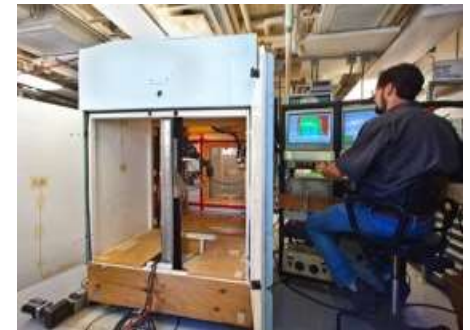
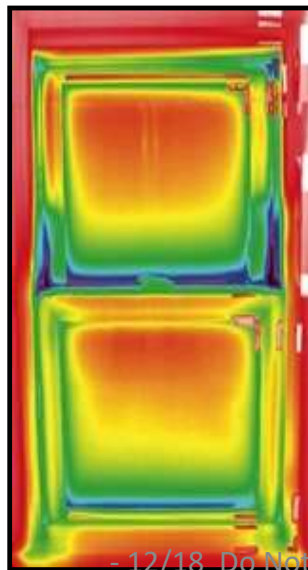


A View Through the Next Generation of High Performance Windows: *“The Thin Triple IGU”*

Stephen Selkowitz

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



Vision for High Performance Windows

- People Friendly** : View, Health, Daylight...
- Building Friendly**: Energy, Comfort
- Electric Grid Friendly**: Load management
- Planet Friendly**: Carbon

- 1. “Net Zero Windows” that Outperform Insulated Walls**
- 2. “Active Control” to manage solar gain and glare**
- 3. Measured Performance Matches Promises; Long term**

Need

- 1) “Hardware/Technology/Systems Solutions”,**
- 2) “Business Delivery System”**

National Energy/Cost Impacts

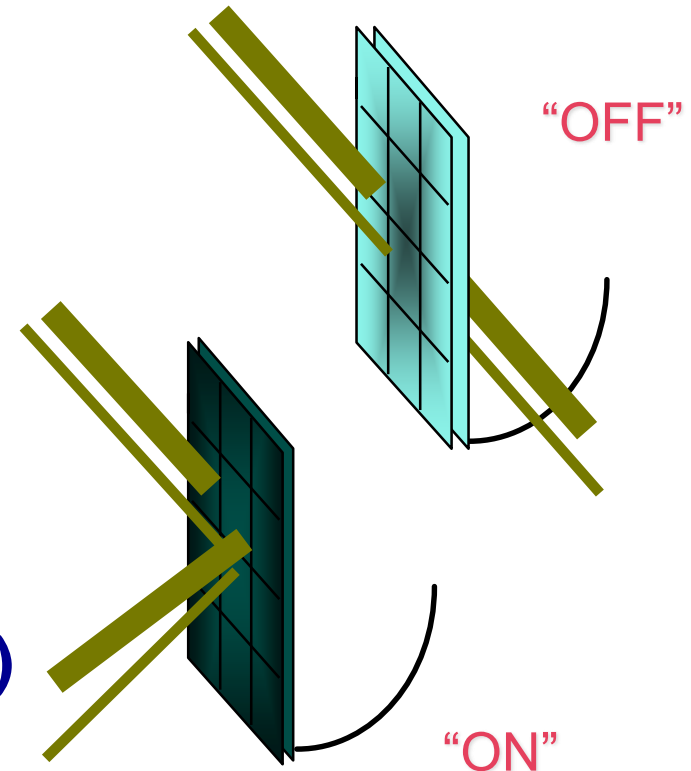
- **Window Impacts on U.S. Energy Use ~ \$50B/yr**
 - **Energy, Electric Demand**
 - HVAC Energy: ~ 4 Q; Electric Lighting Energy: ~ 1 Q
 - Summer cooling peak, load shape, grid impacts
 - Winter Peak heating impact for electric heating
 - **Highly Insulating Windows: Tech Potential – 2.8Q**
 - Residential and Commercial; Heating and Cooling
- **Longer Term 2020+ Goals**
 - “Net Zero” Buildings → Net Zero Envelope
 - Decarbonize: Gas-> Electric heating
 - Resilience: survivability- no power for days...
 - Occupant: Comfort, Wellness, View, Daylight,...

“SMART WINDOWS”

Dynamic Control of Window Solar Gain, Daylight

Balancing Cooling \leftrightarrow Daylighting, View \leftrightarrow Glare
Optimized, Flexible control of solar gain, daylight

- **“Mechanical Shading”**
 - Interior, exterior, between-glass options
 - Manual or Automated
 - Functional and Aesthetic selections
- **Passive control - glass**
 - Photochromic - light sensitive
 - Thermochromic - heat sensitive
- **Active control - glass**
 - Liquid Crystal (privacy)
 - Suspended particle display (SPD)
 - Electrochromic

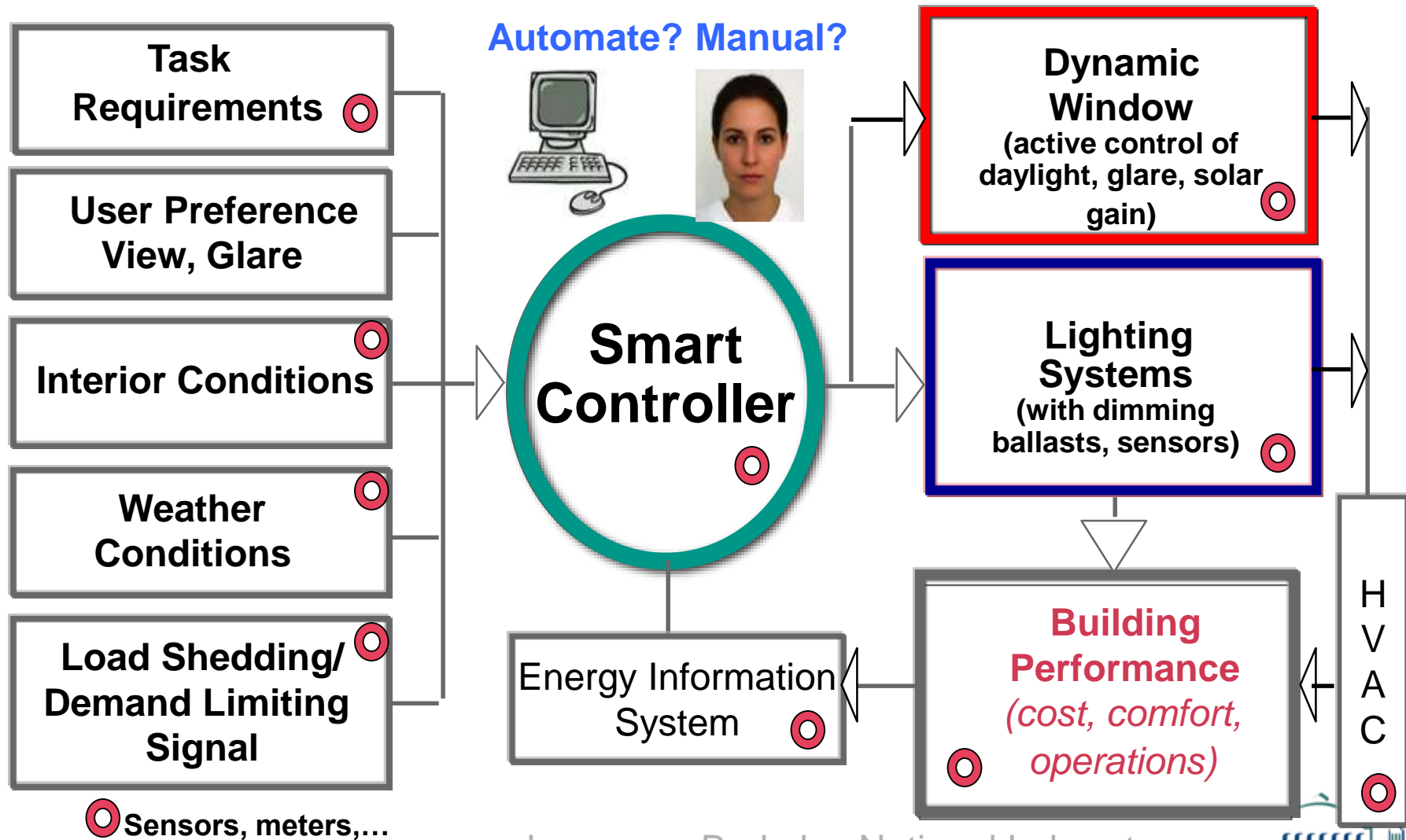


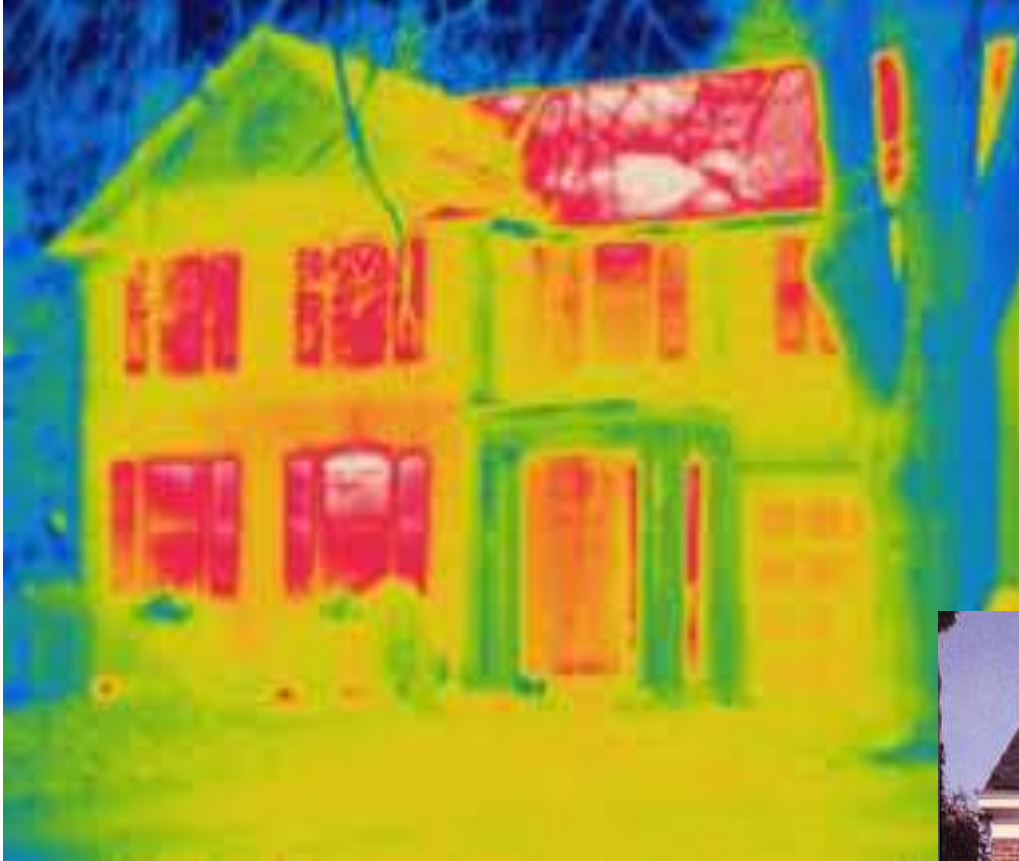
Large Scale EC Applications 2015+



Exploring Intelligent Control Systems:

Optimal performance requires full integration with building systems





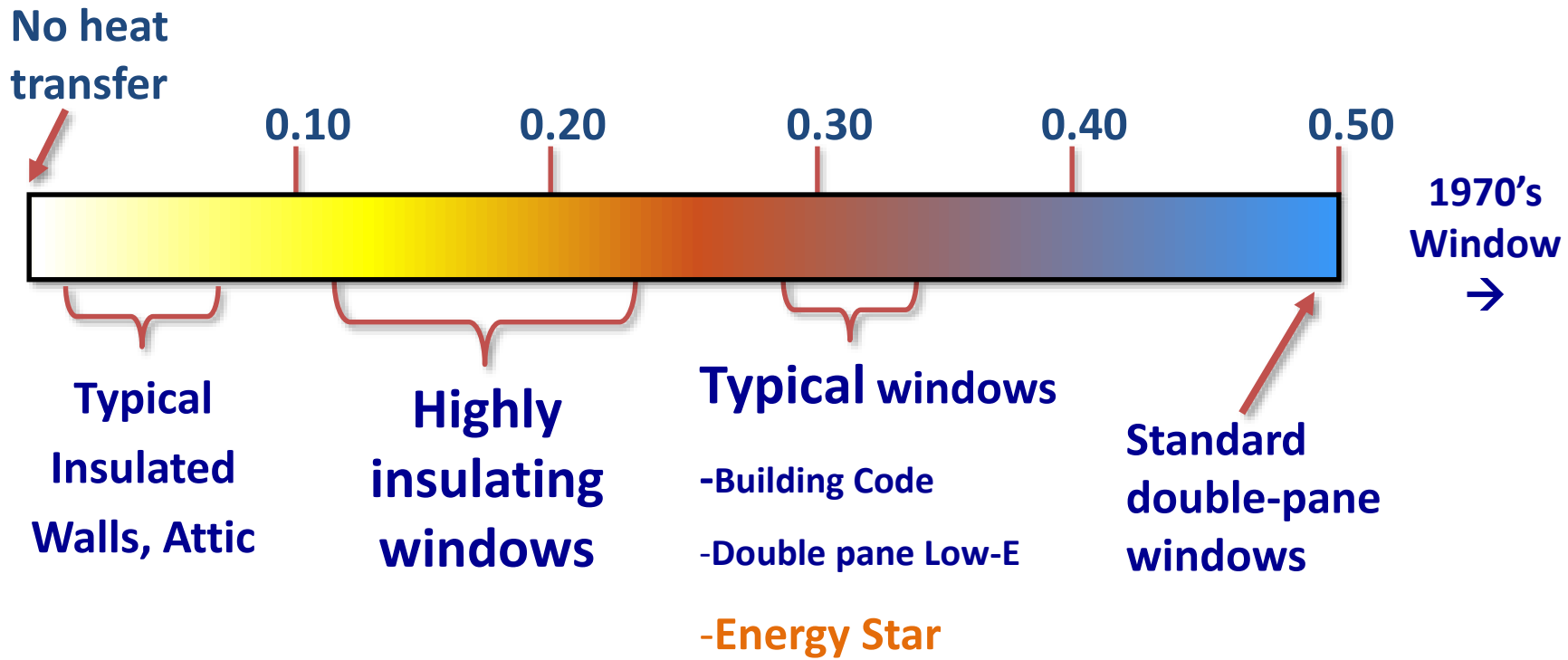
1970 Design Guidance:
If Windows are
thermally poor, then
use less of them....



Current State of Envelope Heat Loss

U- factor

Whole window U-factor



Savings from Better Windows

Annual Heating Cost simulated for a heating climate



Single Glazed w/Storm, **\$1310**

Double Glazed, **\$1218**

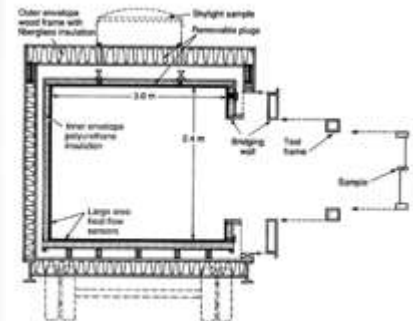
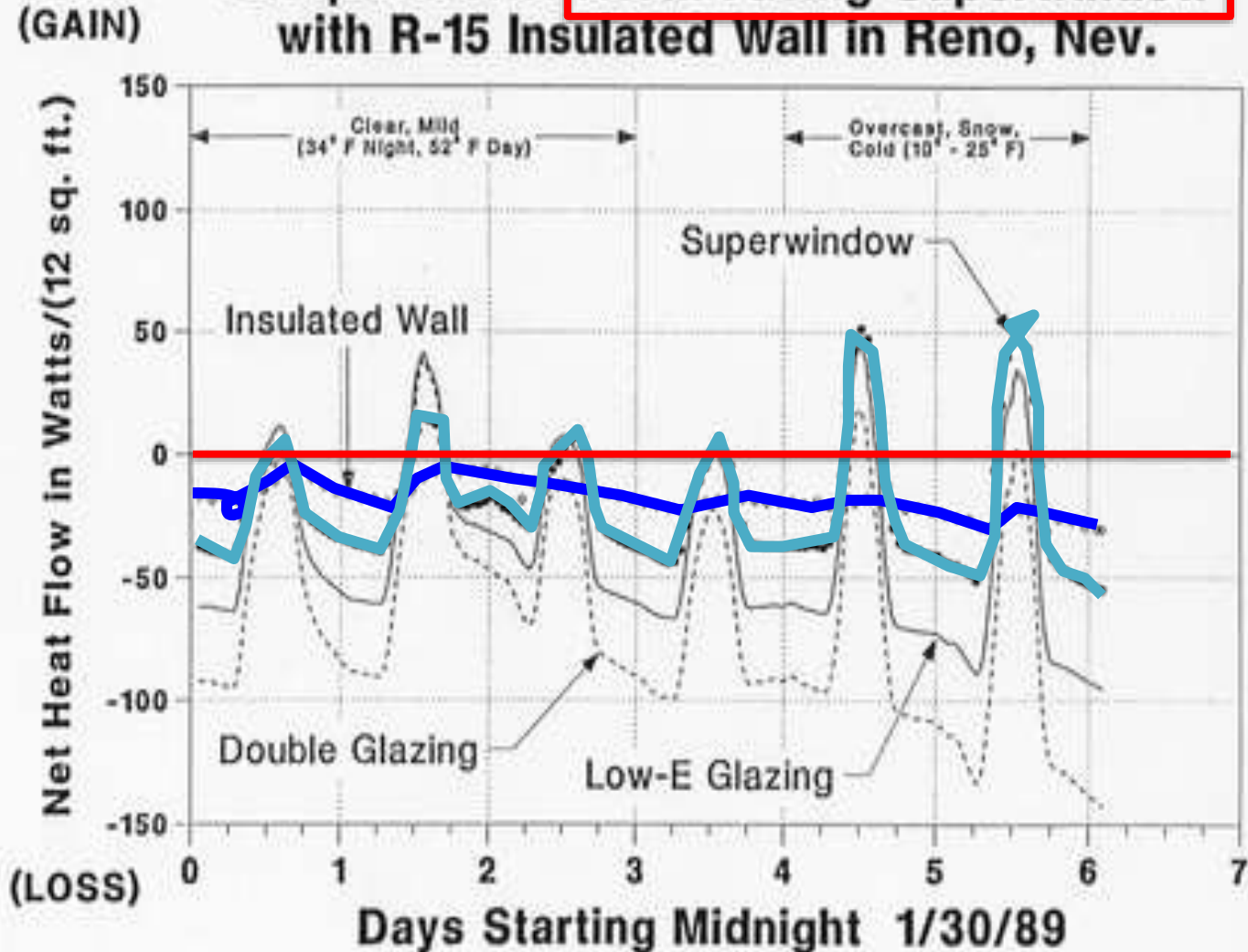
Double w/Low-E, **\$1120**

House with no windows, **\$1000**

“SuperWindow”, **\$960**

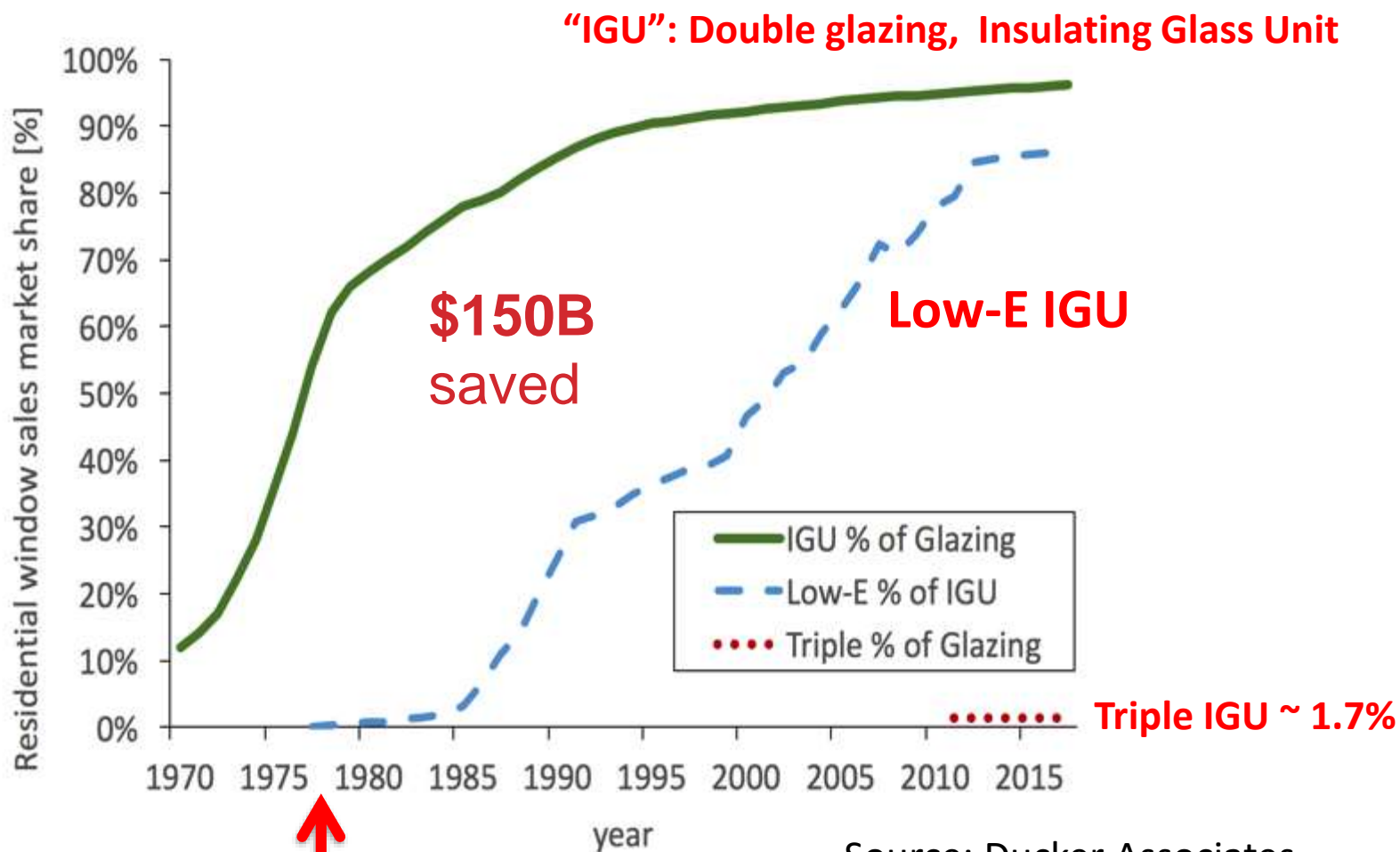
"North-facing Windows Outperform Insulated Walls during winter heating season" (from 1989!)

Comparison of **North-Facing Superwindow** with R-15 Insulated Wall in Reno, Nev.



Good News/Bad News

U.S. Residential Glazing Market Share



Source: Ducker Associates

Success of Low-E, Double Glazed IGU: U: 0.5 -> 0.3

- **3 stage “adoption” process to increase market share**
 1. Introduction -> ~20% market share: **Innovation push**
 2. 20% -> 60% **NFRC Ratings, Voluntary market pull (ES)**
 3. 60% -> 95%: **Codes and Standards**
- **“Criteria” for rapid adoption:**
 - **Window manufacturers** must engage; accept cost and risk
 - New Investment, Disruption to manufacturing process?
 - See a Competitive Market opportunity – or threat
 - **Glass package** is affordable, durable, ...
 - **Market Acceptance and Demand:**
 - Work with Early adopters, Niche Markets, Incentives,...

Why Not Make Better Windows Now... ??

- **Window Manufacturers “could” redesign product lines to offer triple glazing**
 - No “easy path” to high performance window today
 - 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 accommodates triple IGU
 - Offered by all suppliers
 - Supported by codes, higher energy prices
 - So no fundamental “technical” obstacle to adoption

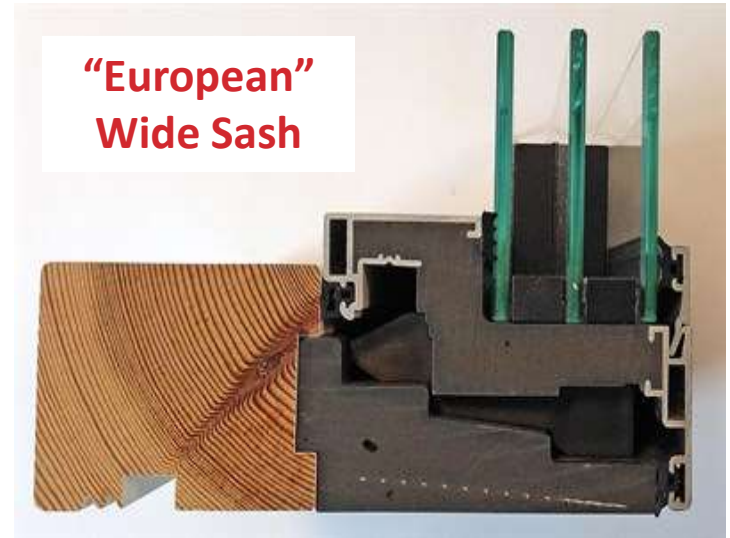
How Do You Fit a 5" Wide Triple-Glazed Window into a 2 x 4 Framed Wall?

Sash/Frame and IGU Dimensions

**Conventional
Slim Sash**



**"European"
Wide Sash**



Highly Insulating, Low Heat Loss Glazing

Today: U-value \sim .3 BTU-sf-h/F

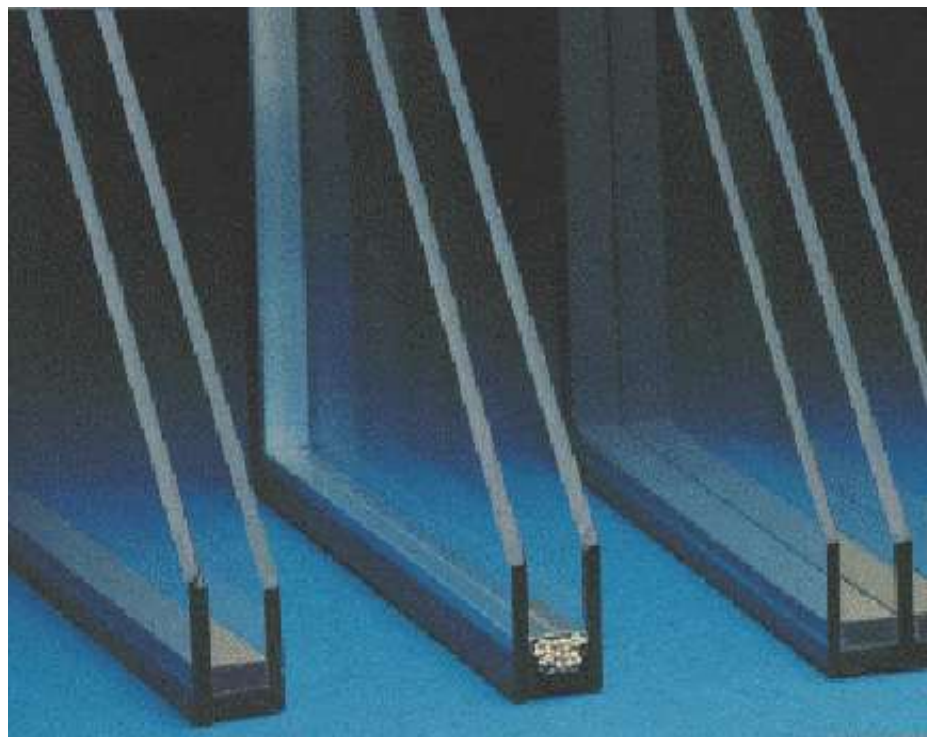
Nearer Term Objective: U-value \sim 0.2 BTU-sf-h/F

Longer Term Target: U-value \sim 0.1 BTU-sf-h/F

Current Approaches: 30 years

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

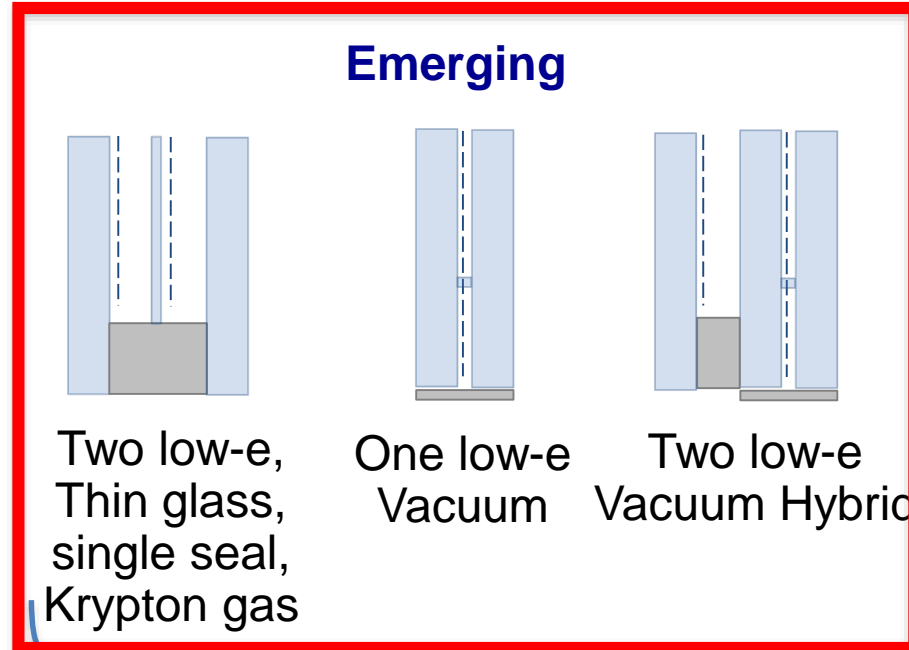
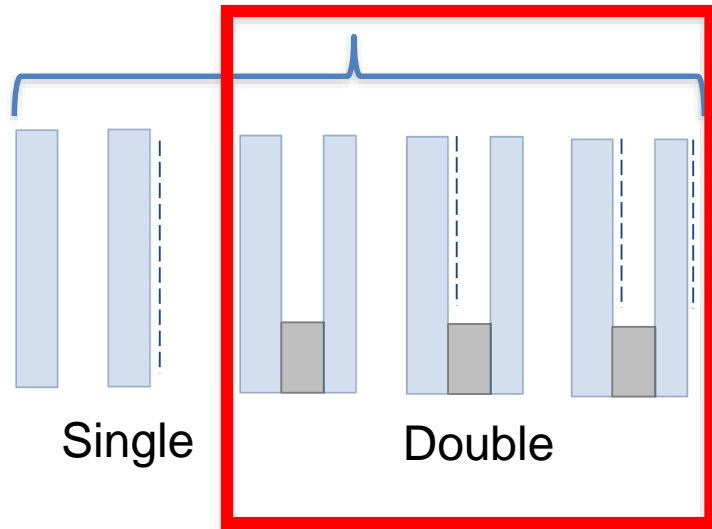
New Approaches??



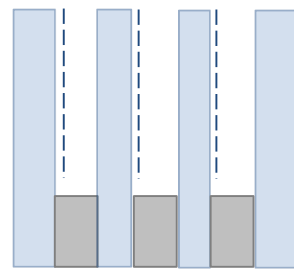
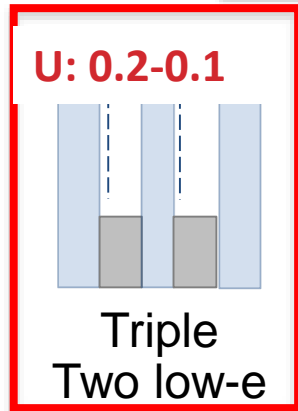
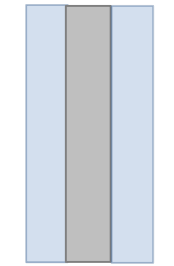
U.S. Insulating Glazing Landscape Today:

Market Today $U: 0.5 \rightarrow 0.3$

$U: 0.2 \rightarrow 0.06$

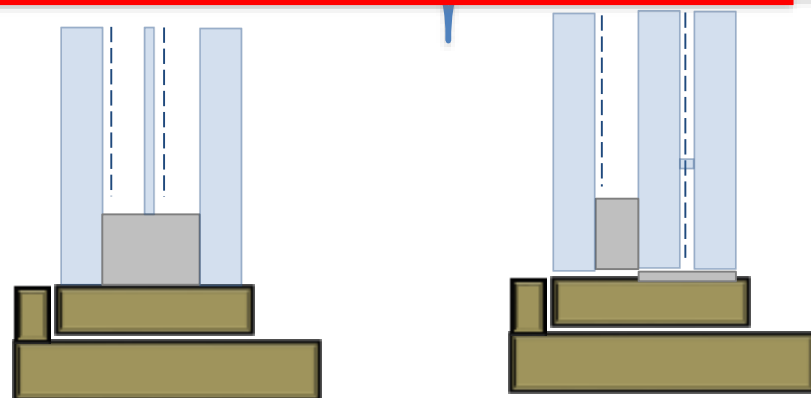


Future



Three low-e

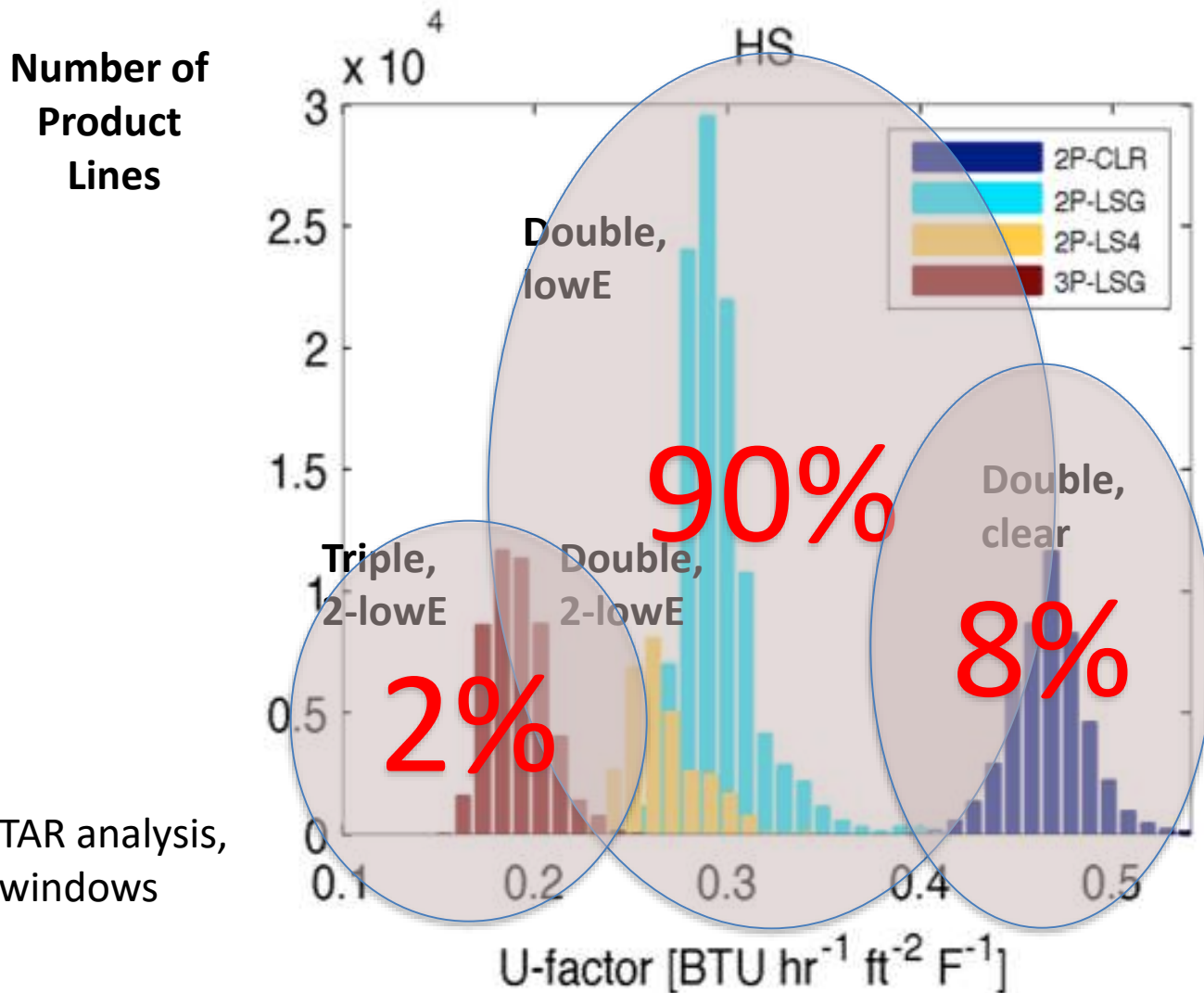
Note: low-E coated polyester film can be alternative middle glazing.



Super-insulating frame with highly insulated glazing

Window Landscape

Market Snapshot: NFRC-Rated Windows by U



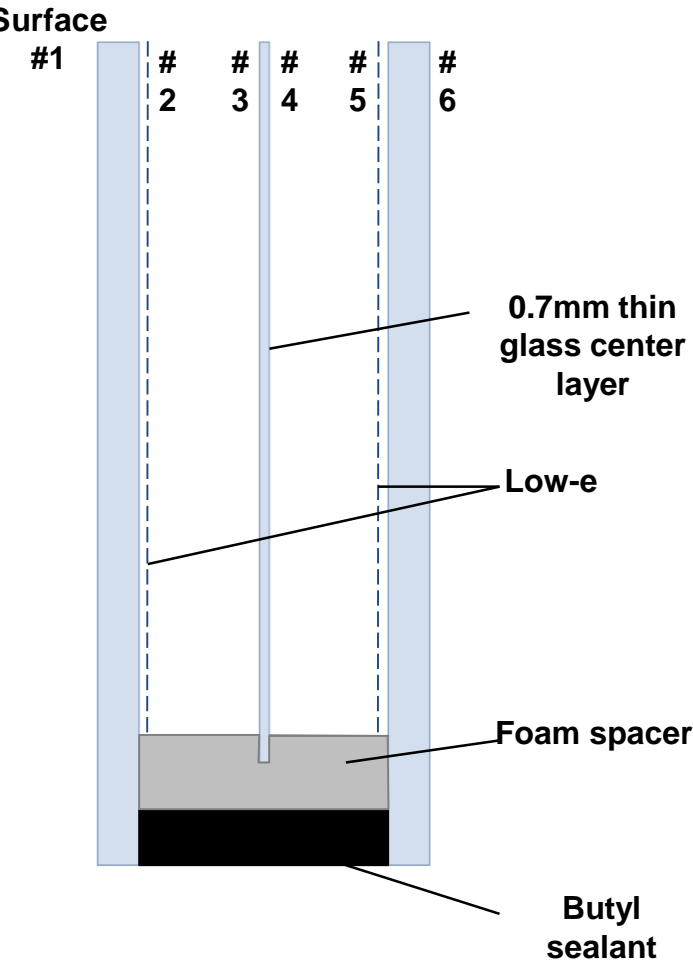
Source:
EPA ENERGYSTAR analysis,
Horiz. sliding windows

Criteria for Success

- Significant Improvement in Thermal Properties: >R5
- Drop-In Replacement for IGU: No Window Redesign
- Affordable Cost: < \$5/sf retail
- Scalable Rapidly
- Low Manufacturer Risk
- Acceptable Aesthetics
- Value Proposition to Builder, Homeowner

Drop-In “Thin Lightweight Triple”

*Upgrade” all R3 double glazed windows to R4-7 without redesign
using new IGU with same width, weight*

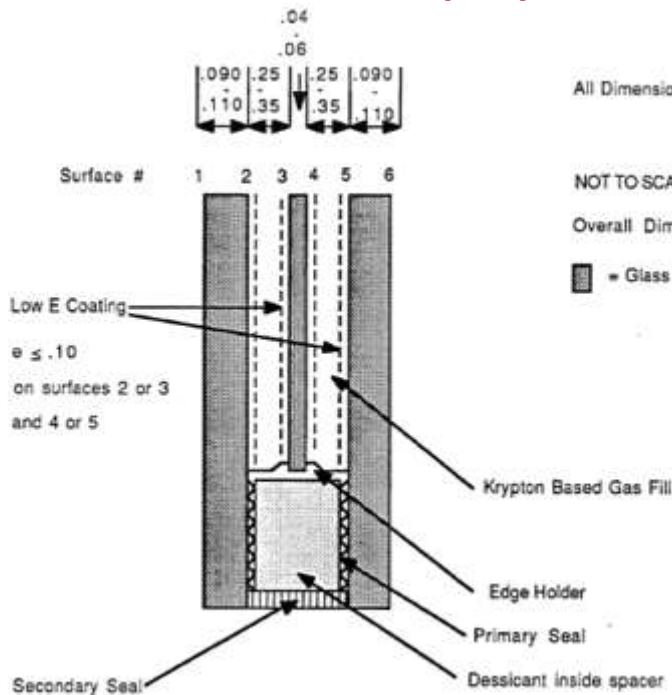


- Platform: U: ~.10-.15
- **Thin float glass**
 - .3, .5, .7, 1.1 mm
- Multiple suppliers
- **2 Low-E coatings**
- **Krypton gas fill**
- Non-structural center
 - 2 seals, not 4
- **Infrastructure exists**
- **“Affordable”**

Not a New Concept; Thin Glass, Thin Triple Concept Developed "Before its Time"

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; Dariush 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.: 428,539

[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. 178,041, Apr. 5, 1988, abandoned.

[51] Int. Cl. E06B 7/12

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

[56] References Cited

U.S. PATENT DOCUMENTS

3,192,575	7/1965	Rosenau et al.	52/171
3,875,706	4/1975	Okawa	52/172
4,019,295	4/1977	Deiner et al.	52/171
4,038,797	8/1977	Hermann et al.	52/306
4,081,934	4/1978	Pranz	52/171
4,149,348	4/1979	Pyzewski	52/172
4,393,105	7/1983	Krcman	408/34
4,459,789	7/1984	Ford	52/656
4,536,998	8/1985	Mastrucci et al.	52/171
4,613,530	9/1986	Hood et al.	428/34

FOREIGN PATENT DOCUMENTS

1143256 11/1986 United Kingdom

OTHER PUBLICATIONS

Glass Magazine, "Low-E", 3-1986, p. 116-131.
Popular Science, "Superwindows", Elaine Gilmore, 3-1986, pp. 76-77.

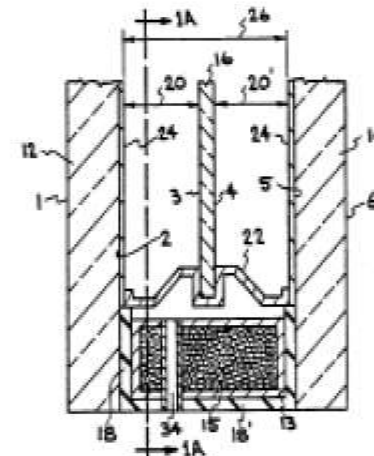
Primary Examiner—Michael J. Carone
Attorney, Agent, or Firm—B. J. Weiss, L. E. Carnahan;
William R. Moser

[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

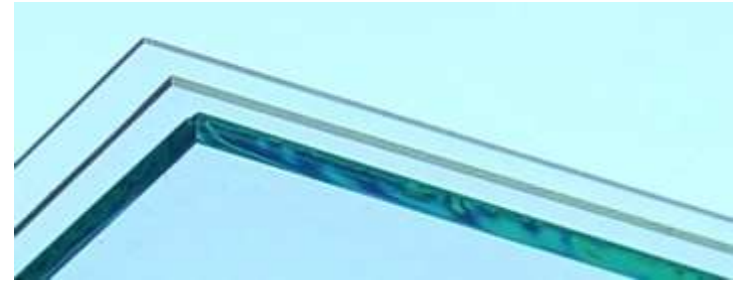
A statutory invention registration is not a patent. It has the enforceable attributes of a patent but does not have the enforceable attributes of a patent. No article or advertisement or the like may use the term patent, or any term suggestive of a patent, when referring to a statutory invention registration.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



Why Will It Work Now?

- **Thin Glass:**

- **4 years ago:** Corning offered glass at ~ **\$5.00/sf**
- **Today:** Major float glass suppliers ~ **\$0.60/sf** due to huge demand for large flat screen TVs



- **Krypton Gas**

- **4 years ago:** variable demand from other sources kept prices high and volatile; Gas fill wasted 50% -> Net cost > **\$2.00/sf**
- **Today:** Xenon requirements make Kr available; traditional Kr use has reduced; suppliers now sign long term contracts at ~**\$0.50/sf**
- New high rate gas fill with only 10% loss

Where Can We Find “Thin” Glass Today? 2017 – Total Glass Area Sold/Year??

Flat Screen TVs



400M sf

Residential Windows

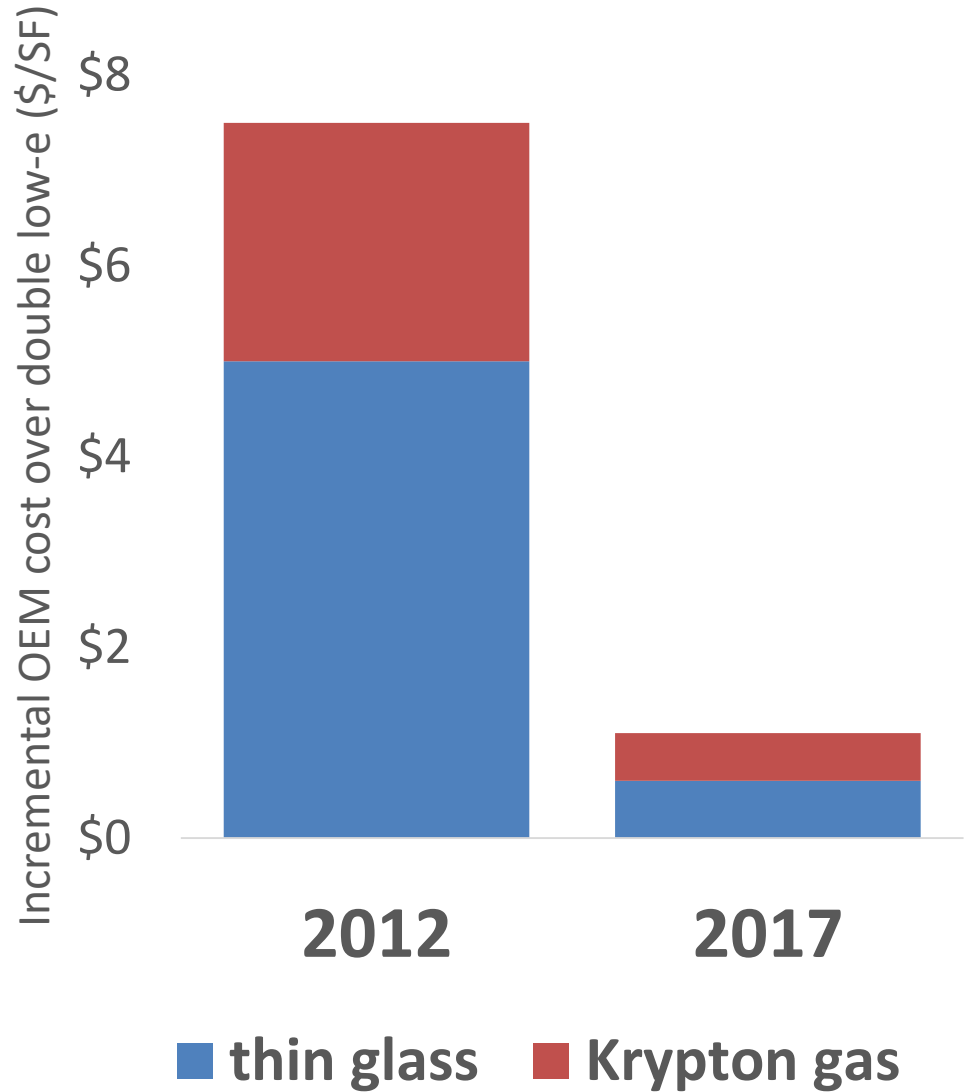


600M sf

Message: Build on the extensive display industry capability in flat glass

Flat Screen TV, Satellites, LEDs

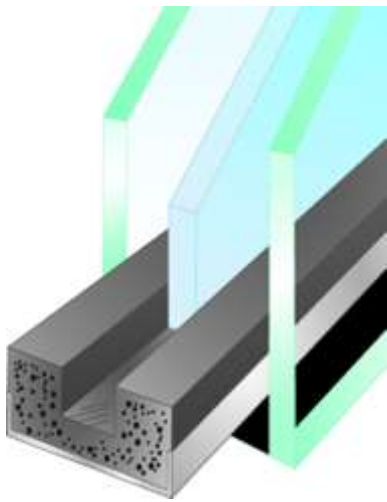
→ 80+% reductions in cost



“Thin-triple” spacer:

Single spacer, dual seal systems

Products are already entering the market



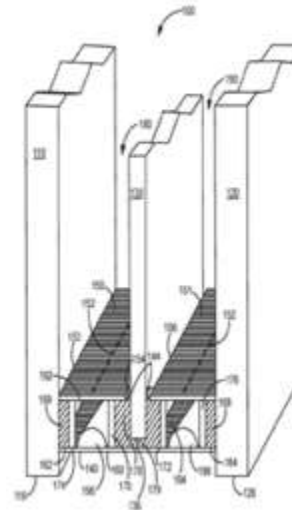
Edgetech



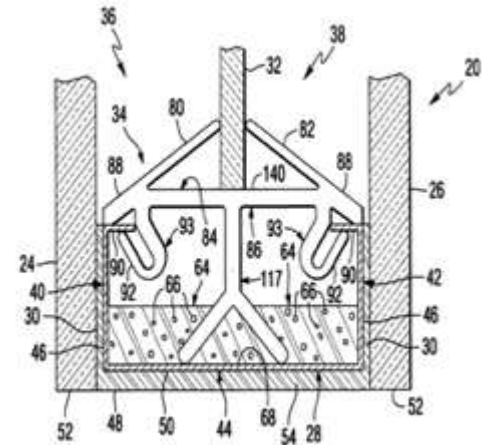
Swisspacer



SORA



Guardian: US 9,677,321 B2

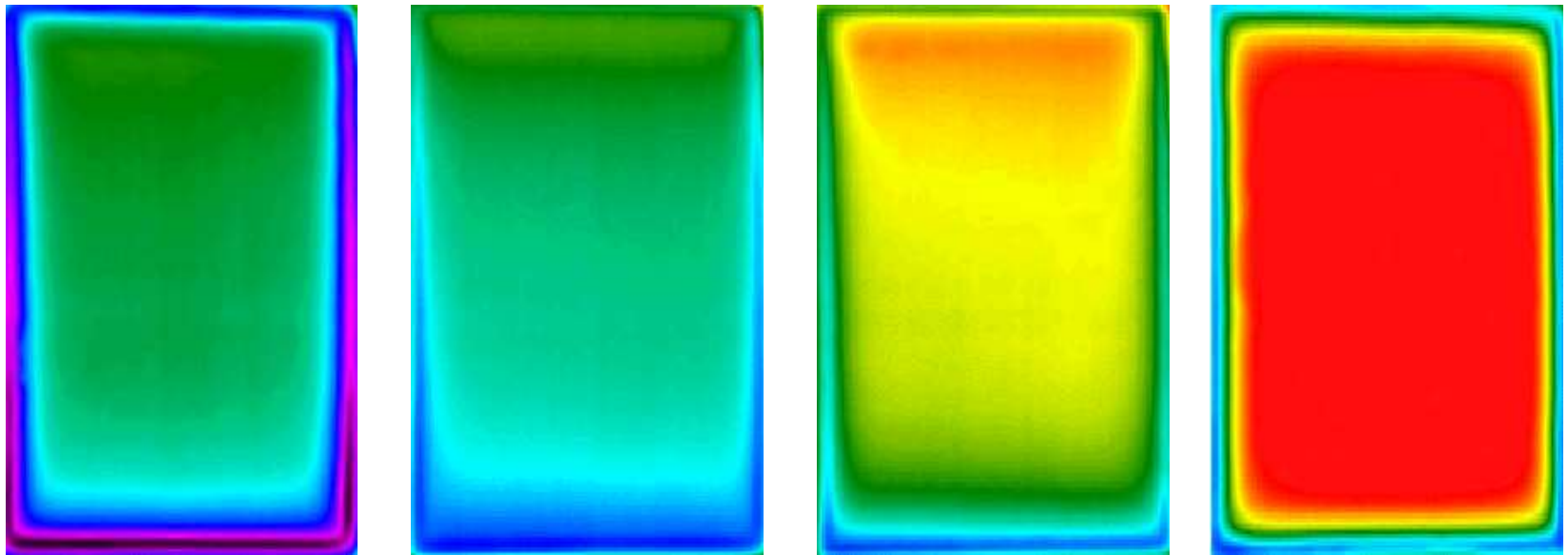


PPG: US6289641B1

Technologies to Reduce Heat Loss

Glass, Glass Edge

Dual, Clear, Alum. spacer *Dual, Clear, Foam spacer* *Dual, Low-e, Foam spacer* *Superwindow, 4-lites, low-e, Kr*



-6.0° C 20° C

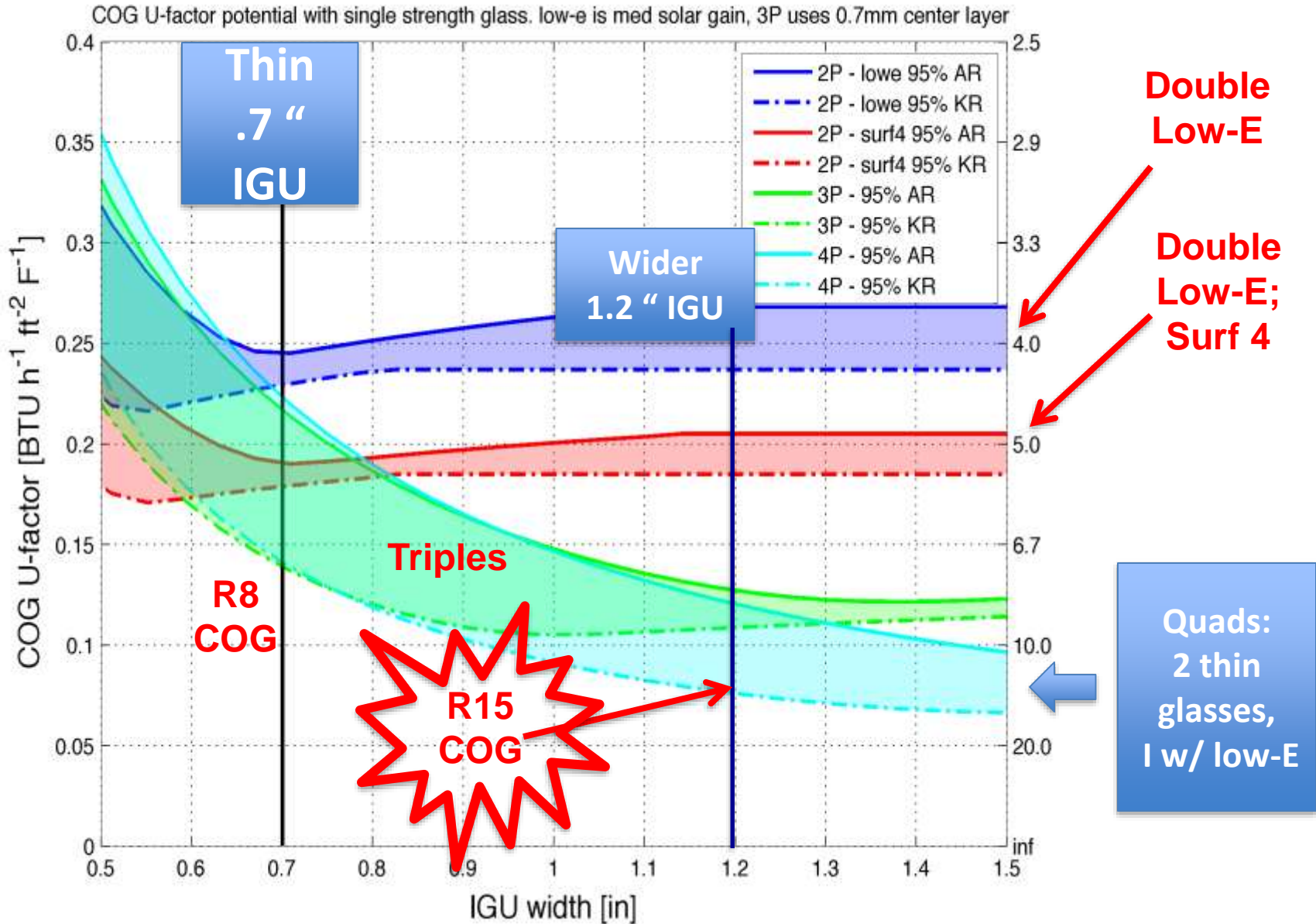


Images from LBNL
Infrared Thermography Lab

National Fenestration Rating Council - NFRC



Thin Lightweight Triple → Thin Quad



Alpen HPP

**Triple and Quad
Windows
Corner Samples**

**In Fiberglass
Frames**



Market Drivers: Who Wants This? Needs This?

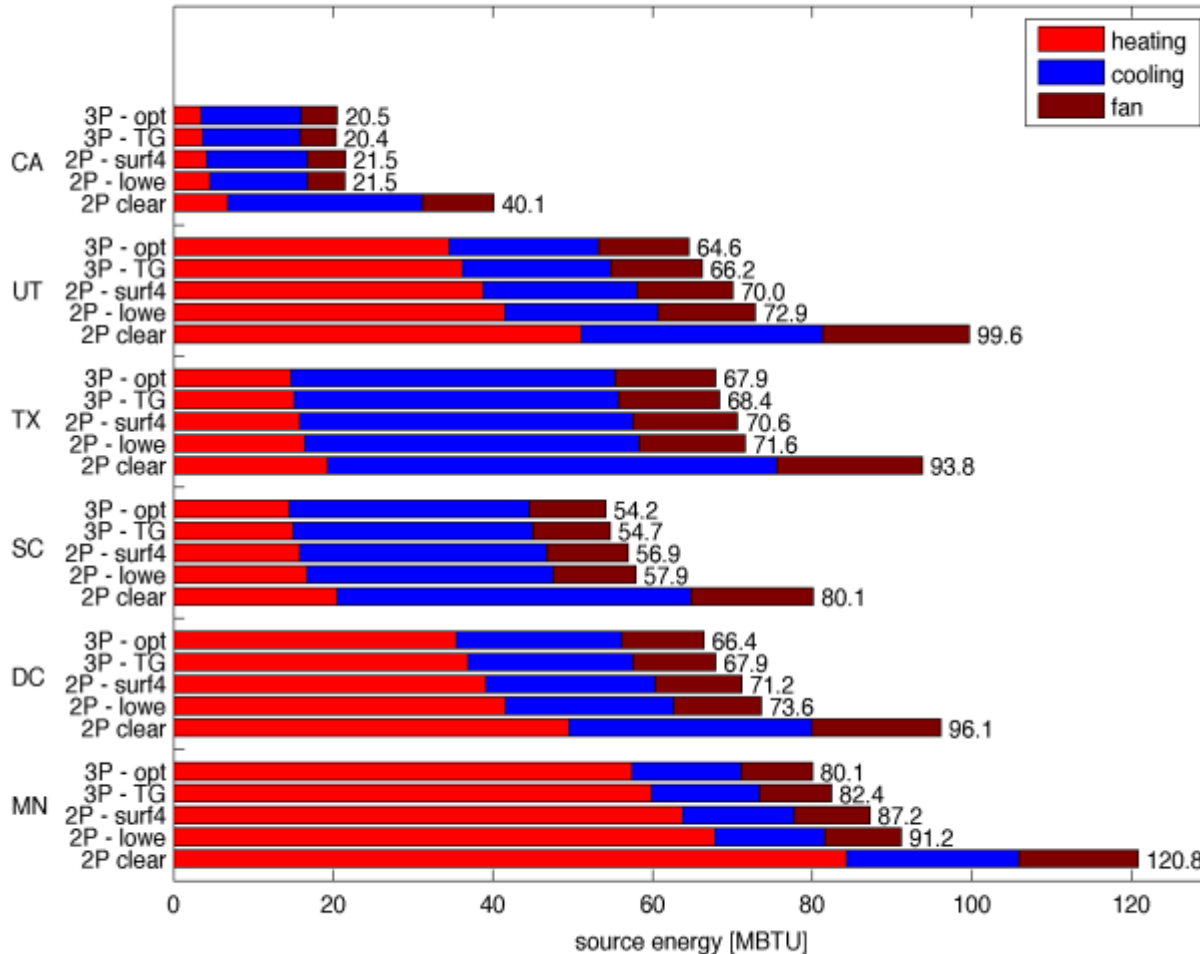
- **Builders/Building Owners**
 - Energy/\$\$ Savings
 - Thermal comfort
 - Larger window area
 - Early Adopters
 - Passive House buyers
 - Zero Net Energy Home buyers
- **Architects/Engineers**
 - Builders- first cost dominated-
 - Emerging early adopters
 - Comfort/Daylight
 - “Justifying” larger window 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

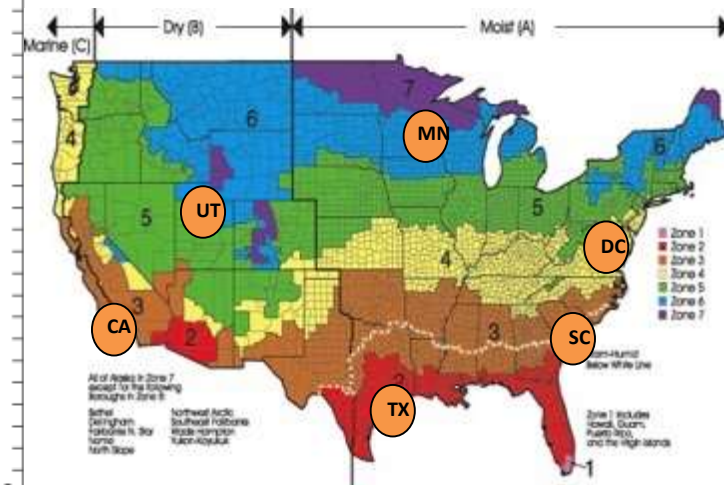
End use multipliers: Elec=3.167, Gas=1.084

Yearly total home energy use



Payback?

Different U.S. Climate Zones



“Early Adopters”

Passive House/Buildings

- Need “highly insulating” windows
- Two Competing Certification Groups, PHI, PHIUS
- Many builders import windows from Europe
- **Activity Level ??**

Zero Net Energy Homes/buildings

- Role of High Performance Windows
- Systems impacts on HVAC Design, sizing
- **Activity Level =?**

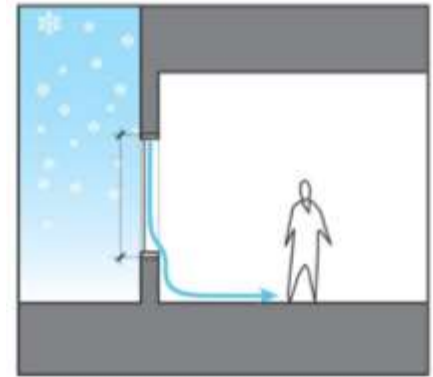
LEED/ Living Building Challenge

- Need for High Performance Windows?

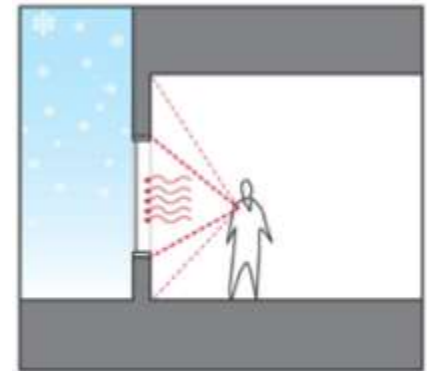
Building the Case for High R Windows

- **Energy (current supply -> decarbonize)**
- Load shape, demand
- Occupant comfort ----->
- HVAC System peak sizing
- HVAC System type, distribution

- **Codes**
- **Utility Incentives and Rebates**
- **Energy Star**



**Draft Discomfort
(Ankle Discomfort)**

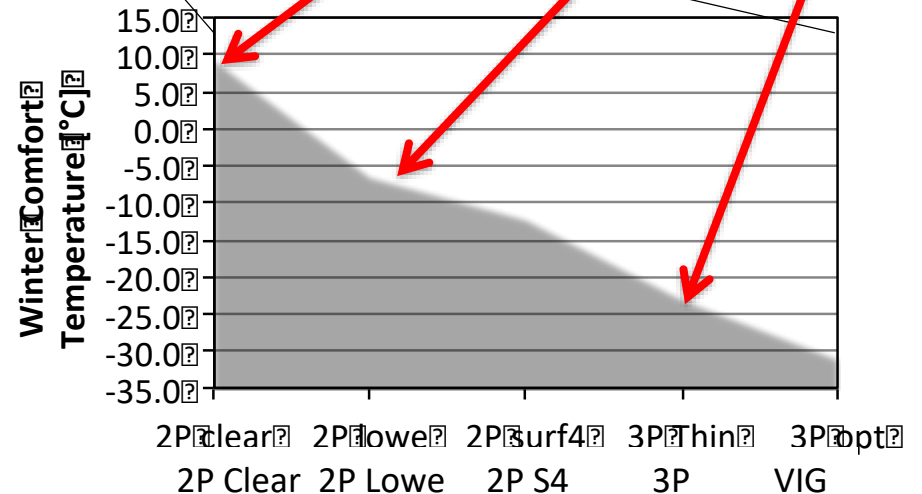
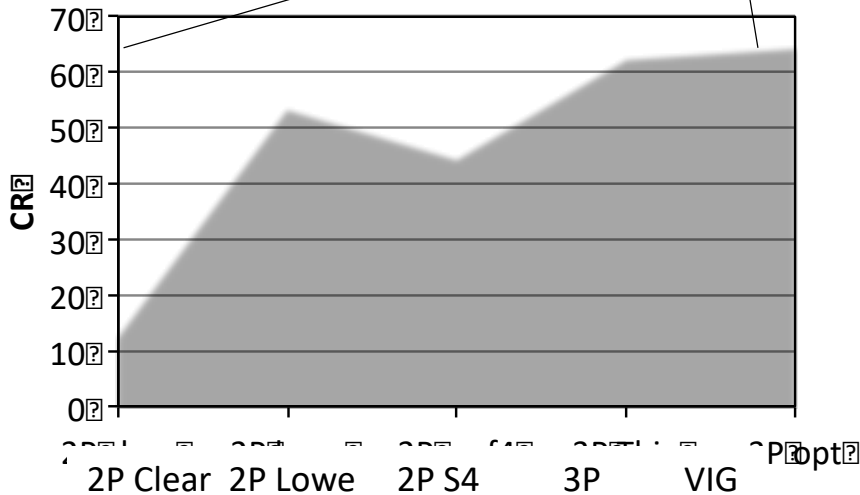


**Radiant Discomfort
(Full-body Discomfort)**

Thermal Comfort Considerations

- Condensation Resistance
- Winter Outdoor Comfort Temperature

	Glazing Type	Condensation Resistance [CR]	Winter Comfort Temperature [°C]	Acoustic	Security
1	2P clear	13	9.7		
2	2P lowe	54	-6.1		3 panes
3	2P surf4	45	-11.8	?	>
4	3P Thin Glass	63	-22.6		2 Panes
5	3P opt	65	-30.6		



Double 50 F
Double Low-E: 21F
Triple -11F

Window Industry Partners

- **Alpen HPP**

- Small, “Boutique” manufacturer, 30+ years, High Performance Markets
- History: R10 windows with fiberglass frame and heat mirror film
- Currently supplying prototypes for pilot projects
- Aggressively pursuing thin triple window product designs
 - Double spacer design
 - Fabricating larger size IGUs



- **Andersen Corporation**

- “Largest” U.S. manufacturer; National markets, 100+ years
- History: Early adopter of low-E, Energy Star leader
- Fabricating windows for initial LBNL testing
- Scaling/Manufacturing issues being explored

- **Others in Discussion**

- **Full supply chain engagement**

Industry Attention

DWM 11/2018

Building Green 2/4/2019



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 Vost

February 4, 2019

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-4, 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.



Energy & Environmental News

NET-ZERO

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

Even with the latest windows producing U-factor ratings of as low as 0.11 (roughly equivalent to R-9), windows have quite a way to go before they catch up to solid walls in insulating performance. Meanwhile, a price check on the best windows shows that current costs are prohibitive enough to deter the average homeowner. But a recent report by Rocky Mountain Institute (RMI), an independent, nonprofit organization, suggests that glass harvested from the flat-panel televisions market is about to upend the costs for triple-pane glass, making it feasible for everyday windows while also making net-zero homes more attainable. The idea corroborates with info gained by Door and Window Market (DWM) magazine from researchers at Lawrence Berkeley National Laboratory (LBNL). RMI's report, "The Economics of

Zero-Energy Homes: Single Family Insights," by Jacob Corvidae, Michael Gorman and Alisa Petersen, suggests that, these days, builders can still upgrade to building envelopes for residential homes in order to achieve net-zero energy performance, to the tune of a 6-8 percent increase in costs—a far cry from the nearly 20 to 30 percent increases previously cited by some experts.

"It's now clear that zero-energy-ready homes make sense economically today, even as they provide multiple benefits over standard construction," says Corvidae, RMI's principal and coauthor of the report. And for this reason, he suggests that net-zero homes may become the norm sooner than later. "Building anything else today runs a risk of creating homes that will be seen as out of date in only five years," Corvidae suggests.



Taken from flat-panel televisions, thinner glass makes triple-pane R more economically feasible, researchers say.

In addition to more efficient HVAC, lighting and insulation, RMI's prescription for cost-feasible, net-zero performance includes the use of triple-pane windows, which researchers say they've found to be more economically feasible these days, thanks to what they say is an approximately 80-percent price drop in some of the glass that's used to produce such products. These decreases, they say, stem from a crossover from the glass used to flat-panel televisions to the inner-lite of triple-pane windows, dropping their price to as little as \$300. According to DWM's research, that number is on par with the cost of even a middle-of-the-road, double-pane window from just two years ago, when it cost around \$236 to upgrade to R-8 performance (the best available at the time). That's also a number that may decrease going forward, according to researchers at LBNL (see article with full details on page 20), who say they're closing in on a more than 20-year project, aimed at developing super-efficient, cost-effective, triple-pane windows.

"Twenty years ago we couldn't find any companies that could make thin glass sheets in volume," says LBNL researcher Charlie Cordeiro. "Now the flat screen TV industry has pushed the glass industry to create precisely the glass we need for windows, and at a price the window market can afford." ■

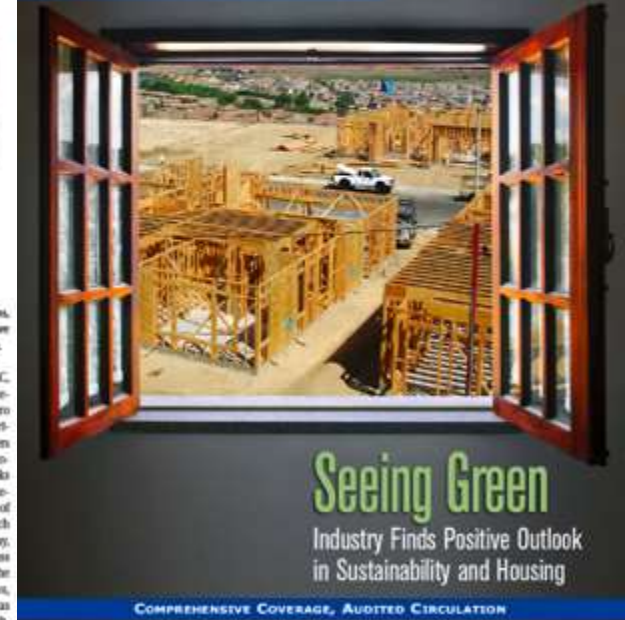
CMS Proves 100 Percent Landfill Free Attainable



CMS Window Systems recently set a high mark for door and window manufacturers, by reaching its goal for becoming 100 percent "landfill free"—eliminating any and all waste previously sent to landfills. Officials for the U.K.-based manufacturer say they reached that goal by using a special waste system that separates leftover steel and windows (removed and broken down) into seven different waste streams, including: plastic, mixed metal, timber and glass. Materials are then sent away for recycling.

"Hitting our zero landfill target is a tremendous achievement which reflects the focus and effort of everyone in the CMS team to re-use and recycle," says David Ridge, the company's CEO.

"It's a vitally important milestone in being one of the most sustainable fenestration partners in the U.K. market and is coupled with our strategy to maximize resource use by designing out waste at project inception. Waste is also minimized during manufacture and installation and our range of windows and doors are designed to help our end-customers cut their own energy consumption." ■



COMPREHENSIVE COVERAGE, AUDITED CIRCULATION

Utility Collaboration Around Aggressive Market Acceleration Programs

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

Energy Trust of Oregon – Window Rebates

Windows

\$1.75–\$4.00/sq. ft. cash incentive

Windows play a large part in regulating energy use and costs. ENERGY STAR® certified windows reduce condensation, decrease drafts and air leaks, and can increase your curb appeal. Installing new, tight-fitting windows also helps seal your home against intrusion or escape.

Table 1: Percent of Sales by Efficiency Tier

U-Value Tier	Relative Market Share
> 0.35	2.78%
.33 to .35	26.25%
.31 to .32	15.05%
.29 to .30	45.87%
.26 to .28	7.91%
.25 or lower	2.15%
Total	100.00%

Steps

Details

Resources

Equipment	Incentive	Requirements
Windows	\$1.75 per square foot	U-Value 0.28-0.30
Windows	\$4.00 per square foot	U-Value 0.27 or less

California T24 Code, 2019 U: .32 -> .30

High Efficiency Window Tradeoffs

Measure	EDR Contribution	43.5	18.9
HPA	4.2		
HPW	1.7	3000 sf	
QII	2.0	Deficit If	
QII+Entire HPA&HPW	7.9	Measure	
4-Orientation Impact	2.5	Removed	
Windows - 2019 Over 2016	0.6		
HP Windows-0.23U&0.20 SHGC	0.23	1.6	300 sf
HP Windows-0.21U&0.21 SHGC	0.21	1.8	
HP Windows-0.20U&SHGC	2.2	Compliance	
R38 Below Deck Insulation	0.9	Credit If	
94 Furnace	1.2	Measure	
13 EER	0.8	Installed	
0.94 Water Heater	0.7		
94 Furnace+13EER+0.94 WH	2.7		
Battery Storage Credit	3.2		

EDRs: Energy Design Ratings

Example: Delete
“High Performance
Walls”;
-1.7 EDR

Add “High Efficiency
Windows”
+1.8, +2.2 EDR

California Activities

- CEC and LBNL Launched C-PAW
 - *California Partnership for Advanced Windows*
- Model House “demo” – Fresno Area
 - Replace 5 windows this winter
 - Glazing supplied by Alpen
- Multifamily Pilot Project – 100 units, late 2019
 - w/ PG&E program support
 - New local window partner as potential supplier
- **Beyond CA...**
 - **PNNL Field Test program → National Scope**

Canadian Window Code Changes are Coming...

Fenestration Canada Annual General Meeting, June 2017

Aspirational goals for residential windows

- By 2020, residential windows for sale in Canada meet an average U-factor of 1.6 (ER 25) **U= .28**
- By 2025, **U= .21**
 - All residential windows for sale in Canada meet a U-factor of 1.2 (ER 34)
 - Residential windows with a U-factor of 0.8 can be manufactured and installed cost effectively.
- By 2030, all residential windows for sale in Canada meet a U-factor of 0.8 (~ ER 40) **U= .14**

© Her Majesty the Queen in Right of Canada, as represented by the Minister of Natural Resources, 2017



Natural Resources
Canada

Ressources naturelles
Canada

Canada

Market
Pull

Design Flexibility to Meet More Stringent Codes

Commercial

Make the case to **architects**,
engineers, and **builders**, early
adopters (PH, ZNE, etc)

Increase window **size**

Decrease perimeter HVAC

Reduce overall building **cost**

Condensation resistance

Comfort

Resilience

Peak heating and cooling

Stable load

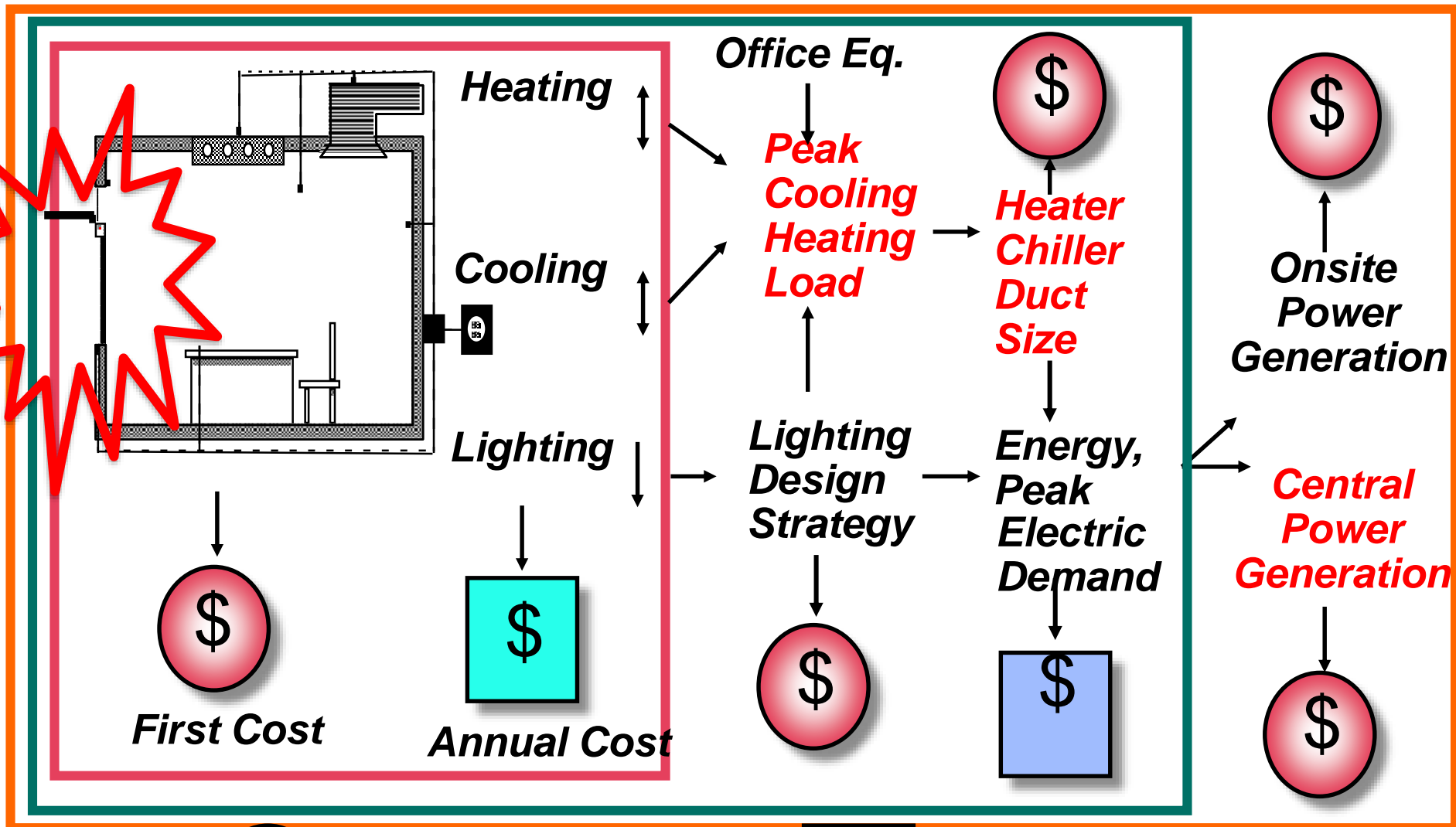


We wouldn't need this

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

HVAC System Size and Cost vs Window Properties

Thermally Improved Glazing = Lower HVAC System Cost

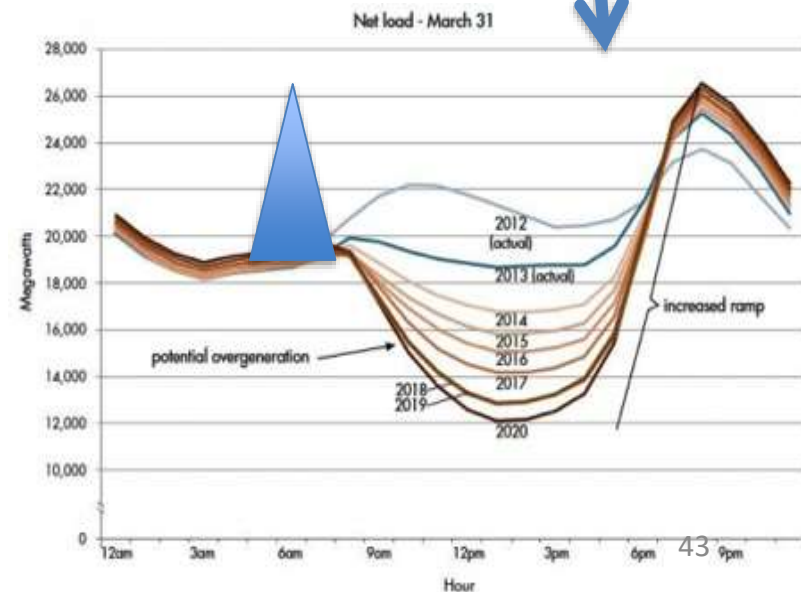


 = First Cost

 = Annual Cost

Electric Utility: Load Shape, Peak

- Most utilities are midday “summer peaking” due to Air Conditioning; (heating is gas)
- Photovoltaics -shifts peak to evening- “Duck Curve”- for many months
- **Utilities with electric heating often have (early morning) winter peaks**
- **California: shift heating from gas to electric**
 - New early morning winter peak??
 - **Opportunity for better windows**



Utility Collaboration: New Market Acceleration Programs

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

Next Steps ...

- **Enhanced “Industry-Utility Partnerships” :**
 - **Supply/Technology Focus – LBNL w/ manufacturers**
 - Address Technical Issues
 - Address Manufacturability and Cost
 - **Drive Market Demand**
 - **Early Adopters:** Passive House, Zero Energy Homes
 - **Value proposition:** energy savings, comfort, design,...
 - **Utility Programs – upstream rebates?**
 - **PNNL Field test and demonstration**

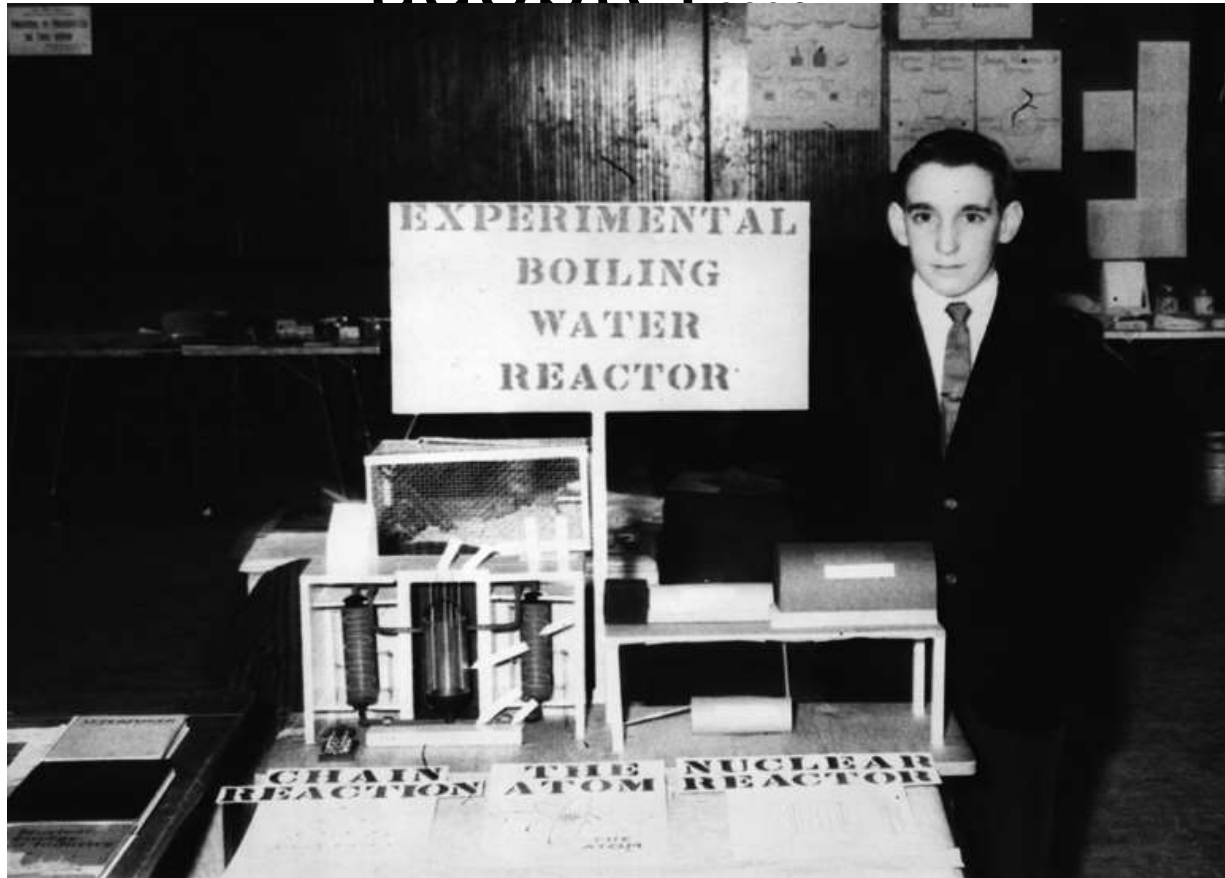
NEEA Northwest Collaboration

Expand C-PAW:

“California Partnership for Advanced Windows”

Pacific Coast Builders Show- May, SF

Steve as an early low carbon adopter



Stephen Selkowitz

seselkowitz@lbl.gov

510/ 590-1016