_g



PHIUS WINDOW COMFORT

Project Name	
Project #	
State	VIRGINIA
City	WASHINGTON DC REAGAN AP
ASHRAE 99% Design Temperature [°F]	20.3

<http://ashrae-meteo.info/>

CONDENSATION RISK

ISO 13788 Calculation for Low Thermal Inertia Elements

Is this a Heating Climate?	TRUE
Use simple method for indoor humidity?	TRUE
High occupancy?	TRUE
U-value of window frame/glass [BTU/hr.ft².F]	0.48
Safety Factor	15%

Interior Surface Temperature of window frame/glass [°F]	48.5
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Critical fRsi	0.64
Critical Month	FEB
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Inputs ask for:

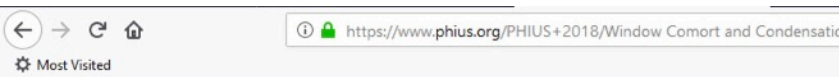
- ASHRAE 99% design temperature
- Information about the indoor humidity
- Safety factor
- U-values of frame and glass: U_f , U_g

Outputs calculate:

- Interior surface temperature of frame and glass at design temp (using 0.74 (IP) surface film resistance)
- Dewpoint based on indoor humidity
- A check whether the interior surface temperature is above the dewpoint
- Can also meet this criterion using an F_{rsi} or CRF calculation based on the coldest month average temp

PHIUS window requirements

Condensation Risk: In general, the easier of the two requirements to meet.
Must be met for both frame and glass, U_f and U_g



PHIUS WINDOW COMFORT

Project Name	
Project #	
State	VIRGINIA
City	WASHINGTON DC REAGAN AP
ASHRAE 99% Design Temperature [°F]	20.3

ASHRAE 99% Design Temperature [°F]

<http://ashrae-meteo.info/>

CONDENSATION RISK

ISO 13788 Calculation for Low Thermal Inertia Elements

Is this a Heating Climate?	TRUE
Use simple method for indoor humidity?	TRUE
High occupancy?	TRUE
U-value of window frame/glass [BTU/hr.ft².F]	0.48
Safety Factor	15%

Interior Surface Temperature of window frame/glass [°F]	48.5
Risk of condensation on interior surface acceptable?	YES
Critical fRsi	0.64
Critical Month	FEB
Critical CRF Rating	64

Required window frame or glass U-value to meet condensation requirement is only U-0.48 for Washington D.C.

(with high occupancy and 15% safety factor specified)

PHIUS window requirements

Comfort Assessment: In general, the harder of the two requirements to meet.
The assessment specifies the required whole-window U-value, U_w

Inputs ask for:

- ASHRAE 99% design temperature
- Window vertical height (ft) (to account for convection effects)

Outputs calculate:

- The max ΔT (between indoor air temp and interior glass surface temp) allowed to meet requirements, generally between 6°F and 13.3°F depending on window height
- Then provides the required window U-value (U_w) to pass max ΔT at ASHRAE 99% design temp

The screenshot shows a web browser window with the URL "on v3.1/Window Comort and Condensation v3.1.htm". The page title is "& CONDENSATION RISK ASSESSMENT". Below the title, there is a section for "PHIUS+ Climate Data" which contains a table of monthly climate data. The table has columns for Month (Jan to Dec) and rows for Ambient Temp (°F) and Dewpoint (°F). The values are: Ambient Temp (°F) [36.3, 34.3, 43.2, 57.4, 63.7, 75.6, 81.0, 78.6, 67.3, 59.7, 46.9, 43.5] and Dewpoint (°F) [23.4, 20.3, 27.7, 42.6, 53.2, 63.3, 65.5, 63.7, 60.6, 49.6, 39.7, 32.7].

Below the climate data table, there is a section for "COMFORT REQUIREMENTS" which states "Applies to all projects." and "Windows >10' in height and above have the same required U-value." Below this, there is a table with two rows: "Window Vertical Height (ft) - Use slider" with a value of 5.0, and "Required Whole Window U-value [BTU/hr.ft².F]" with a value of 0.31. A vertical slider is visible to the right of the table, with a green bar indicating the current value of 5.0.

At the bottom of the page, there is a green bar with the text "Real-time Sync" and a small icon.

PHIUS window requirements

Comfort Assessment: In general, the harder of the two requirements to meet.
The assessment specifies the required whole-window U-value, U_w

Required whole-window U-value to meet comfort requirement is U-0.31 for Washington, D.C.

(for a 5 foot high window)

The screenshot shows a web browser window with the URL "on v3.1/Window Comort and Condensation v3.1.htm". The page title is "& CONDENSATION RISK ASSESSMENT". Below the title, there is a section for "PHIUS+ Climate Data" which includes a table of monthly climate data for Washington, D.C. The table has columns for months (Jan to Dec) and rows for Ambient Temp (°F) and Dewpoint (°F). The values are: Ambient Temp (°F) [36.3, 34.3, 43.2, 57.4, 63.7, 75.6, 81.0, 78.6, 67.3, 59.7, 46.9, 43.5] and Dewpoint (°F) [23.4, 20.3, 27.7, 42.6, 53.2, 63.3, 65.5, 63.7, 60.6, 49.6, 39.7, 32.7]. Below the table, there is a section for "COMFORT REQUIREMENTS" which states "Applies to all projects." and "Windows >10' in height and above have the same required U-value." There is a slider control for "Window Vertical Height (ft) - Use slider" with a value of 5.0. Below the slider, there is a field for "Required Whole Window U-value [BTU/hr.ft².F]" with a value of 0.31, which is highlighted with a red box.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ambient Temp (°F)	36.3	34.3	43.2	57.4	63.7	75.6	81.0	78.6	67.3	59.7	46.9	43.5
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COMFORT REQUIREMENTS

Applies to all projects.

Windows >10' in height and above have the same required U-value.

Window Vertical Height (ft) - Use slider: 5.0

Required Whole Window U-value [BTU/hr.ft².F]: 0.31

Thin Triple Fit with PHIUS Requirements

What range of performance is possible for thin-triples given current window frame and spacer technology?

	Window Product	U-frame	U-cog (center of glass)	Uw (whole window) ¹	Uw (installed) ²
Upper Range	Tilt/Turn w thin Quad IGU IGU = 1 3/8 in. thick (Ex: Alpen Tyrol window)	0.143	0.078 - 0.085	0.107 - 0.113	0.120
Middle	Casement w thin Triple IGU IGU = 7/8 in. thick (Ex: Alpen 725 Series)	0.15	0.106	0.125	0.138
Lower Range	Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.13	0.19 - 0.20	0.223

- 1) Includes psi-spacer: Ψ -0.0117 for Alpen Tyrol and 725 Series, Ψ -0.034 industry standard
- 2) Includes psi-install: Ψ -0.0145 for all windows
- 3) PHIUS climate zone recommendations are based on installed window U-value and SHGC

Thin Triple Fit with PHIUS Requirements

What range of performance is possible for thin-triples given current window frame and spacer technology?

How does this match up to PHIUS climate zone recommendations?

	Window Product	U-frame	U-cog (center of glass)	Uw (whole window) ¹	Uw (installed) ²	PHIUS Climate Zone Recommendation ³
Upper Range	Tilt/Turn w thin Quad IGU IGU = 1 3/8 in. thick (Ex: Alpen Tyrol window)	0.143	0.078 - 0.085	0.107 - 0.113	0.120	Climate Zone 7
Middle	Casement w thin Triple IGU IGU = 7/8 in. thick (Ex: Alpen 725 Series)	0.15	0.106	0.125	0.138	Climate Zone 4-5
Lower Range	Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.13	0.19 - 0.20	0.223	Climate Zone 3 Marine South only (i.e. southern CA)

- 1) Includes psi-spacer: Ψ -0.0117 for Alpen Tyrol and 725 Series, Ψ -0.034 industry standard
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- 2) Includes psi-install: Ψ -0.0145 for all windows
- 3) PHIUS climate zone recommendations are based on installed window U-value and SHGC

But these are recommendations only. Windows in the lower range of performance could still be used in colder climates provided the building meets energy requirements and the windows meet condensation and comfort requirements.

Thin Triple Fit with PHIUS Requirements

How does this range of performance align with PHIUS condensation requirements?

	Condensation risk ⁴	
	Washington, D.C.	Minneapolis, MN
PHIUS+ 2018 maximum U-value	0.48	0.39
Tilt/Turn w thin Quad IGU IGU = 1 3/8 in. thick (Ex: Alpen Tyrol window)	0.143	0.143
Casement w thin Triple IGU IGU = 7/8 in. thick (Ex: Alpen 725 Series)	0.15	0.15
Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.40
--evaluated for frame U-value--		

Color coding: Green – meets requirements, Yellow – possibly meets requirements, Red – does not meet requirements

Thin Triple Fit with PHIUS Requirements

How does this range of performance align with PHIUS condensation requirements?

	Condensation risk ⁴	
	Washington, D.C.	Minneapolis, MN
PHIUS+ 2018 maximum U-value	0.48	0.39
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Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.40
--evaluated for frame U-value--		

In general, even a standard industry frame (R-2.5) can pass condensation requirements in cold climates like Minneapolis.

As long as the glass is a thin triple IGU, such windows could be used throughout most of the country in multifamily buildings or other building types where enclosure performance is less critical for the energy balance.

Color coding: Green – meets requirements, Yellow – possibly meets requirements, Red – does not meet requirements

Thin Triple Fit with PHIUS Requirements

How does this range of performance align with PHIUS comfort requirements?

	Condensation risk ⁴		Comfort Requirement ⁵			
	Washington, D.C.	Minneapolis, MN	Washington, D.C. (5' high)	Washington, D.C. (10' high)	Minneapolis, MN (5' high)	Minneapolis, MN (10' high)
PHIUS+ 2018 maximum U-value	0.48	0.39	0.31	0.21	0.20	0.13
Tilt/Turn w thin Quad IGU IGU = 1 3/8 in. thick (Ex: Alpen Tyrol window)	0.143	0.143	0.113	0.113	0.113	0.113
Casement w thin Triple IGU IGU = 7/8 in. thick (Ex: Alpen 725 Series)	0.15	0.15	0.125	0.125	0.125	0.125
Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.40	0.20	0.20	0.20	0.20
	--evaluated for frame U-value--		----- evaluated for whole-window U-value -----			

Thin Triple Fit with PHIUS Requirements

How does this range of performance align with PHIUS comfort requirements?

	Condensation risk ⁴		Comfort Requirement ⁵			
	Washington, D.C.	Minneapolis, MN	Washington, D.C. (5' high)	Washington, D.C. (10' high)	Minneapolis, MN (5' high)	Minneapolis, MN (10' high)
PHIUS+ 2018 maximum U-value	0.48	0.39	0.31	0.21	0.20	0.13
Tilt/Turn w thin Quad IGU IGU = 1 3/8 in. thick (Ex: Alpen Tyrol window)	0.143	0.143	0.113	0.113	0.113	0.113
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Industry standard frame w thin triple IGU = 3/4 in. thick	0.40	0.40	0.20	0.20	0.20	0.20
	--evaluated for frame U-value--		----- evaluated for whole-window U-value -----			

Comfort requirements are more challenging, but even an industry standard frame with a thin triple IGU could be used throughout the country in buildings where the enclosure is less critical for the energy balance. Window heights might be restricted.

Collaborate with Us

- Your Market Views/Feedback
 - Are adequate low U products available?
 - At Reasonable cost? Delivery times ?
 - What size, operator types are you looking for?
- What added information/data/tools on window performance do you need?
- Do you have projects suitable for use as potential test houses?
- Rolf Jacobson jaco0630@umn.edu
- Steve Selkowitz seselkowitz@lbl.gov