

ARPA-E

Philadelphia, November 6, 2014

Single Pane Windows: Dinosaurs in a Sustainable World ?

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1970s Energy Crisis: Optimal Windows?



U.S. Building End Use Energy Consumption

Buildings consume 40% of total U.S. energy

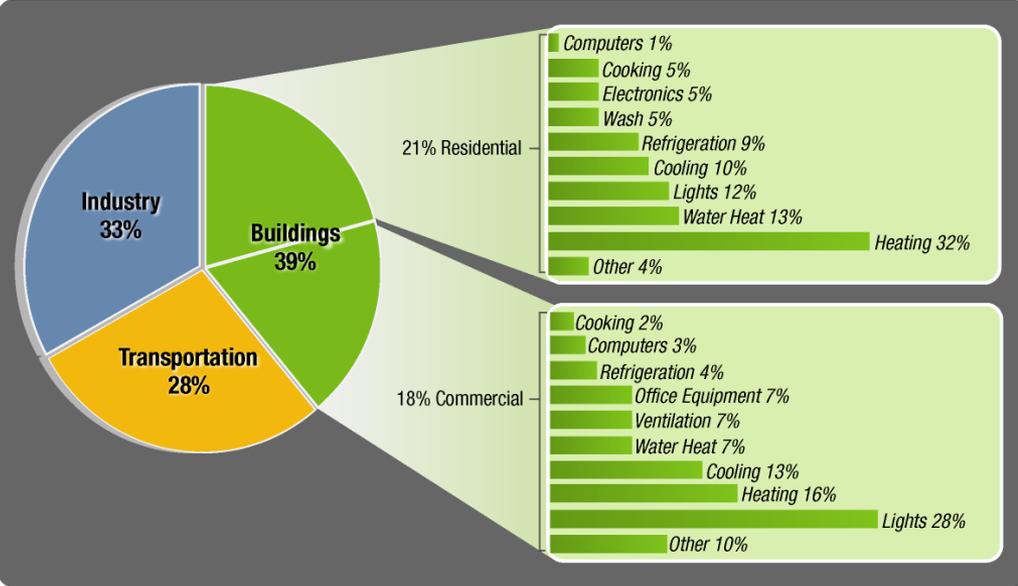
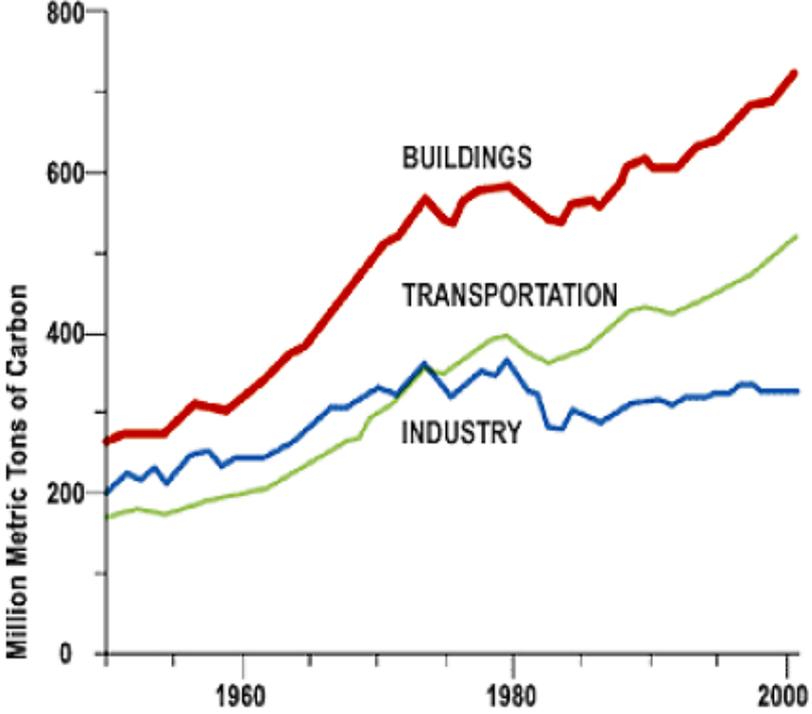
- 71% of electricity
- 54% of natural gas

Windows:

~ 10-12 % of Buildings

~ 4-5% of Total Energy

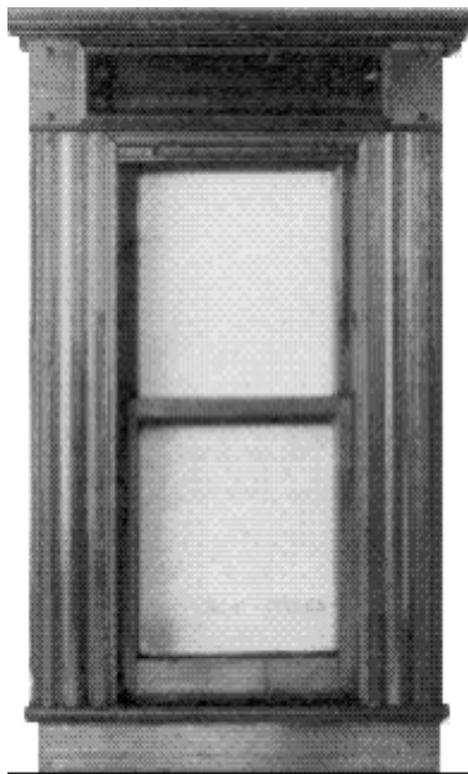
~ \$50 billion/yr



Window/Glazing Performance Needs

- **Energy**

- Comfort
- View/Privacy
- Security
- Acoustics
- Structure
- Recycled Materials



- Daylight
- Aesthetics
- Weatherproof
- Cleaning
- Maintenance

Windows Overview

- **Context**

- Windows are a ~5Q/yr, ~ \$50B/yr cost and opportunity
- **Vision: change windows from net loss to net supply**
- **Highly “visible” component- window selection is “complex”**
- Long-Lived Component- one chance to make the right decision!

Window-Related Energy Consumption (Quads)

	Residential	Commercial	
Heating	1.65	0.96	Daylight: +1 Q
Cooling	1.02	0.52	
<i>Total</i>	<i>2.67</i>	<i>1.48</i>	

- **Scope, Scale, Impact**

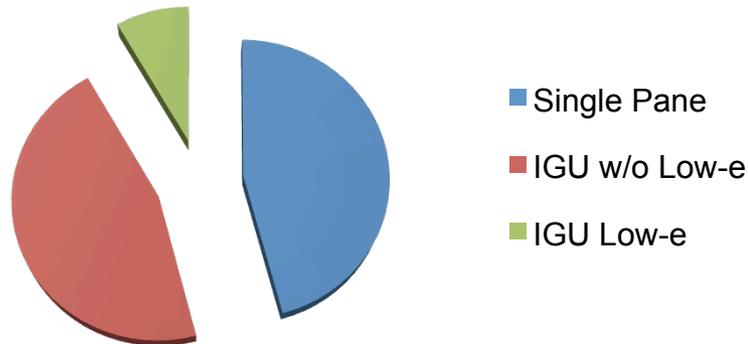
- Comprehensive program: spans materials science to specific product R&D to systems integration
- Research – Development – Demonstration – Deployment
- All Climates, All Building Types, New and Retrofit
- Significant Industry Collaboration and Cost Share
- Measurable impact on technology, products, energy savings

U.S. Window Stock (based on Ducker 2010)

Window Improvement Opportunities

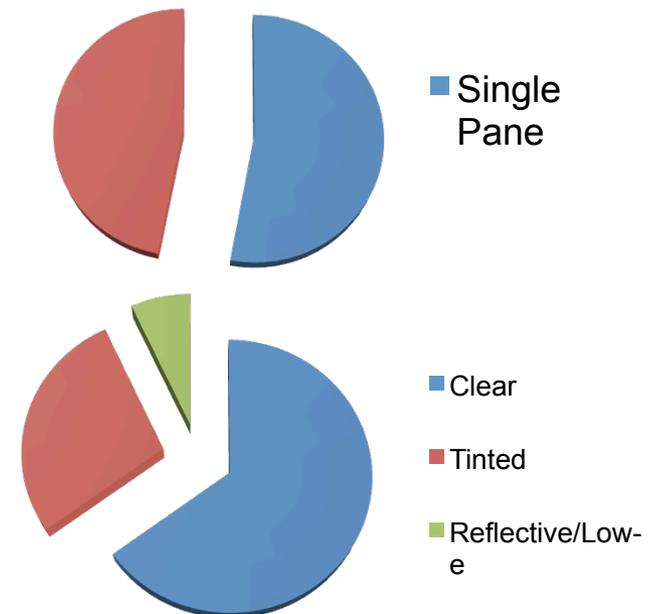
- Current U.S. window stock has large number of single glazed and/or clear glazing
- Need a range of options in performance and cost
 - Replace Window When Feasible
 - Retrofit: a) Window, 2) Glazing, 3) Attachments
- Market Size: ~ 7.6 B sf of single glazed windows

Residential



Existing Window Glazing Distribution for Residential Market

Commercial

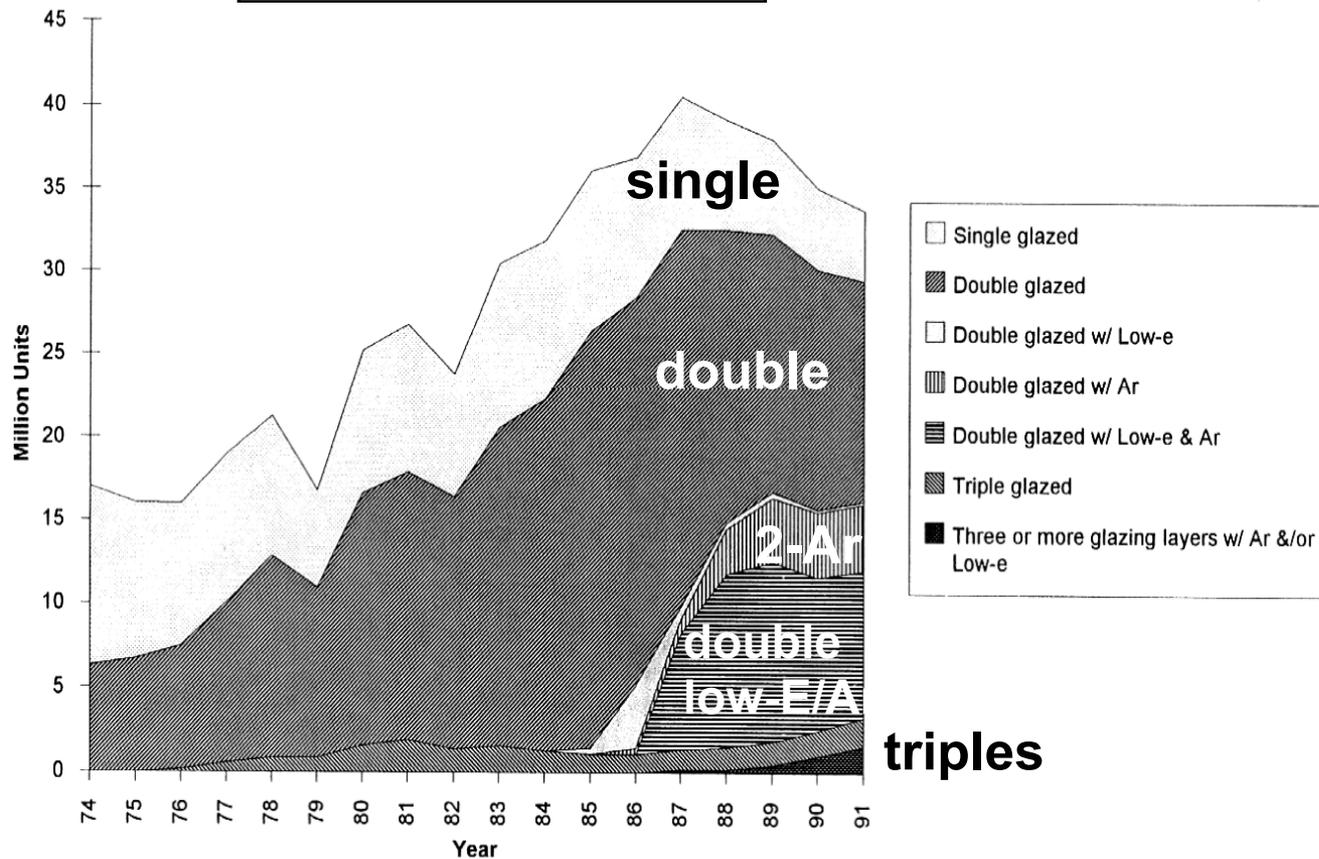


Existing Window Glazing Distribution for Commercial Market

Glazing System Sales: 1974 – 1996

Tracking Early Market Penetration of Low-E, a New Glazing Technology

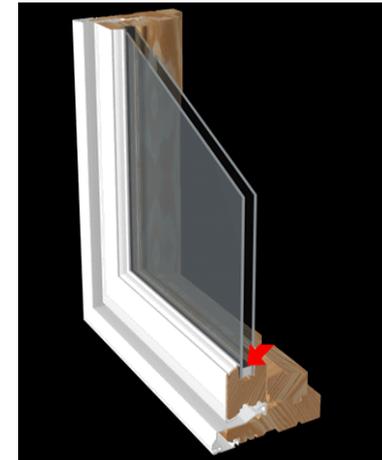
Glazing System Sales



Progress in U.S. Window Markets

(Example: Improved Insulating Properties in Residential market)

- **1973: Typical Window:**
 - clear, single glazed,
 - double or storm window in north,
 - $U_{\text{average}} = 4.8 \text{ W/m}^2\text{-K}$
- **2003: Typical Window:**
 - 95% double glazed
 - 50% have a low-E coating
 - 30-65% energy savings vs. 1973
 - $U_{\text{average}} = 2.5 \text{ W/m}^2\text{-K}$
- **2013: Typical Window:**
 - 97% double glazed
 - 80% have a low-E coating
 - 30-65% energy savings vs. 1973
 - $U_{\text{average}} = 2.5 \text{ W/m}^2\text{-K}$
- **2030: Future Window:**
 - Zero net energy use (typical)
 - Net winter gain; 80% cooling savings
 - $U_{\text{average}} = .6 \text{ W/m}^2\text{-K}$
 - Dynamic solar control



AEIC Paper:

Case Study on the Government's Role in Energy Technology Innovation: Low Emissivity Windows:

**....the trek from
prototype to 80%
market share**



CASE STUDIES ON THE GOVERNMENT'S ROLE IN ENERGY TECHNOLOGY INNOVATION

Low-Emissivity Windows

By Jeffrey Rissman and Hallie Kennan

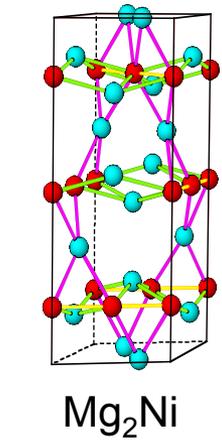
EXECUTIVE SUMMARY

Improving the energy efficiency of buildings has great potential to boost the U.S. economy, improve public health, and protect the environment. The energy used by buildings costs \$418 billion annually and accounts for 39% of all U.S. carbon dioxide emissions. A major driver of building energy consumption is heat and cooling loss through the walls, roof, and windows. Low-emissivity ("low-e") windows use a transparent coating that blocks infrared radiation, keeping heat outside the building on hot days and keeping it inside the building on cold days. Relative to an ordinary, single-pane window, the best low-e windows can reduce heat loss by 85%.

Since the 1970s, the government has used four primary mechanisms to drive low-e window technology development and commercialization: basic research and seed investments; computer tools for simulating window performance; standardized testing procedures and performance ratings; and educational outreach to manufacturers and consumers.

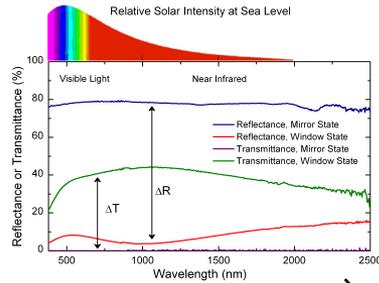
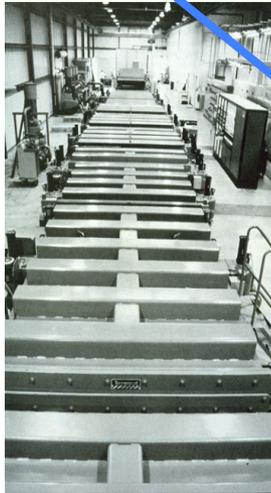
- American Energy Innovation Council

New Glazing Solutions: From R&D to Market Ready and Market Share



Invent New Materials

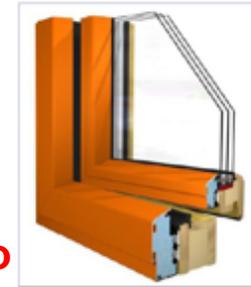
Invent Innovative Manufacturing Process



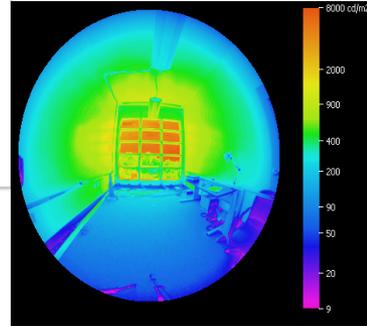
Characterize Coating Performance



Assess Savings



Integrate Technology into Window



Assess Human Factors



Field Test Installed Systems



How “Efficient” Can A Window Be??

Is our goal an R100 Window?

Vision: “Net Zero-Energy Window”

Energy Losers --> Neutral --> Net Suppliers

- **Heating climates**
 - Reduce heat losses so that ambient solar energy balances and exceeds loss
 - Need lower heat loss technologies
- **Cooling climates**
 - Reduce cooling loads
 - Natural ventilation
 - Static control -> dynamic control
- **All climates**
 - Replace electric lighting with daylight
- **Electricity supply options**
 - Photovoltaics-building skin as power source

Savings from Better Windows

Annual Heating Cost simulated for a heating climate



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

Double Glazed, **\$1218**

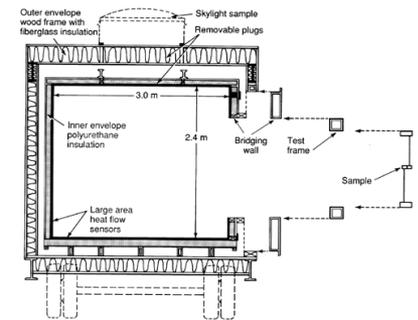
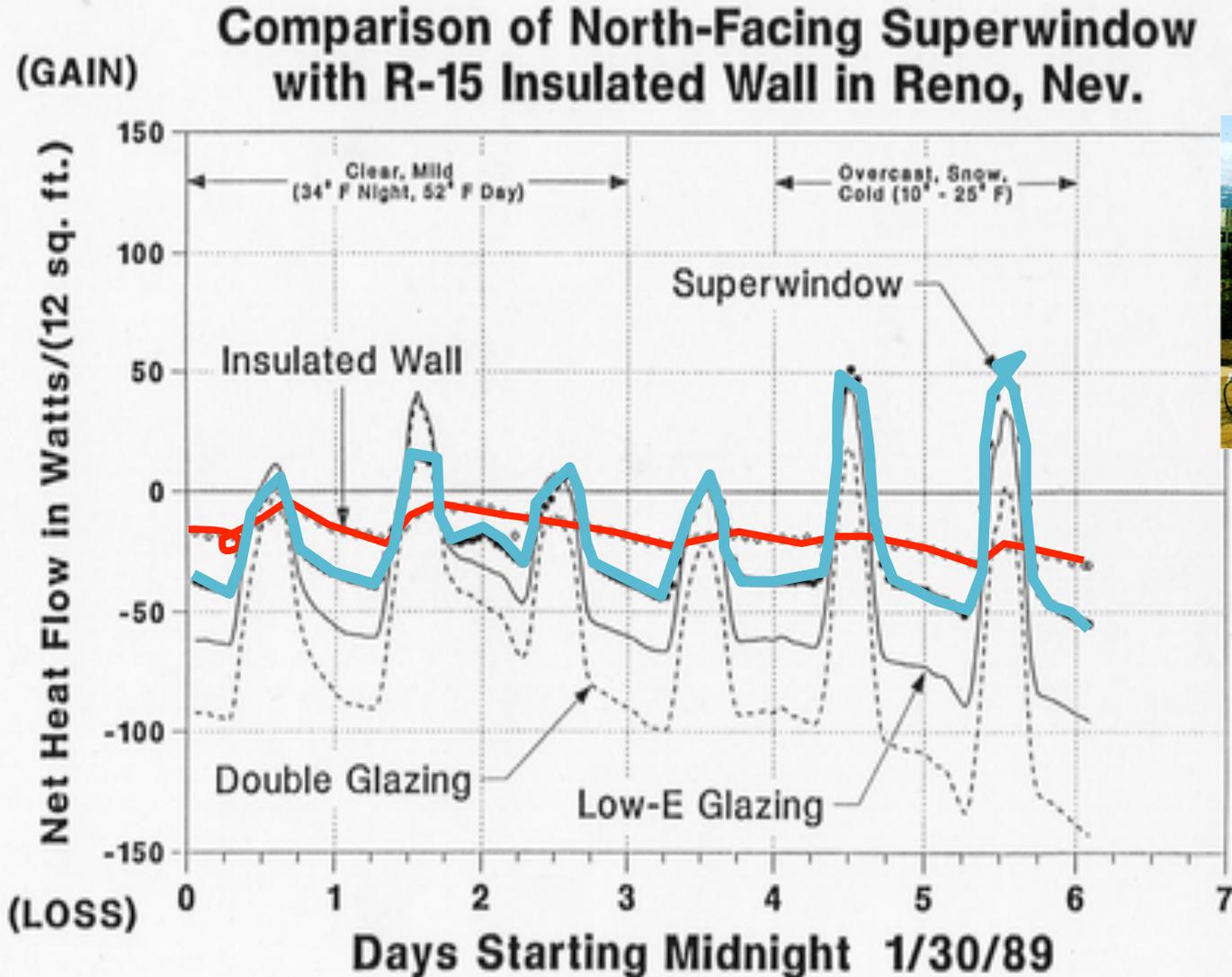
Double w/Low-E, **\$1120**

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

“SuperWindow”, **\$960**

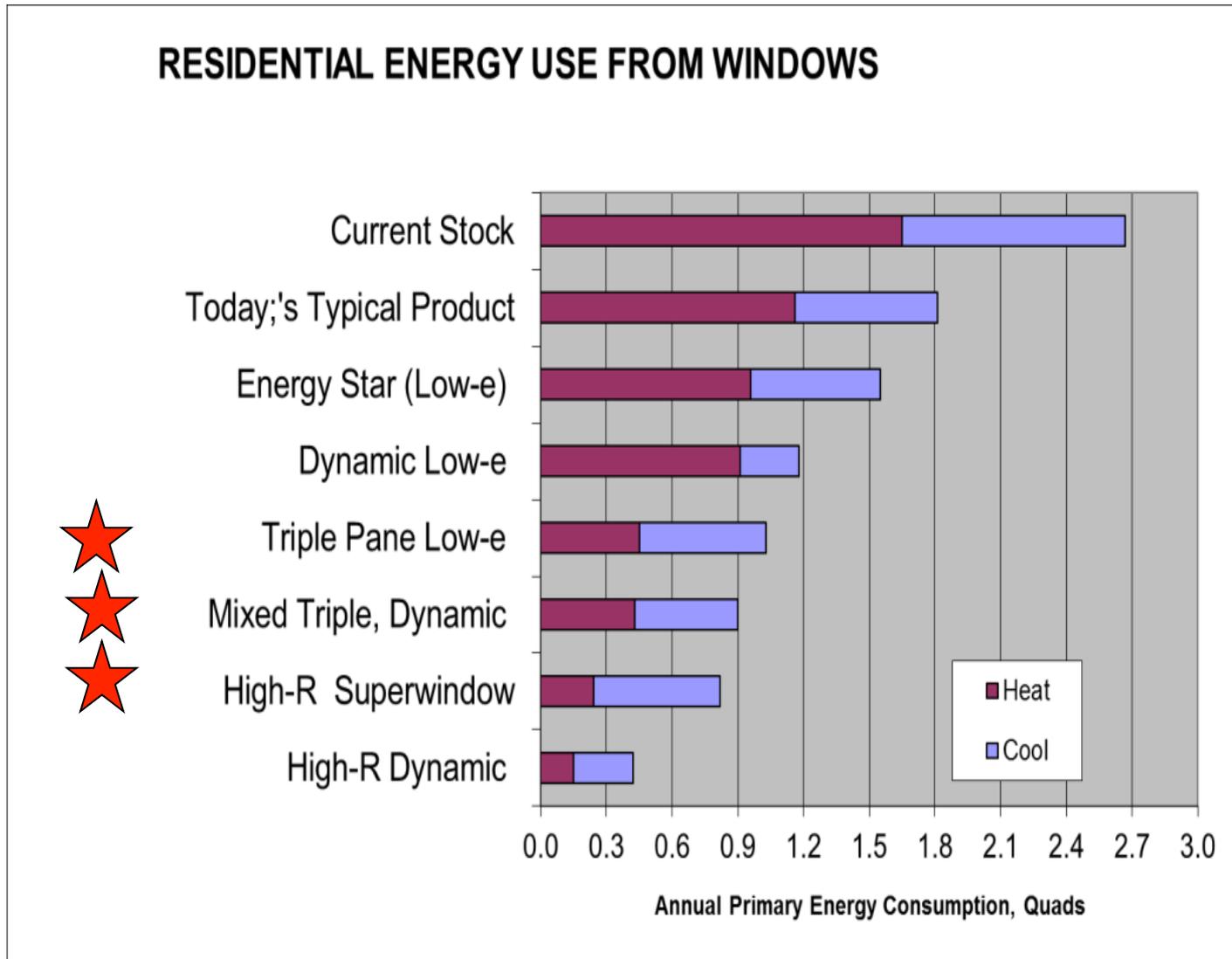
NEWSFLASH (from 1989!):

”North-facing Windows Outperform Insulated Walls during winter heating season”



ML 8110-1271A

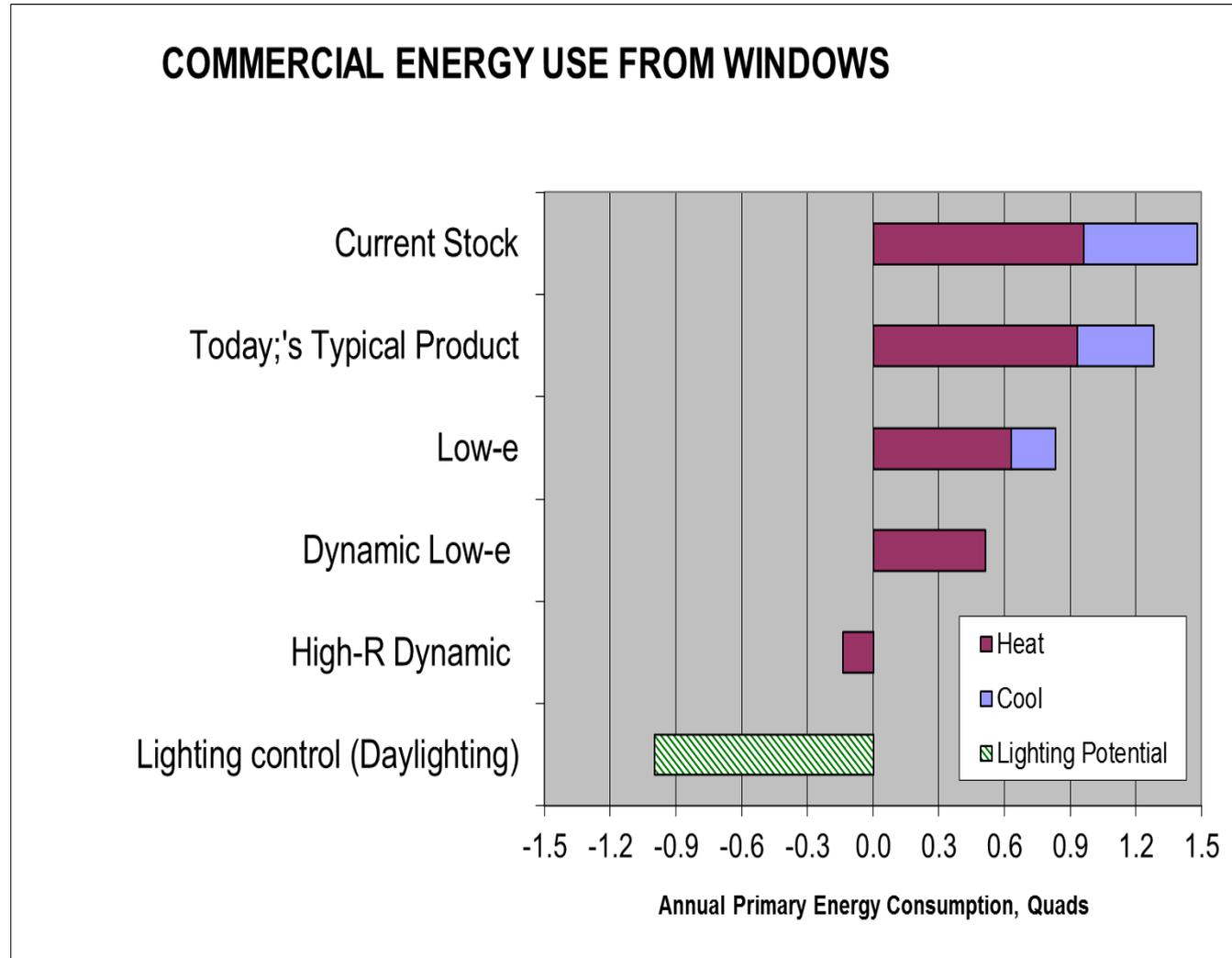
How Would We Get to This “Net +” Goal?



Current Energy Use Based on US Energy Information Administration, BTP Data

Commercial windows?

Commercial Sector – w/ Lighting Impacts

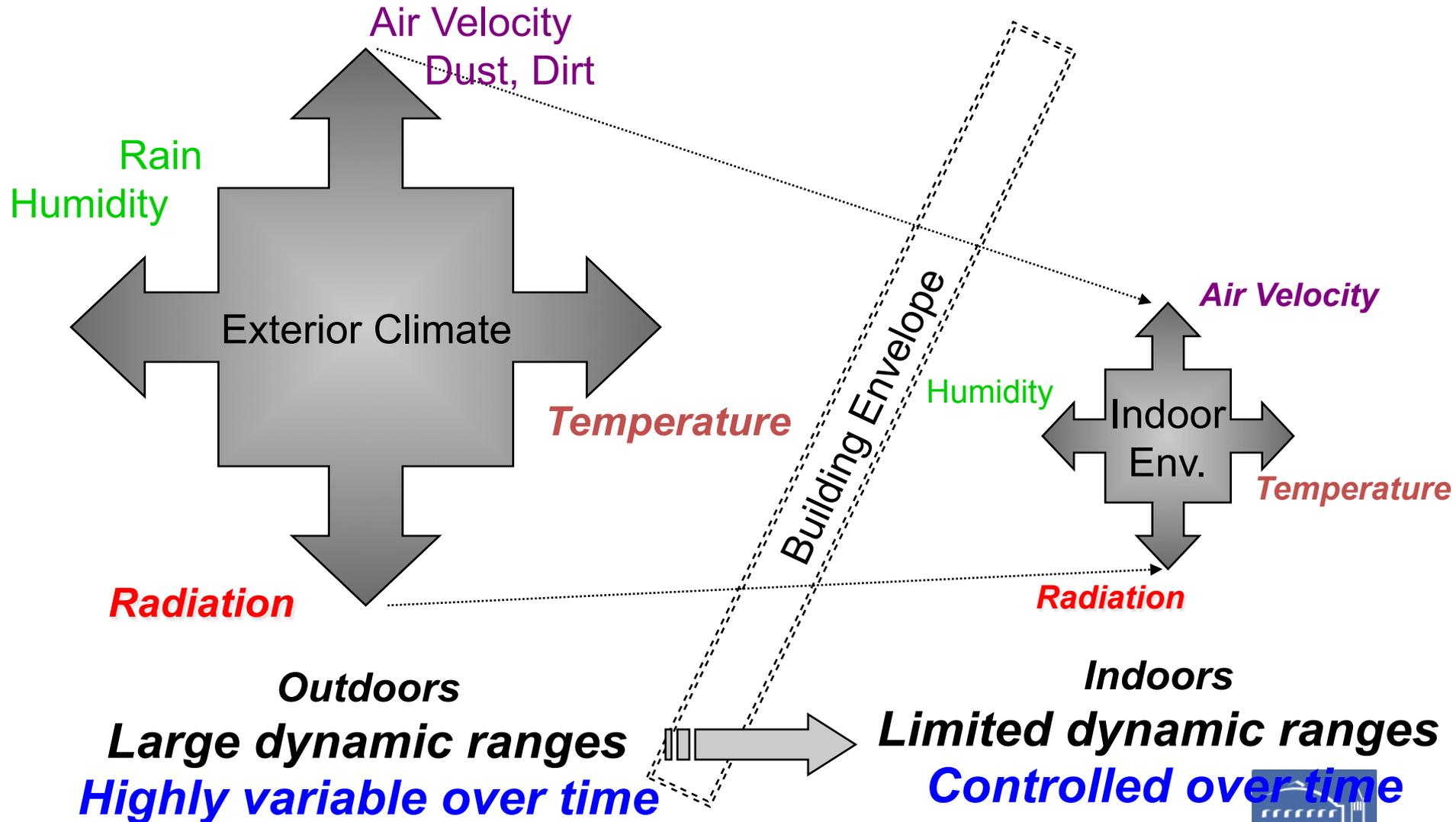


Current Energy Use Based on US Energy Information Administration, BTP Data

Where are the Game Changers?

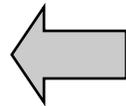
- Double/triple the insulating value of new IGU/window
- **High performance retrofits**
 - **Add-on for existing glazing/windows**
 - **Window attachments**
- Independent control of U and SHGC
- Dynamic control of SHGC and Tv
- Daylight control, glare free, daylight redirection
- Air flow management – natural ventilation

Building Envelope as Dynamic Filter

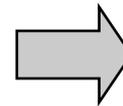


Glazing and Window Technology Landscape: Changing “Scale” and Function for R&D

“1 μ ”
coating



“1mm”
glass



“1m”
Window,
shading

- + Numerous options
- + Minimal mass
- + Versatile
- + Low Maintenance
- +/- Cost
- +/- Durability
- +/- Operable

- + Numerous options
- + Low Maintenance
- + Cost
- + Durability

- + Numerous options
- + Versatile
- + Operable
- Maintenance
- Cost
- +/- Durability

Intelligent Control of Dynamic Conditions, Properties:

Thermal flows: U value

Daylight/Solar Gain: SHGC, G, Tv

Intensity

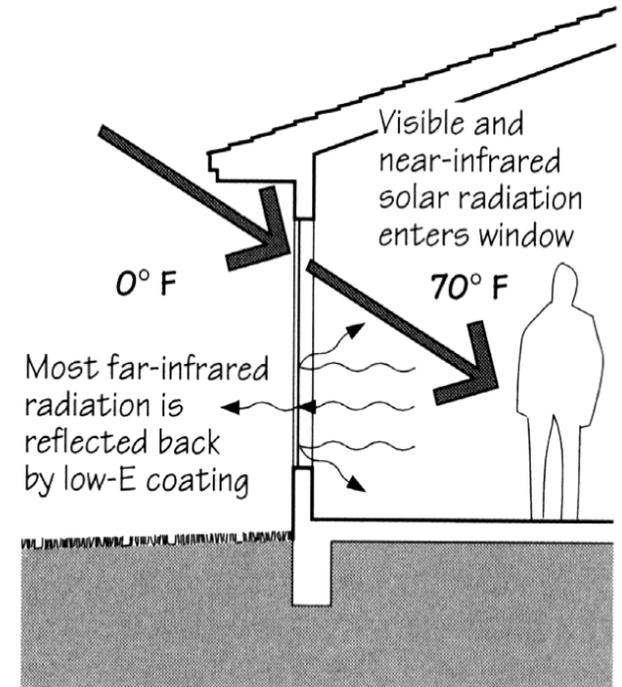
Spectral content, color

Directional

Winter Heat Loss Control

- **Minimize conductive heat transfer (low U)**
- **Minimize air leakage**
- **Maximize useful solar gain (high SHGC)**
- **Actual Energy Use influenced by:**
 - Climate
 - Orientation
 - House Design Features

winter heat loss

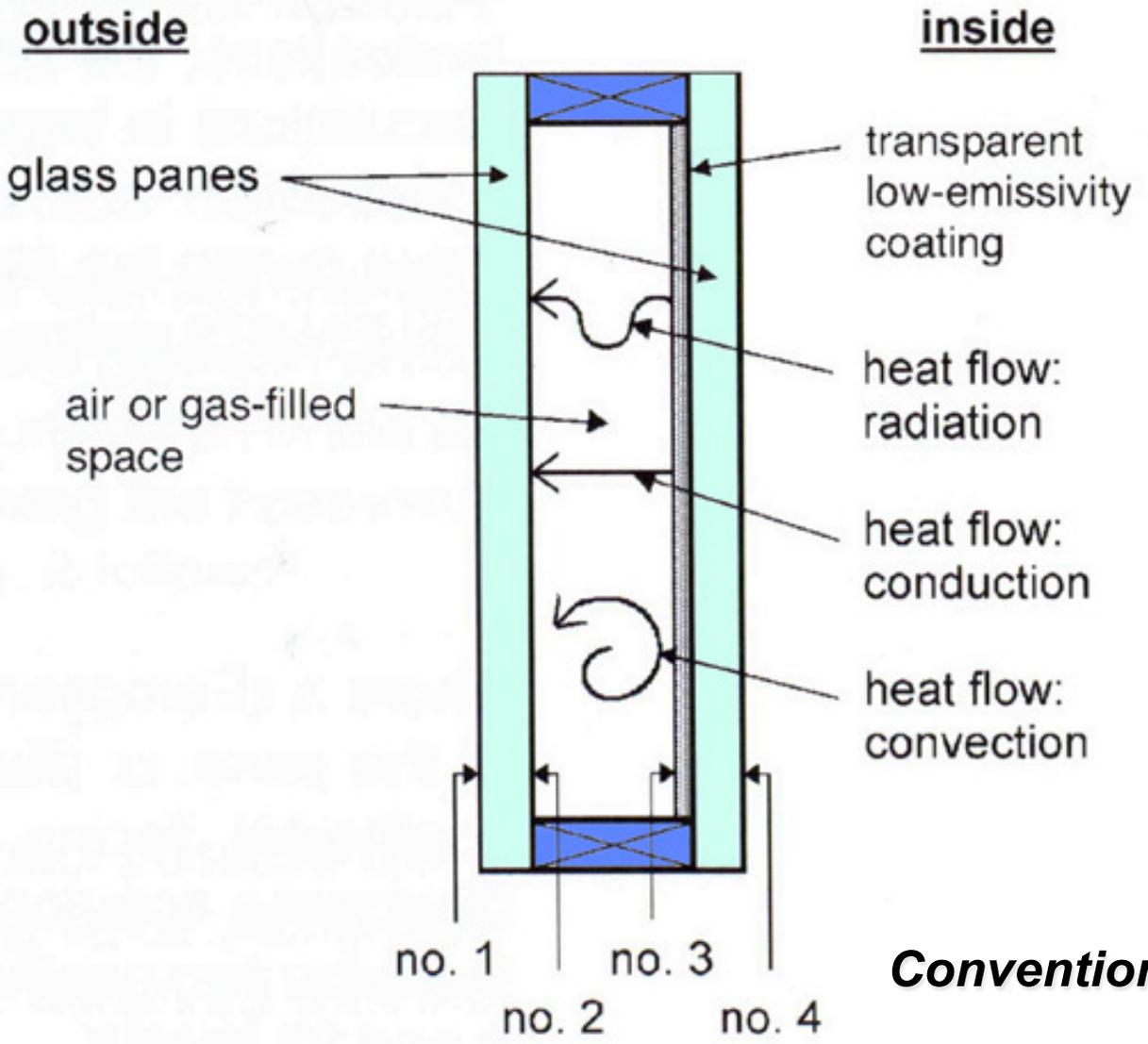
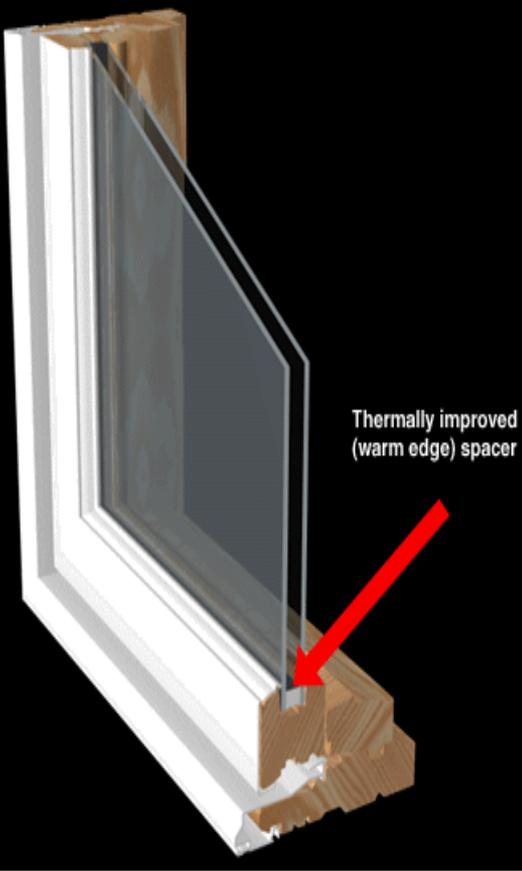


High Transmission low-E glass provides solar heat gain and reduces winter heat loss.

R and U values: a reminder....

- **R-value** = thermal resistance
 - SI unit $\text{K}\cdot\text{m}^2/\text{W}$, IP unit $\text{ft}^2\cdot^\circ\text{F}\cdot\text{h}/\text{Btu}$
 - $1 \text{ K}\cdot\text{m}^2/\text{W} = 5.675 \text{ ft}^2\cdot^\circ\text{F}\cdot\text{h}/\text{Btu}$
- $1/R$ = thermal conductance
- **U-value** = thermal transmittance
 - **$U=1/R$** if convection and thermal radiation can be neglected
 - more general, U-value contains all forms of energy transfer: thermal conductance + convection + radiation
 - SI unit $\text{W}/\text{K m}^2$, non-Si unit $\text{Btu}/\text{ft}^2 \text{ }^\circ\text{F}\cdot\text{h}$
- **Heat Loss, \$\$ Saved $\sim U$, not R**

Adding Low-E Coating to Insulated Glass Unit – IGU (keep track of heat transfer mechanisms)



Glazing “Systems” Ecosystem

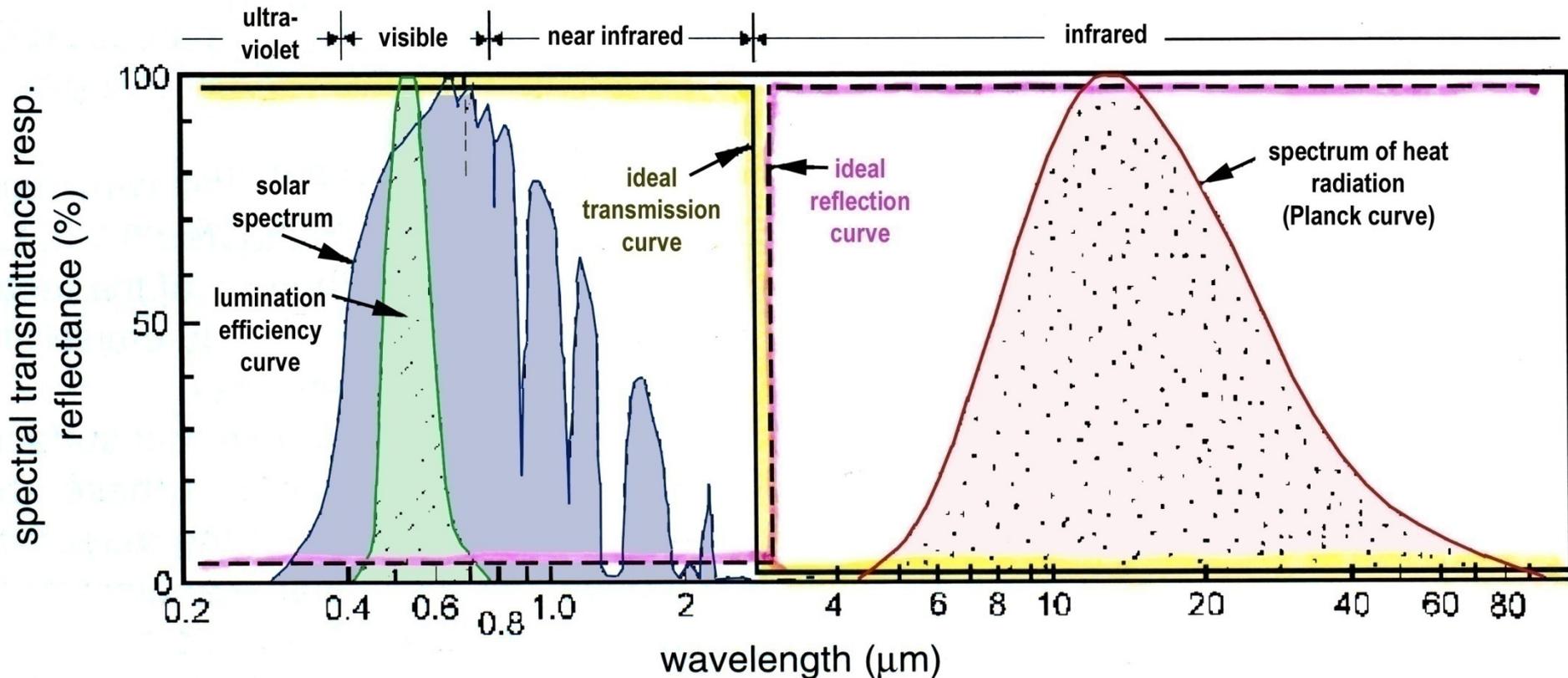
- **Glass: Monolithic <--> Multiple pane**
 - Glass thickness: historically > 3mm....
 - Now .1mm glass options
 - Multilayer: Gas fills
- **Clear – Body Tinted – Coated**
 - On line, off-line, retrofit
- **Processed: Laminated, Tempered**
- **Multipane: Low conductance Spacers**
- **Vacuum glazings**
- **Aerogel, Transparent insulators,...**

- **Polymeric glazings**
 - **Plastic films - suspended and glue-on**
 - Extruded and ribbed polymers
 - Fiberglass panels
 - Prismatic glazings

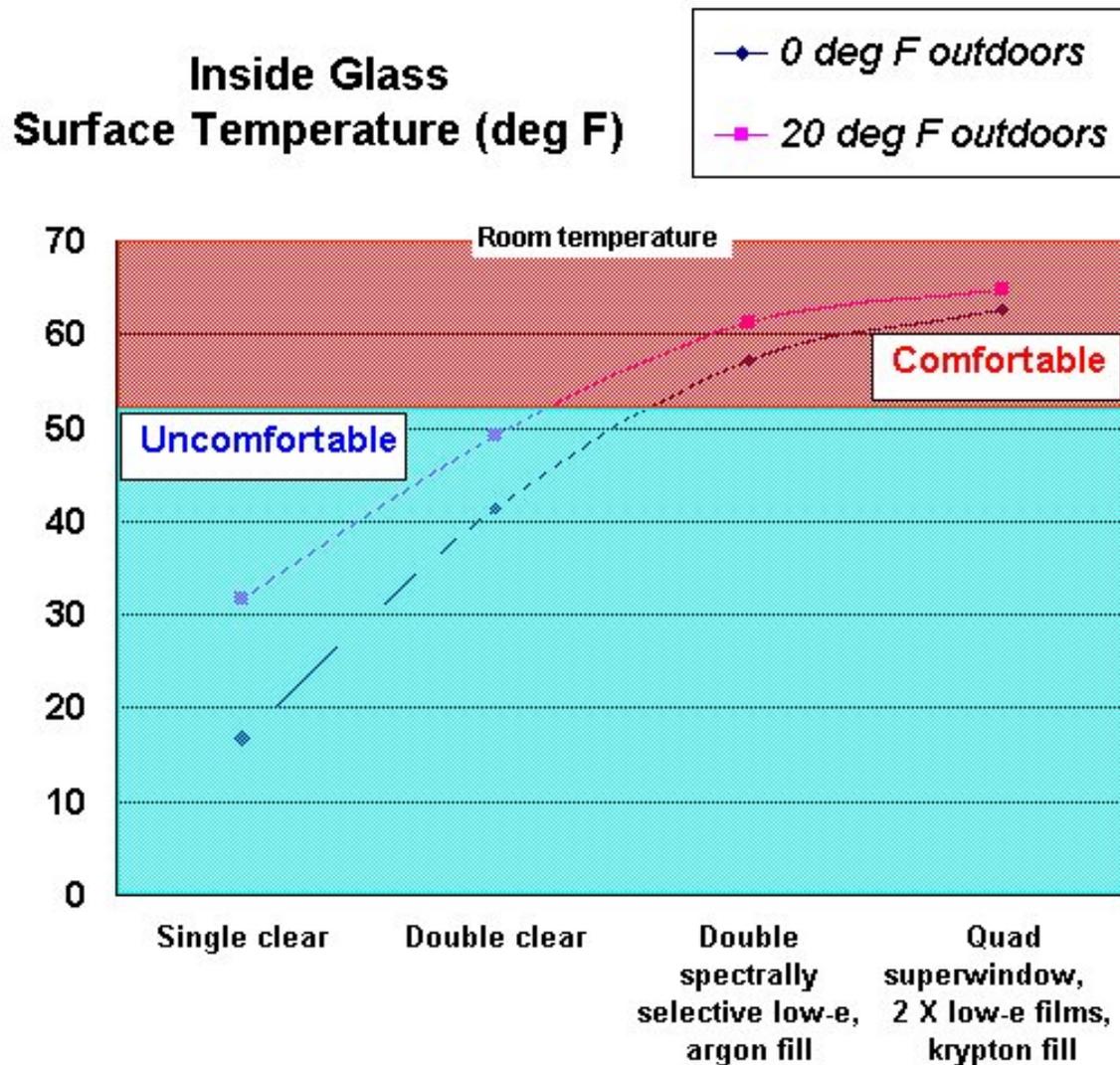
Radiation and the Ideal Energy-Saving Window:

Solar Radiation:
cooling vs lighting

Long Wave IR:
thermal transfer



Thermal Comfort – Interior Glass Temp

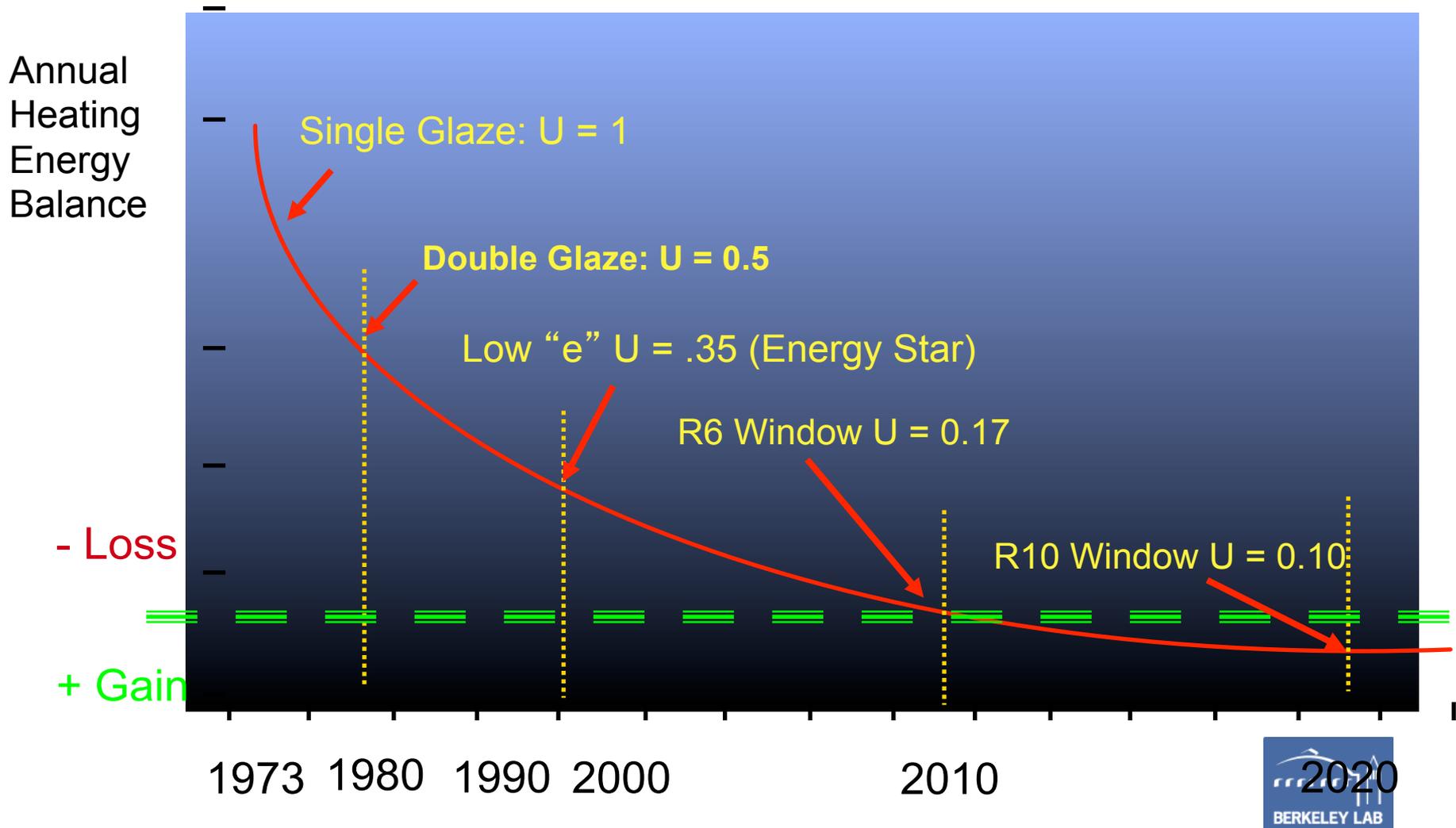


Technology Trends/Opportunities

**Highly Insulating
Solar Gain Management
U – SHGC tradeoffs**

Windows Can Become Net Energy Producers as $R > \sim 5$:

Caution: Balance of loss and gain in cold climates



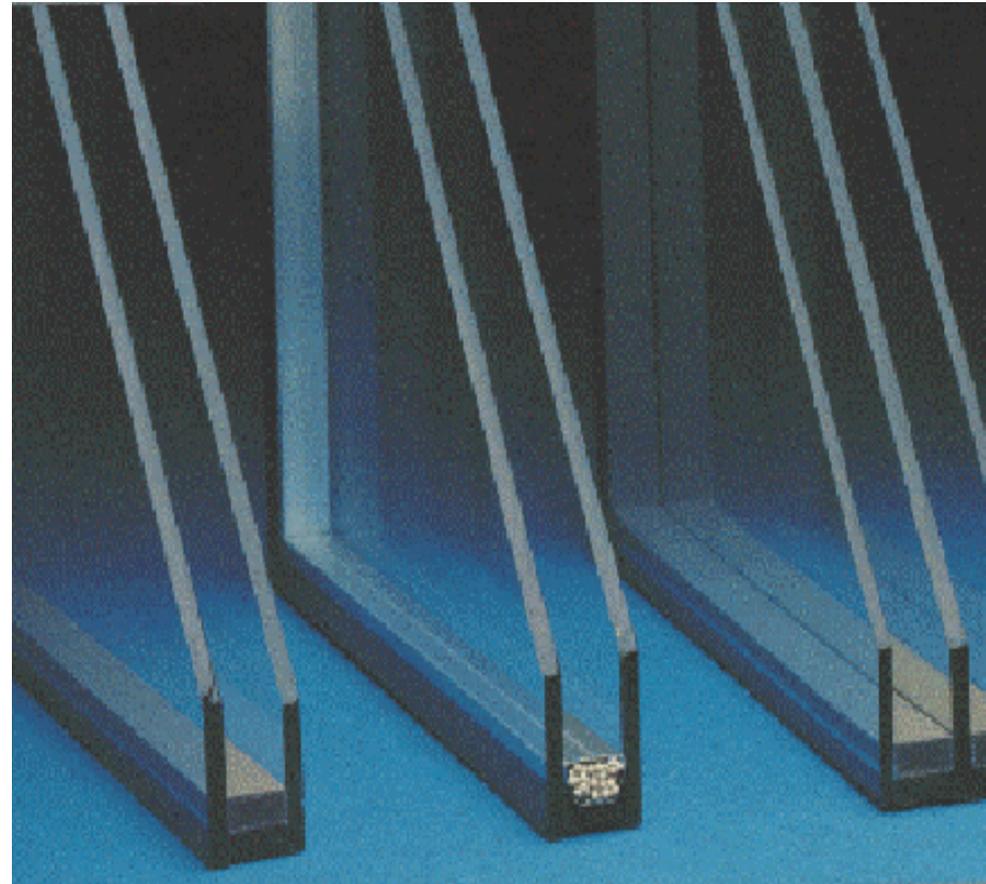
Highly Insulating Window Strategies

Nearer Term Objective: U-value < 0.25 Btu/sf-hr-F

Longer Term Target: U-value < 0.15 Btu/sf-hr-F

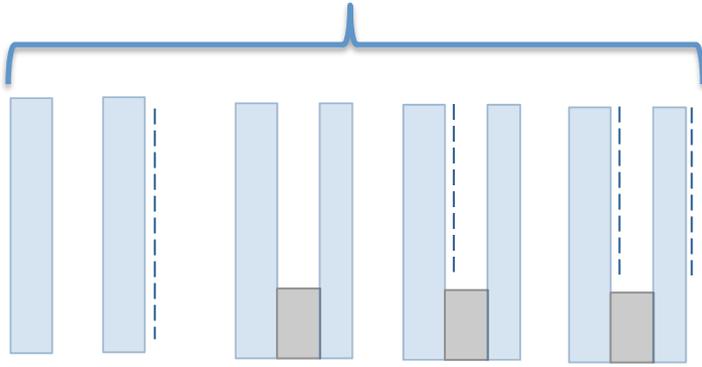
New Window Approaches:

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



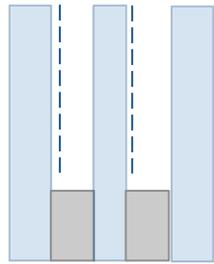
GLAZING SOLUTIONS: $U \sim .1 \text{ BTU/h-ft}^2\text{-F}$

Market Today

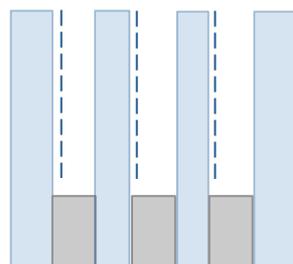


Single

Double



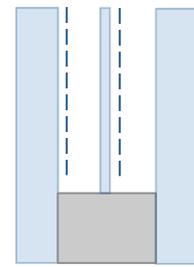
Two low-e



Three low-e

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

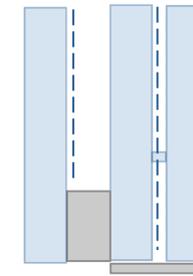
FY12-FY15



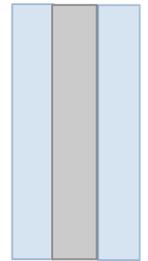
Two low-e
Thin glass
single seal
Krypton



One low-e
Vacuum

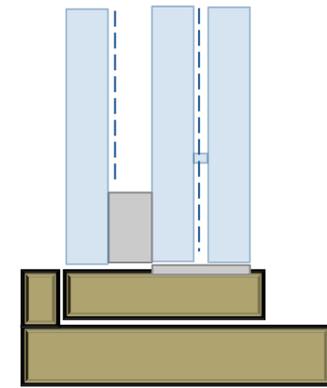
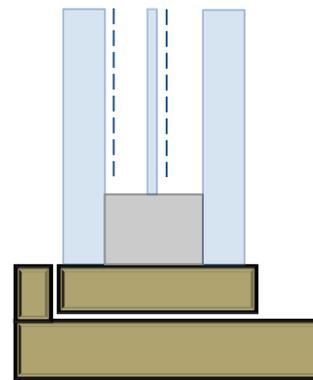


Two low-e
Vacuum Hybrid



Aerogel

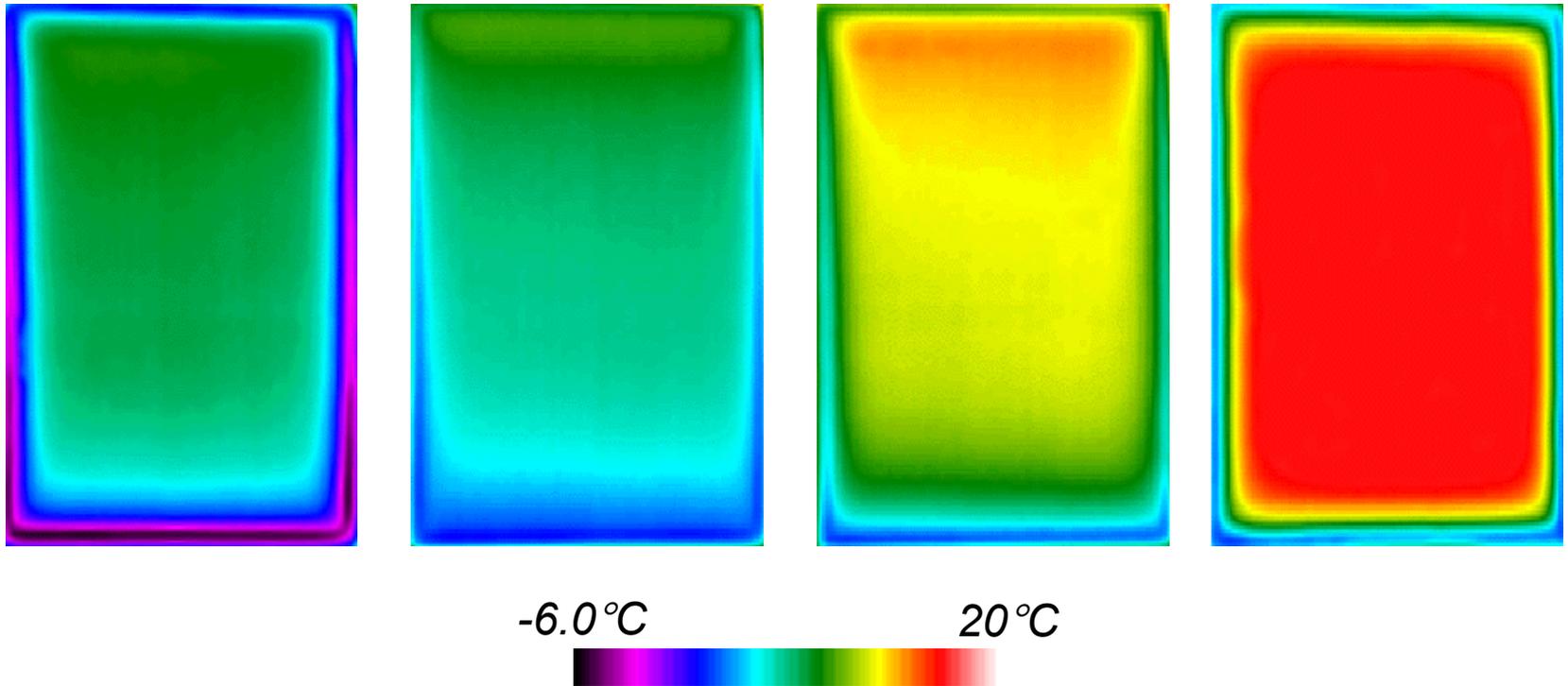
> FY15



Super-insulating frame with highly insulated glazing

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*

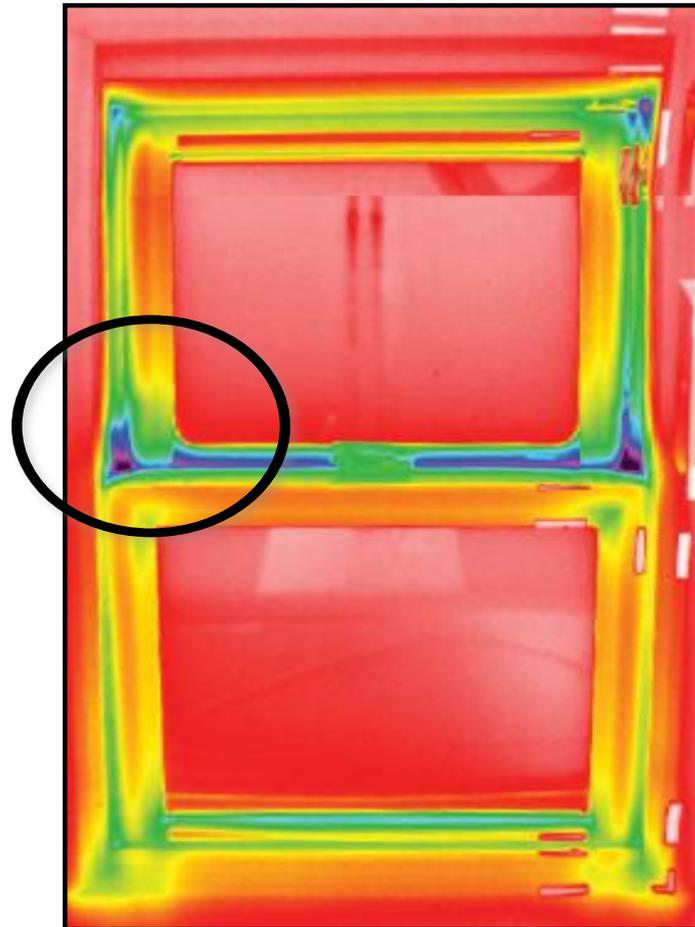
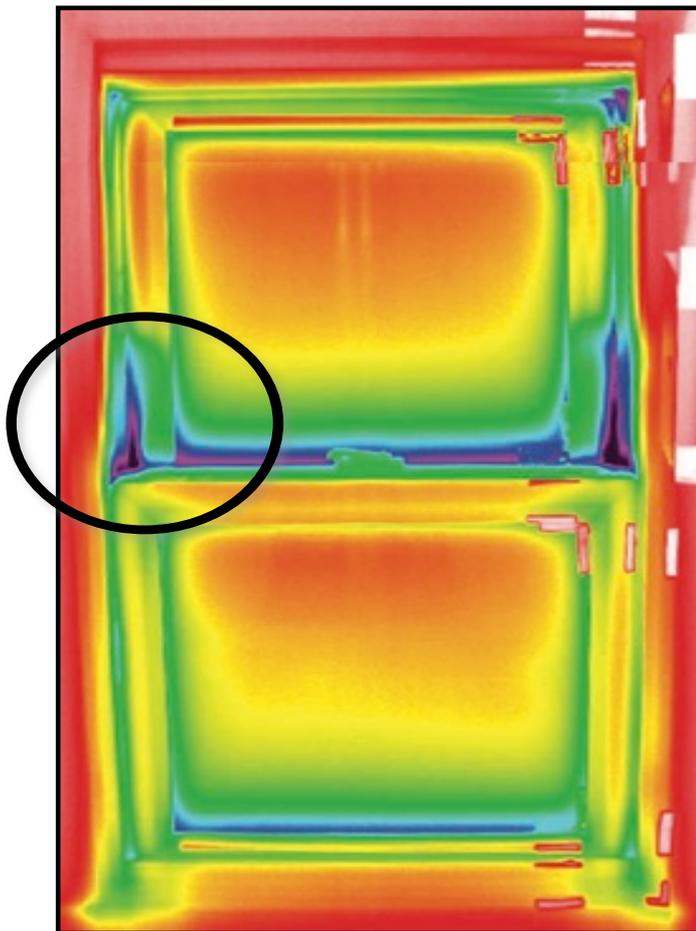


Images from LBNL Infrared Thermography Lab showing glass edge/spacer effects and convective loops in IGUs

Measurement: LBNL IR Thermography Lab

Quantitative Analysis

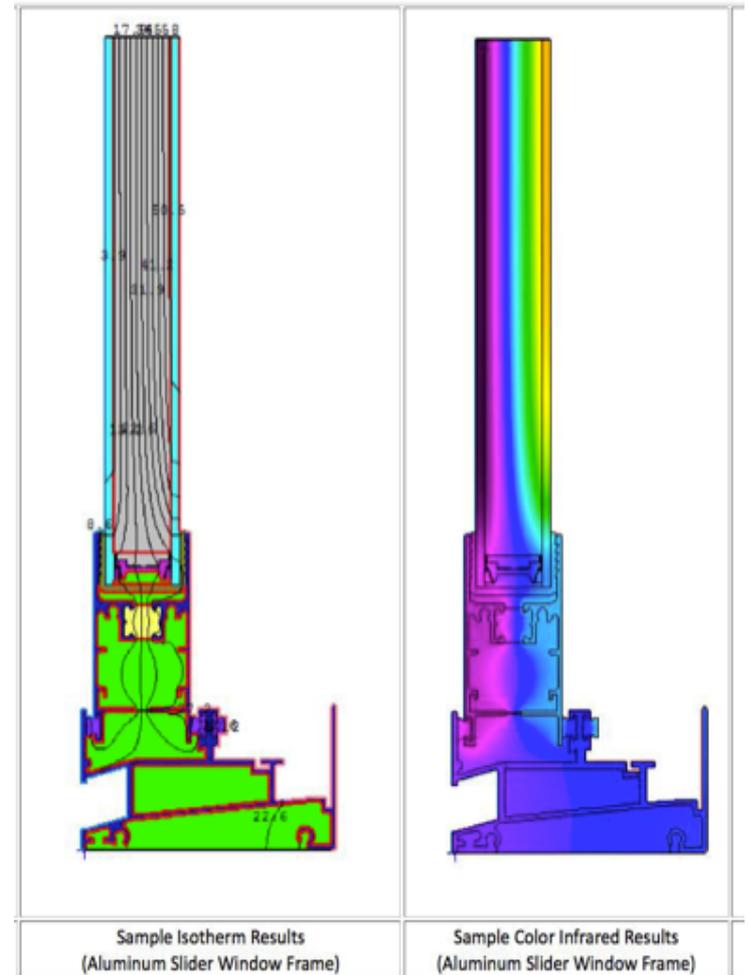
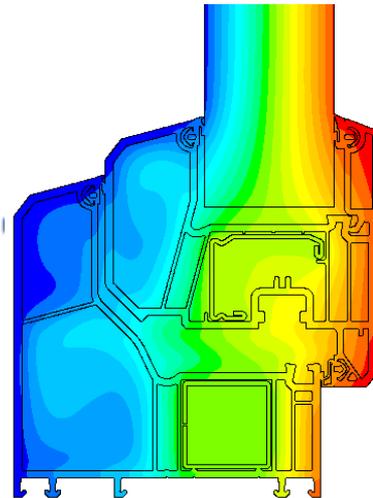
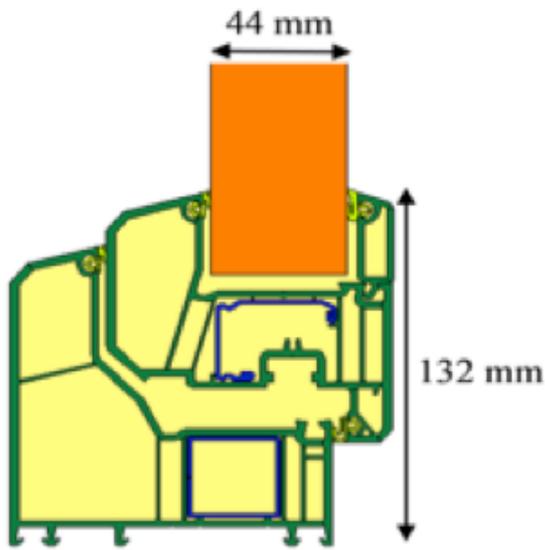
Lab cold chamber and Field Tests



THERM: Heat Transfer in Glass Edge and Window Frames

Impact of low conductance warm edge spacers
and thermal breaks in window frames

(THERM software downloads from windows.lbl.gov/software/)



Solar-Optical Properties of Glazing

Tvis, Solar Heat Gain Coefficient SHGC

- **Highly Transparent**
 - View, Daylight
 - Passive solar gain in winter
- **Solar Protection**
 - Reduce Cooling energy
 - Minimize cooling system size and cost
 - Manage Glare
- **Energy Control Options:**
 - Spectrum
 - Intensity
 - Transmission: specular vs diffuse

Capturing Useful Solar Gain in Winter (to balance winter heat loss)

- **Goal- net energy improvement:** what happens when insulation improvements also reduce solar gain?
- Most strategies to reduce U (extra glazing layers and coatings) will also reduce SHGC
- Lower U may NOT have better annual performance, if solar gain is lost

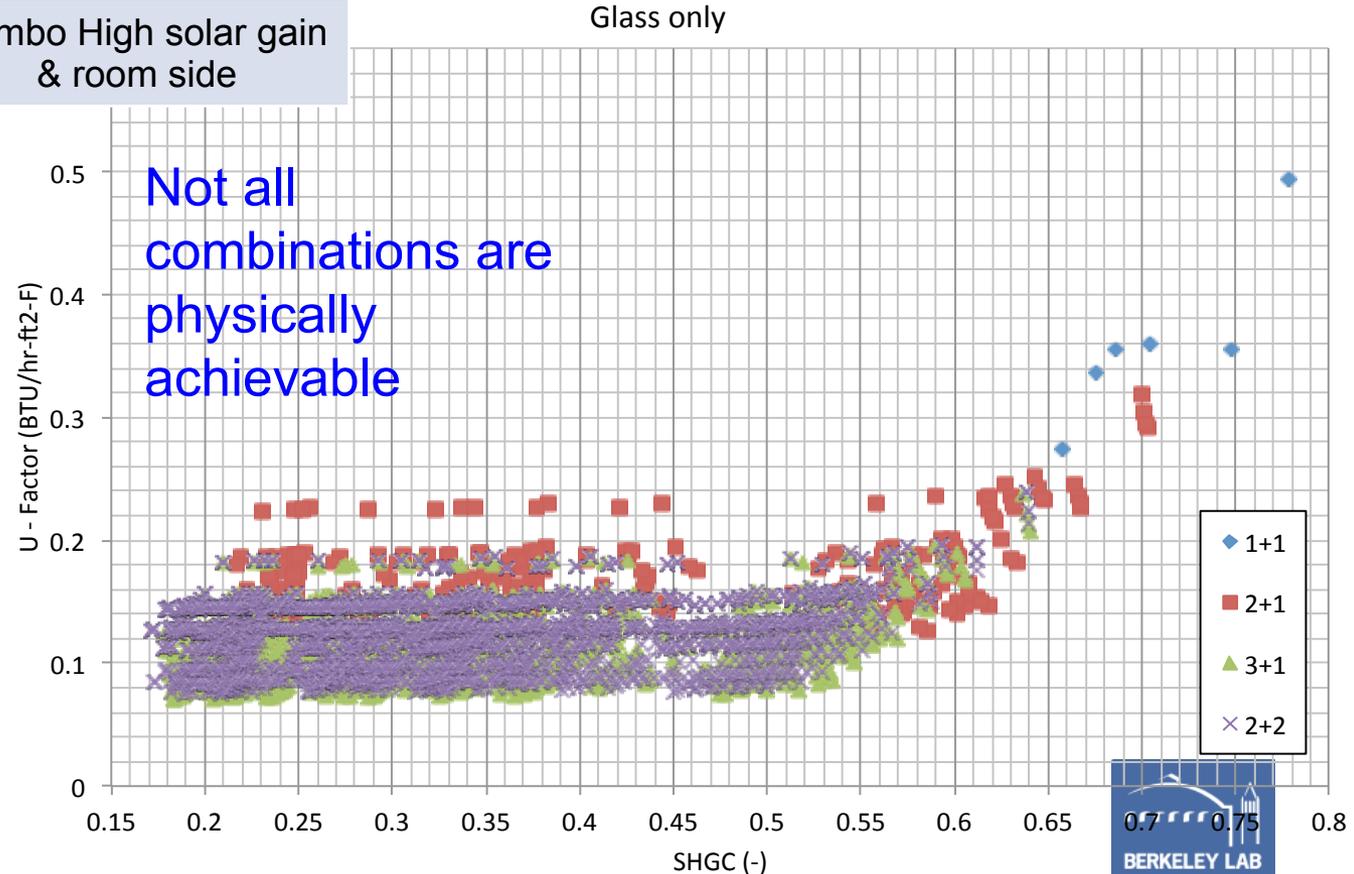
NFRC ID	NAME	TYPE
2001	clear	Clear
2011	Low-e ² 272	Moderate solar gain
2154	Low-e ³ 366	Solar control
2159	Low-e i89	Room side low-e
2191	Low-e 180	High solar gain
5001	Starphire (PPG)	Low iron
*	Low-e i89/180	Combo High solar gain & room side

GAS FILL
Air
Argon (90%)
Krypton (50%) / Argon (45%)
Krypton (90%)

Goal: Find the U/SHGC properties that minimize annual energy

6213 total combinations

Finding a Needle in a Haystack: 6,000 Glazing, coating, gas combinations U vs SHGC



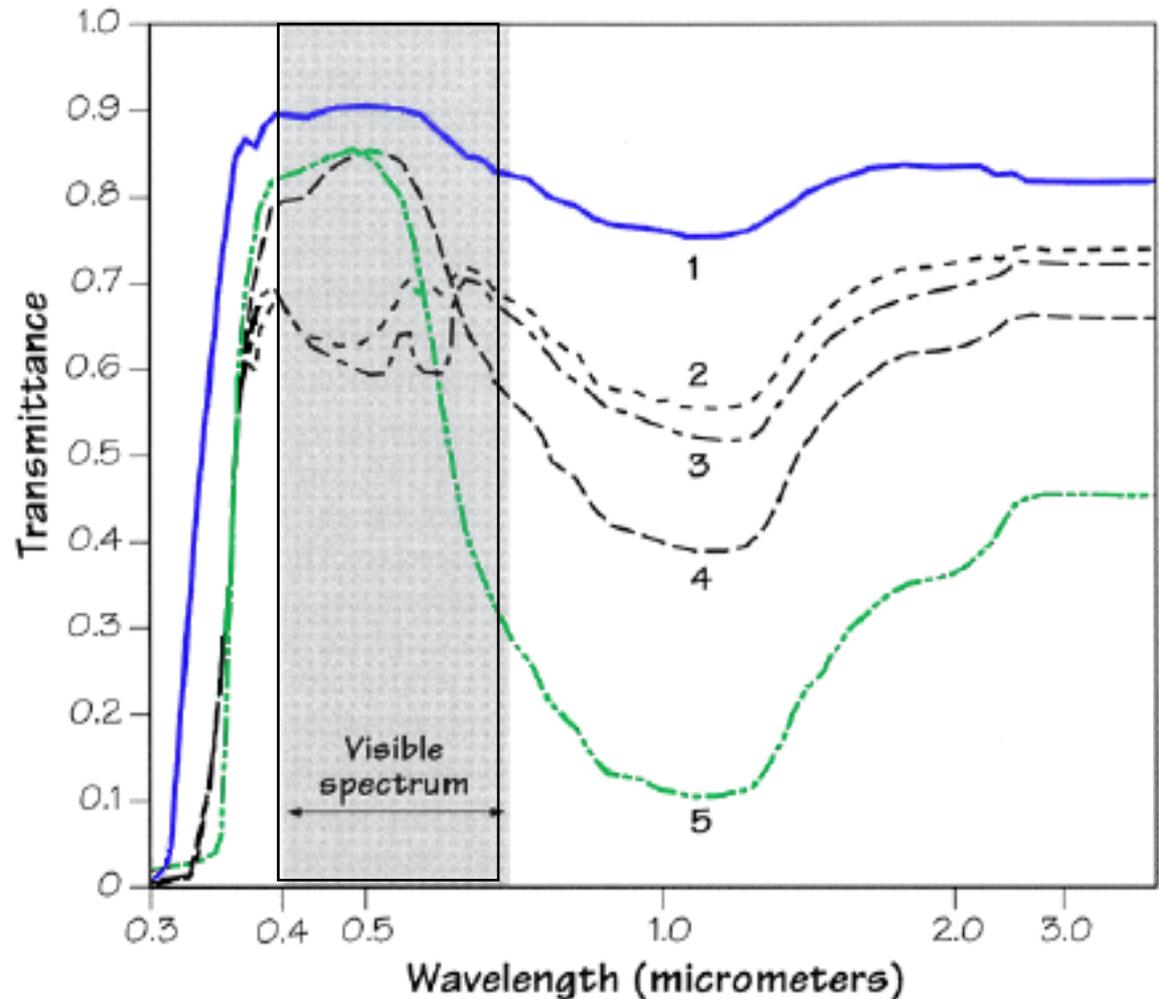
Spectrally Selective “Cool” Glazings:

Providing daylight with minimal solar gain
(All are low-E as well)

Spectral transmittance curves for common tinted and spectrally selective glazings

- 1 — Clear
- 2 — Bronze tinted
- 3 — Gray tinted
- 4 — Green tinted
- 5 — Spectrally selective

All cases are 1/8-inch glass.

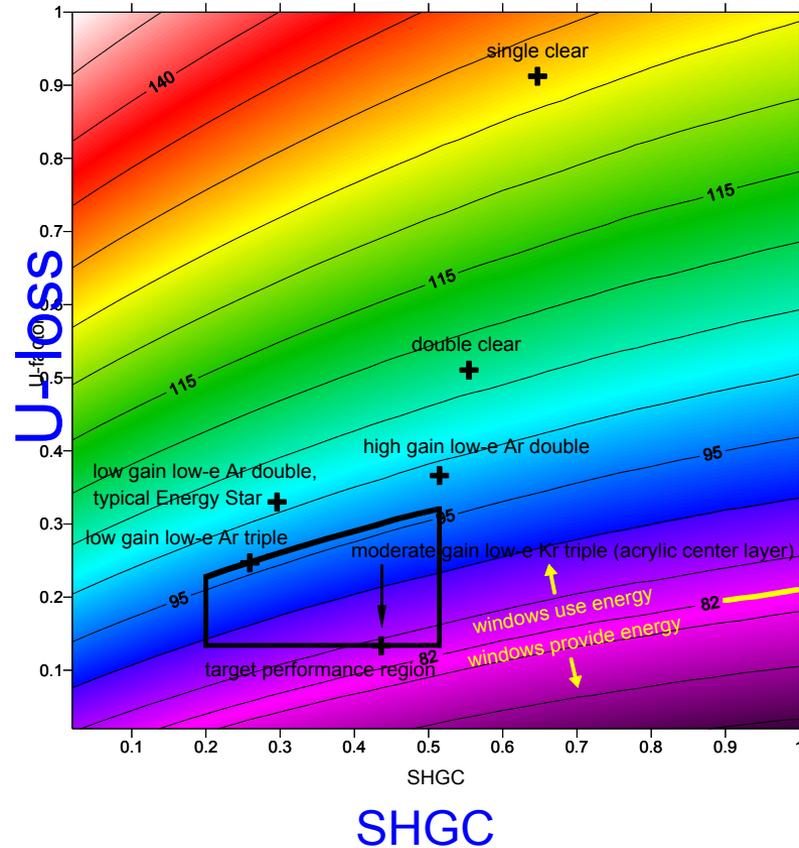


Darwin's Finchs: Adapting to Climate?

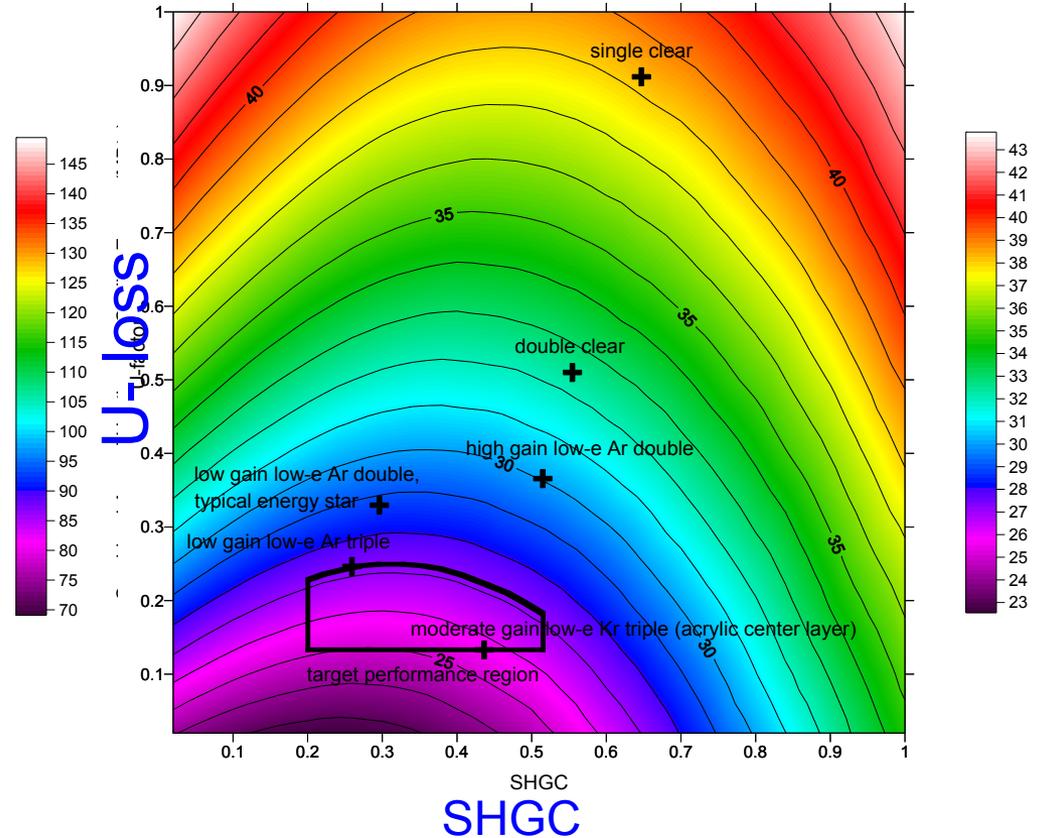
Minneapolis MN vs Riverside CA

(plots of equal energy use differ dramatically by climate)

Minneapolis, MN - Combined Annual Heating and Cooling Energy (MBtu)



Riverside, CA - Combined Annual Heating and Cooling Energy (MBtu)

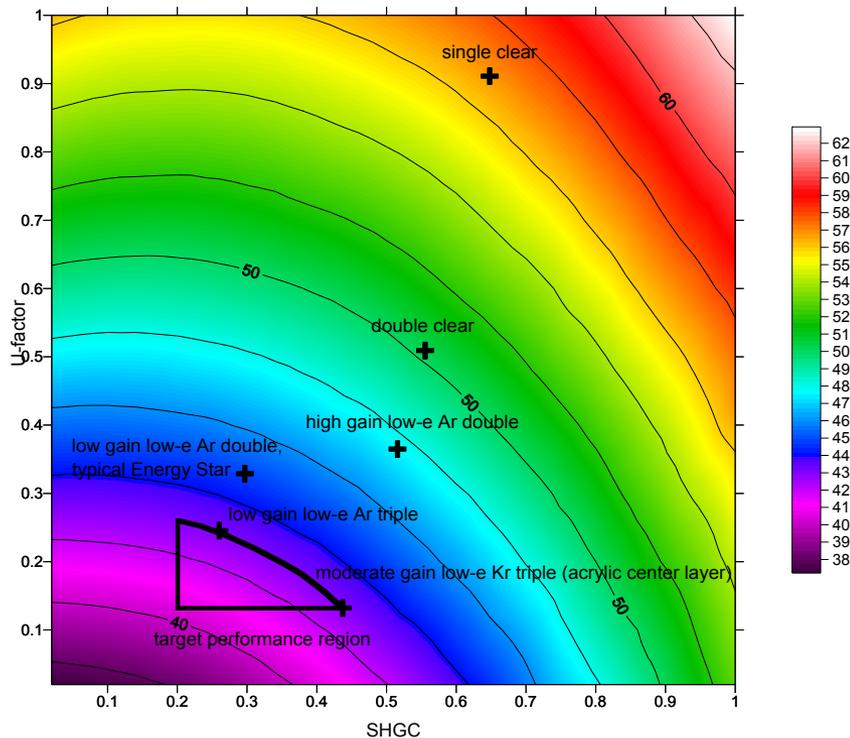


Static vs Dynamic Solar Control Create Dramatically Different Energy Profiles: Charleston, SC - Cooling Climates:

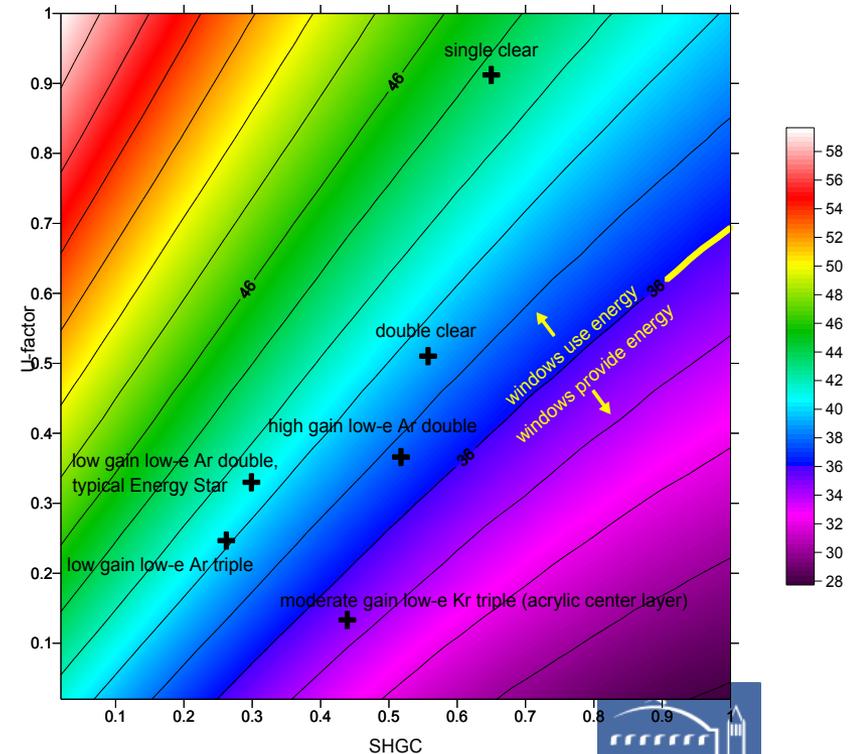
Left: Conventional Static Window

Right: Dynamic or ultra-low-solar, hi-R (U=0.1-0.3 Btu/h-ft²-F) approaches ZEH goals

Charleston, SC - Combined Annual Heating and Cooling Energy (MBtu)



Charleston, SC - Combined Annual Heating and Cooling Energy (MBtu)
Dynamic Solar Gain, 0.16 SHGC for periods requiring cooling



Impact of Incremental Insulation Improvements: Reductions with Alternate Glazing Improvements to 3 Base Windows

**% Reduction in Heat Loss by Adding Rx to Base Window
\$\$ Savings Associated with Each**

Added R-> Base Window	R1	R2	R3	R5	R8	Initial Value
Single U= 1.1	50%	67%	75%	85%	90%	\$1.00
Double Clear U= .5	33%	50%	60%	72%	80%	\$0.50
Double Low-E U= .25	20%	33%	42%	55%	67%	\$0.25

Single Glazing “Add-on” Issues

- Where to intervene:
 - Glass, Sash, Window
 - Modify window or “add-on” **attachments**
 - Different impacts of each
- Business Models for Retrofit
- New Technology Options
- Tool for parametric analysis of properties and energy impacts

WINDOW ATTACHMENTS

Window attachments (coverings) are products added to existing windows to:

- improve energy performance, comfort, glare, privacy, security, or enhance the appearance of a home.
- The primary energy impact from the attachments is ability to **reduce U, manage SHGC and Tv and/or reduce air leakage**

• Exterior attachments:



Low-e Storm Window



Fixed Awning



Dynamic Awning



Roller Shutter - Window



Roller shade



Solar screen

• Interior attachments:



Drapes



Louvered blinds



Roller shades



Surface applied film



Cellular shade



Window quilt



Seasonal film kit

• Between Glass (applies to non-sealed glazing systems only – applied as a retrofit option):



Louvered blinds



Roller shades



Cellular shades



Solar screens



Surface applied films

Existing Models for Single Glass Retrofit? Window Film Industry

- Historical focus on solar control, (blast)
- New: Low-E options
 - $E < .05$
- Future:
 - Smart Coating
 - Insulating coatings

Issues

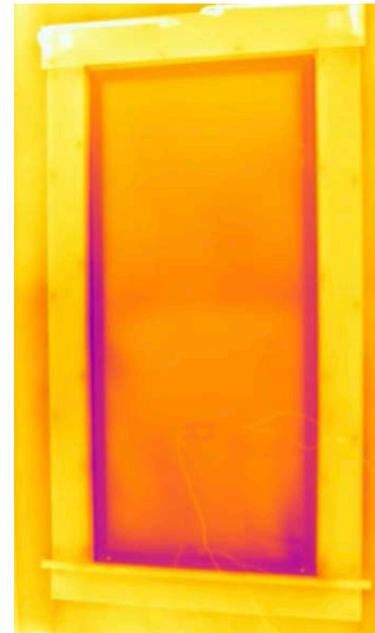
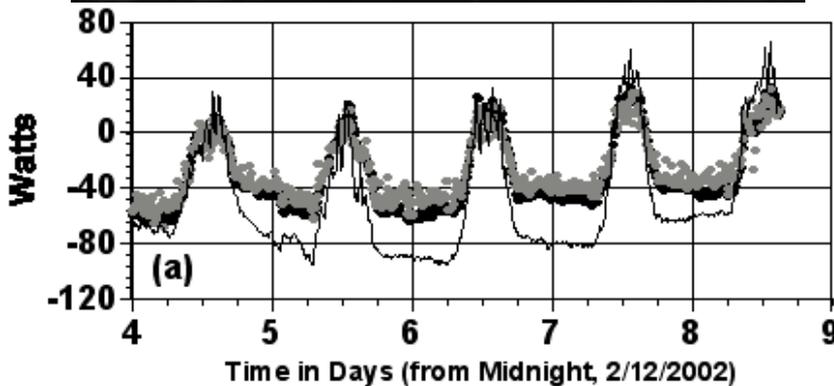
- Service models/costs:
 - On site “sizing”
 - Labor
- Cleaning
- Lifetime

The screenshot displays the IWFAX website. At the top left is the IWFAX logo with the text "INTERNATIONAL WINDOW FILM ASSOCIATION". To the right are links for "Login" and "Register", and the date "Wednesday, November 05, 2014". A prominent blue banner advertises the "NORTHEAST REGIONAL CONFERENCE" with "Free Accreditation! For Members" on "Friday Nov 14th". It specifies the dates "Nov 14 & 15th" and the location "King Of Prussia PA VALLEY FORGE CASINO RESORT". A "Register Now!" button with a mouse cursor is on the right. Below the banner is a navigation menu with links: Home, Business Locator, Consumer Info, Member Info, News, Events, and Contact Us. A sidebar on the left contains "Consumer Information" and "Window Film Professionals". The main content area features a "Consumer Info" section with a search bar and a "Why Professional Installation is Best" heading. Below this heading are three paragraphs of text explaining the benefits of professional installation, such as manufacturer recommendations, performance longevity, and experience/training.

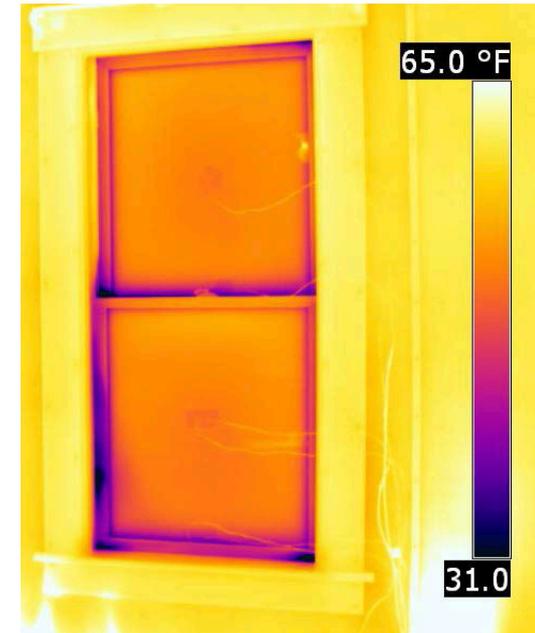
Existing Business Models: Storm Panels (interior and exterior low-E storms work well) (DOE Projects, Building America Webinar)

2000: LBNL Field Testing - MoWiTT
Low-E Storms Added to Single Prime
~ = New Double Low-E

2011: LBNL Field IR
Testing in Vermont
Interior Low-E Panels



Interior Low-E
Retrofit Panel



Low-E Sash
Replacement

Existing Business Models: DIY

Home Energy Solutions

Products

Resources

Where To Buy

Contact

United States > All 3M Products > Home and Leisure > Home Energy Solutions > Home Energy Solutions > 3M™ Indoor Window Insulator Kit, 2 Windows

3M™ Indoor Window Insulator Kit, 2 Windows

Print Share

Need Help?

Questions? We can help
[Contact Us](#)



Available in a variety of indoor and outdoor window sizes, 3M™ Window Insulator Kits keep cold drafts out and warm air in through heat shrink window film and Scotch® Window Film Mounting Tape. Easy to install, 3M™ window kits have the clearest film and stay up all season long with Scotch® tape technology.

- Clearest window film available
- Scotch® double sided tape holds firmly between films and surfaces
- Saves energy and reduces heating costs

Save
\$2.00

3M Indoor Window Insulator Kit, 5-Window
by 3M

\$12.99 ~~\$22.54~~ ✓ Prime
Get it by **Friday, Nov 7**

More Buying Choices
\$12.85 new (49 offers)
\$12.08 used (1 offer)

Cost:
\$3/window
~\$.30/sf



Overview

Related Products

Reviews



Home Energy Solutions

- Products
- Resources
- Where To Buy
- Contact Us

10 Windows, 10 sf each
Calculated Payback: ~ 1 mo!

United States > All 3M Products > Home and Leisure > Home Energy Solutions

How much could you save with 3M™ Window Insulator Film?



MINNESOTA MINNEAPOLIS

Calculate Your Savings

1. Window Details

Height (in): 60 Width (in): 24 # of Windows: 10

Sealing: Average Glass: Double Pane

2. Thermostat Settings

Day (°F): 70 Night (°F): 62

3. Fuel Type

#2 Fuel Oil

Estimated Total Savings* (per heating season)

\$233.07

*Based on 2014 - 2015 projected fuel costs.

How much could you save with 3M™ Window Insulator Film?



MINNESOTA MINNEAPOLIS

Calculate Your Savings

1. Window Details

Height (in): 60 Width (in): 24 # of Windows: 10

Sealing: Average Glass: Single Pane

2. Thermostat Settings

Day (°F): 70 Night (°F): 62

3. Fuel Type

#2 Fuel Oil

Estimated Total Savings* (per heating season)

\$332.42

*Based on 2014 - 2015 projected fuel costs.

Single Pane \$3/sf-yr savings

New Designs/Materials - What is Possible?

Prototype MATLAB Tool to Assess Window System Properties as a function of “Window Add-on Parameters”

Primary Glazing
 Single Clear Double Clear Double Low-e Progress

Shade Location
 Exterior shade Interior shade

Result Display Type
 Absolute
 % less than Primary Glazing alone

Property
 U-Factor (W/m²-K) SHGC (-)

Emissivity 1 (-)*
0.5

Emissivity 2 (-)
0.5

Conductance (W/K)
0.0015023

Gap (mm)
6.8478

Openess (%)
0.05

Transmittance (%)**
50

Reflectance (%)**
50

*Interior only
**SHGC only

The 2D contour plot shows U-Factor (W/m²-K) on the vertical axis (0 to 4) as a function of Openess (%) on the horizontal axis (0 to 0.1) and Gap width (mm) on the vertical axis (4 to 14). Contour lines are labeled with values 2.50, 3.00, and 3.50. The plot shows that U-Factor generally increases with both Openess and Gap width.

The 3D surface plot shows U-Factor (W/m²-K) on the vertical axis (0 to 4) as a function of Openess (%) on the horizontal axis (0 to 0.1) and Gap (mm) on the horizontal axis (4 to 14). The surface is colored according to the U-Factor values, showing a clear upward trend as both parameters increase.

What's Possible?

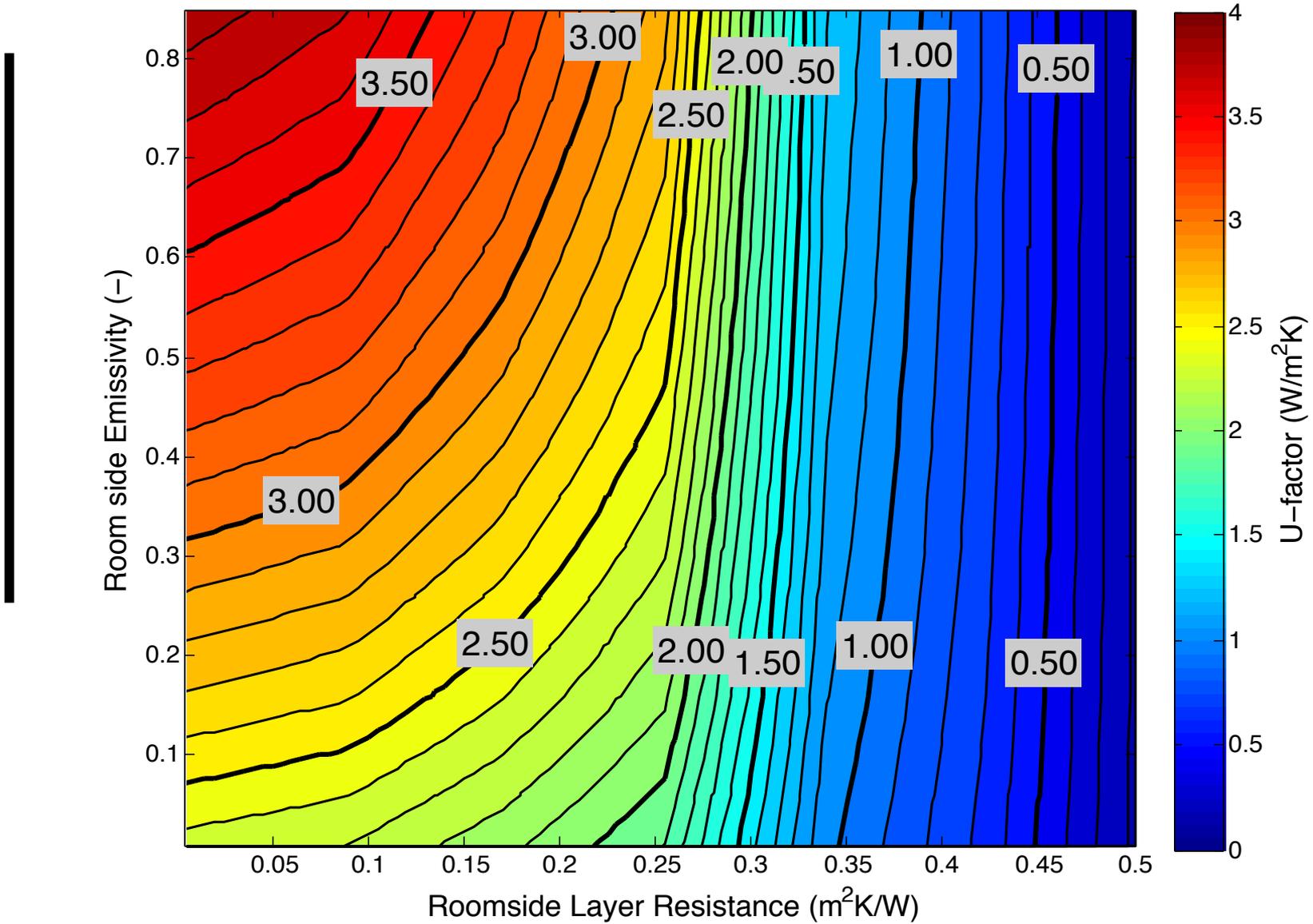
Representative Conductance values

Materials	C (W/m ² K)	R (m ² K/W)
2.5 mm air	12.2	0.082
3mm glass	333.3	0.003
1mm Aerogel*	17.0	0.059
1mm ev Aerogel**	8.0	0.125
10mm Aerogel*	1.7	0.588
10mm ev Aerogel**	0.8	1.250
100mm Aerogel*	0.2	5.882
100mm ev Aerogel**	0.1	12.500

*typical aerogel 0.017W/mK

**evacuated aerogel 0.008 W/mK

Overall U as a function of added layer thermal resistance and room side emissivity

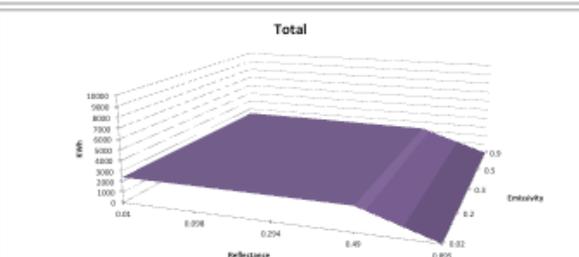
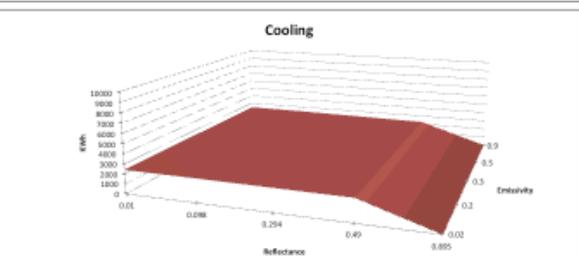
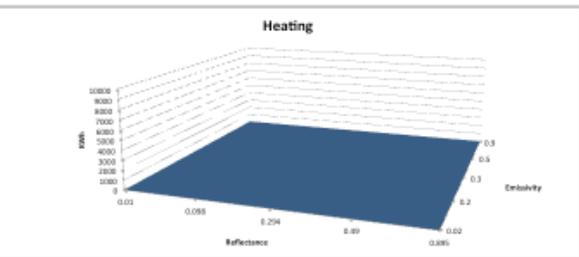


Examples: Maps of Annual Energy Use vs Thermal Properties (U, E, SHGC)

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	-1425.08	-1425.08	-1311.31	-1225.62	-1125.62
0.2	-1388.89	-1388.89	-1466.67	-1463.89	-1463.89
0.7	-1311.31	-1300.00	-1394.44	-1388.89	-1388.89
0.9	-1281.31	-1275.00	-1341.67	-1338.89	-1338.89
0.9	-1197.22	-1186.67	-1261.31	-1241.67	-1241.67

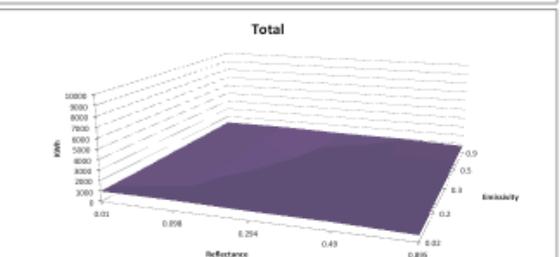
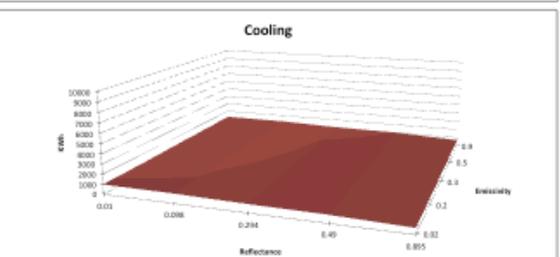
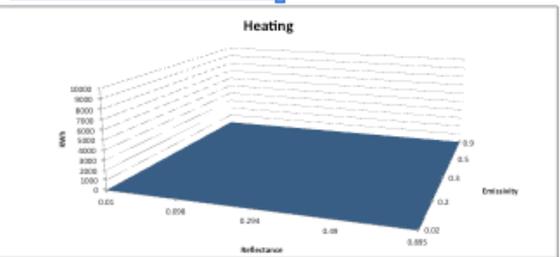
Window Type = Double-Air High T
 Surface Number = 2
 Window Orientation = South
 Location = South

Miami, FL



Window Type = Double-Air LC
 Surface Number = 2
 Window Orientation = South
 Location = South

Miami, FL



Total GHG

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	-1425.08	-1425.08	-1311.31	-1225.62	-1125.62
0.2	-1388.89	-1388.89	-1466.67	-1463.89	-1463.89
0.7	-1311.31	-1300.00	-1394.44	-1388.89	-1388.89
0.9	-1281.31	-1275.00	-1341.67	-1338.89	-1338.89
0.9	-1197.22	-1186.67	-1261.31	-1241.67	-1241.67

FL

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	0.00	0.00	0.00	0.00	0.00
0.2	0.00	0.00	0.00	0.00	0.00
0.7	0.00	0.00	0.00	0.00	0.00
0.9	0.00	0.00	0.00	0.00	0.00
0.9	0.00	0.00	0.00	0.00	0.00

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	2416.67	2397.22	2352.78	2336.33	0.00
0.2	2422.22	2397.22	2347.22	2297.22	0.00
0.7	2433.33	2432.78	2338.89	2272.78	0.00
0.9	2438.89	2438.33	2336.11	2266.67	0.00
0.9	2432.78	2416.67	2333.33	2252.78	0.00

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	2416.67	2397.22	2352.78	2336.33	0.00
0.2	2422.22	2397.22	2347.22	2297.22	0.00
0.7	2433.33	2432.78	2338.89	2272.78	0.00
0.9	2438.89	2438.33	2336.11	2266.67	0.00
0.9	2432.78	2416.67	2333.33	2252.78	0.00

FL

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	2.79	2.79	2.79	2.79	0.31
0.2	2.79	2.79	2.79	2.79	13.89
0.7	2.79	2.79	2.79	2.79	14.44
0.9	2.79	5.59	5.59	8.33	25.01
0.9	5.59	5.59	8.33	11.11	33.33

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	383.81	369.44	338.81	328.81	351.21
0.2	370.59	351.89	327.78	320.54	313.81
0.7	319.44	320.00	341.67	383.33	347.22
0.9	3175.00	3172.78	388.89	393.89	422.22
0.9	3250.00	3244.44	393.89	3200.00	725.54

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.01	0.099	0.294	0.49	0.899
0.02	961.67	972.22	941.67	791.67	600.00
0.2	1033.33	1016.67	887.89	883.33	627.78
0.7	1122.22	1132.78	944.44	888.89	666.67
0.9	1177.78	1183.33	964.44	947.22	687.22
0.9	1235.59	1230.00	1072.22	1011.11	788.81

R _g	R _g				
	Very_Low	Low	Medium	High	Very_High
0.01	0.1	0.3	0.5	0.8	0.9
0.02	0.1	0.3	0.5	0.8	0.9
0.1	0.1	0.3	0.5	0.8	0.9
0.1	0.1	0.3	0.5	0.8	0.9
0.1	0.1	0.3	0.5	0.8	0.9
0.1	0.1	0.3	0.5	0.8	0.9

Requirements for High Performance Insulating “Glazing” Layers

Table I. Proposed requirements of the future high performance thermal insulation materials and solutions.

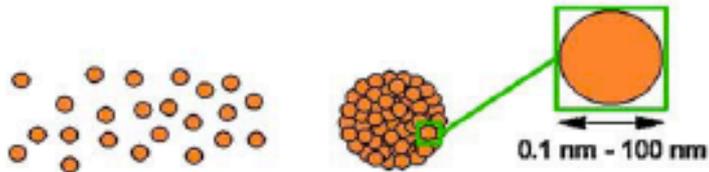
Property	Requirements
Thermal conductivity – pristine	<4 mW/(mK)
Thermal conductivity – after 100 years	<5 mW/(mK)
Thermal conductivity – after modest perforation	<4 mW/(mK)
Perforation vulnerability	Not to be influenced significantly
Possible to cut for adaption at building site	Yes
Mechanical strength (e.g. compression and tensile)	May vary
Fire protection	May vary, depends on other protection
Fume emission during fire	Any toxic gases to be identified
Climate aging durability	Resistant
Freezing/thawing cycles	Resistant
Water	Resistant
Dynamic thermal insulation	Desirable as an ultimate goal
Costs vs other thermal insulation materials	Competitive
Environmental impact (including energy and material use in production, emission of polluting agents and recycling issues)	Low negative impact

Nano- Insulating Materials

B.P. Jelle / Energy and Buildings 43 (2011) 2549–2563

Nanotechnology:

Technology for controlling matter of dimensions between 0.1 nm - 100 nm.



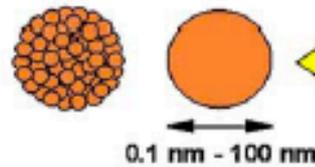
For comparison: Solar radiation: 300 nm - 3000 nm
 Atomic diameters: Hydrogen: 0.16 nm
 Carbon: 0.18 nm
 Gold: 0.36 nm
 Molecular length: Stearic Acid: 2.48 nm
 ($C_{17}H_{35}COOH$)



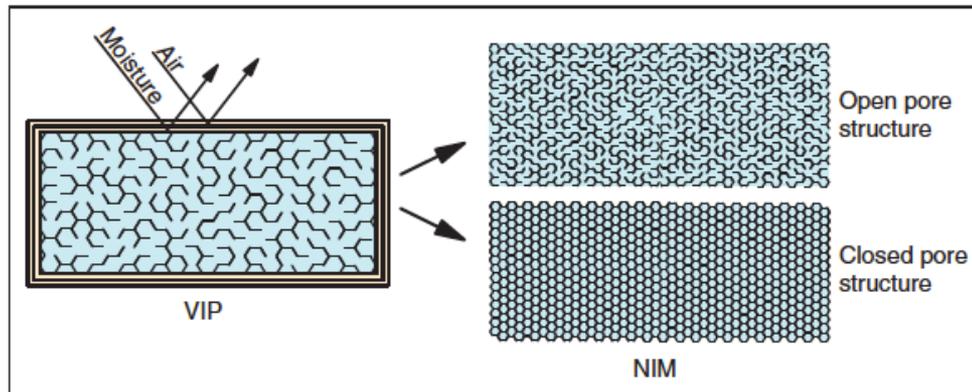
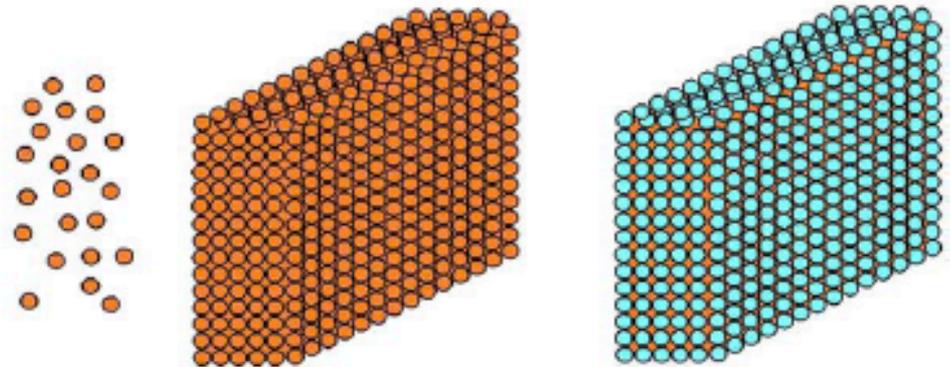
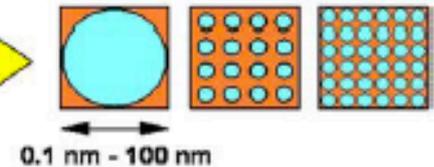
Nanotechnology:

Technology for controlling matter at an atomic and molecular scale.

Nano Particles



Nano Pores



Comparative Performance of Insulating “Glazing” Layers

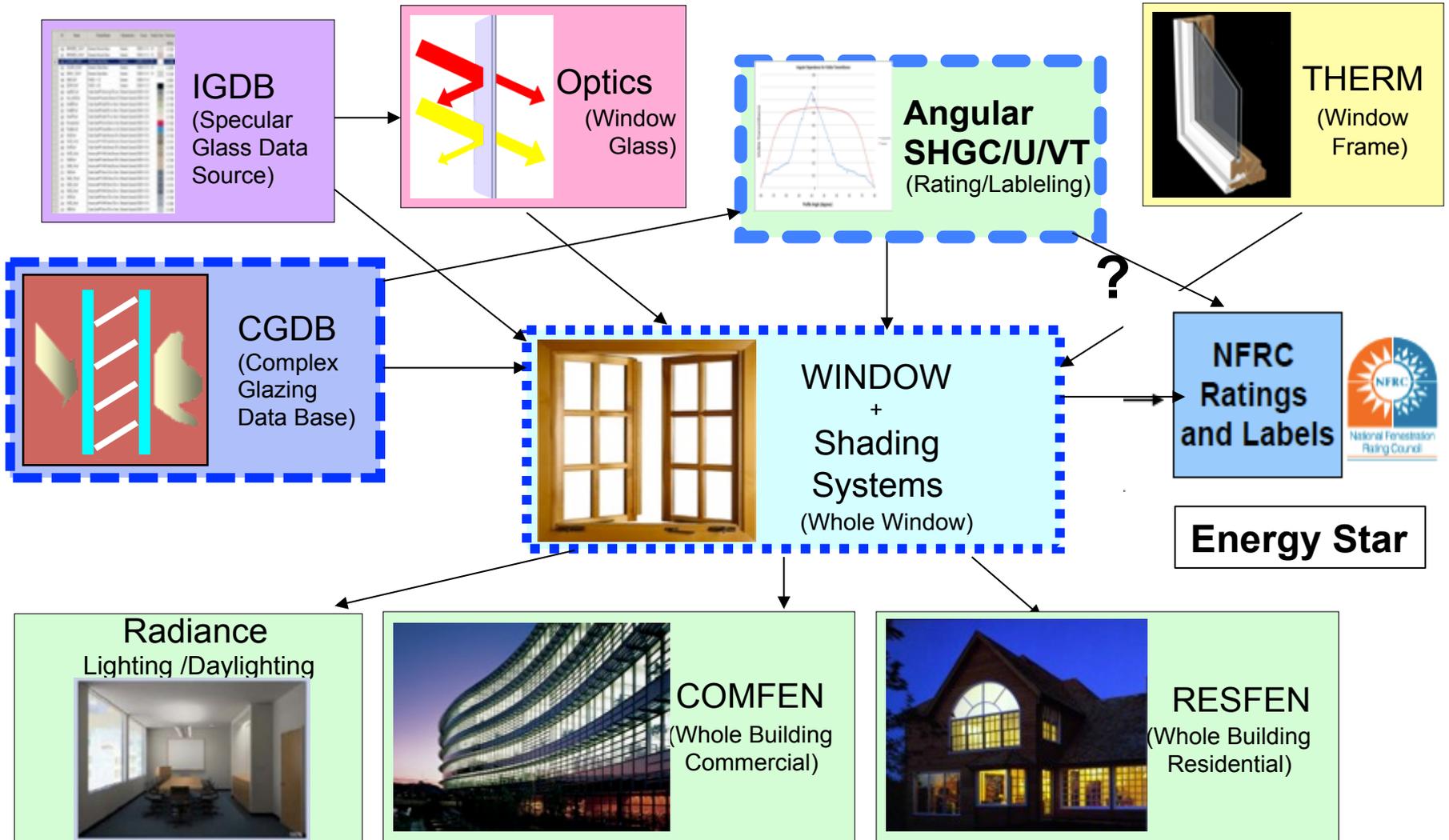
Thermal insulation materials and solutions	Low pristine thermal conductivity	Low long-term thermal conductivity	Perforation robustness	Possible building site adaption cutting	A thermal insulation material and solution of tomorrow?
<i>Traditional</i> Mineral wool and polystyrene	No	No	Yes	Yes	No
<i>Today's state-of-the-art</i>					
Vacuum insulation panels	Yes	Maybe	No	No	Today and near future
Gas-filled panels	Maybe	Maybe	No	No	Probably not, near future
Aerogels	Maybe	Maybe	Yes	Yes	Maybe
Phase change materials	–	–	–	–	Heat storage and release
<i>Beyond state-of-the-art – advanced insulation materials</i>					
Vacuum insulation materials	Yes	Maybe	Yes	Yes	Yes
Gas insulation materials	Yes	Maybe	Yes	Yes	Maybe
Nano insulation materials	Yes	Yes	Yes, excellent	Yes, excellent	Yes, excellent
Dynamic insulation materials	Maybe	Maybe	Not known	Not known	Yes, excellent
Others?	–	–	–	–	Maybe

Table 2 from Jelle et al, *Journal of Building Physics* 2010 34: 99

How Can Simulation Tools Help Inform the Search for Solutions?

Tools for Glazing Window and Façade Decision

Download <http://windows.lbl.gov/software/> FY13 ~ 40,000 Downloads; ~2000 uses/day



Commercial Windows Website

Efficient Windows Website

Design /Simulation Tools



WINDOW: Glazing System and Whole Product Tool

Window Library (C:\Program Files\LBNL\WINDOWS\w51b-SimMan.mdb)

File Edit Libraries Record Tools View Help

List

Calc

Dividers

Dividers

Display mode: Normal

ID #: 3

Name: Horizontal Slider Divider

Mode: NFRC

Type: Horizontal Slider, ...

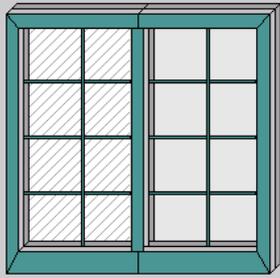
Width: 1200 mm

Height: 1200 mm

Area: 1.440 m2

Tilt: 90

Environmental Conditions: NFRC 100-2002



Total Window Results

U-factor: 2.5206 W/m2K

Click on a component to display characteristics below

ID #: 15 Name: Clear Double -- Integral Venetian Blind

Layers: 3 Tilt: 90° IG Height: 39 inches

Environmental Conditions: NFRC 100-2001 IG Width: 39 inches

Comment:

Overall thickness: 1.712 inches Mode: ?

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Ttr	E1	E2	Cond	A
Glass 1	34004	CLEAR_3.DAT		0.120	<input type="checkbox"/>	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	0.520	
Gap 1	1	Air		0.500	<input type="checkbox"/>											
Shade 2	6	Venetian Blind		0.472	<input type="checkbox"/>							0.000	0.900	0.900	0.578	0.0
Gap 2	1	Air		0.500	<input type="checkbox"/>											
Glass 3	34004	CLEAR_3.DAT		0.120	<input type="checkbox"/>	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	0.520	

Temperature Data | Optical Data | Angular Data | Color Properties

Tvis	Visible		Tsol	Solar			Abs1	Abs2	Abs3
	Rfvis	Rbvis		Rfsol	Rbsol	Abs3			
0.4446	0.4335	0.4335	0.3793	N/A	N/A	0.1241	0.0821	0.0416	

W6 - Shading Layer Library (C:\Program Files\LBNL\WINDOW6\w6.mdb)

File Edit Libraries Record Tools View Help

List

New

Copy

Delete

Save

Shading Layer Library

ID #: 2

Name: Venetian A45

Type: Venetian blind, horizontal

Material: 30101 Slat Metal A

Effective hole area fraction: 0.050

Matrix Calc

Venetian Blind

Slat width: 16.0 mm

Spacing: 12.0 mm

Tilt: 45 degrees

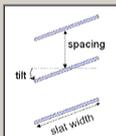
Blind thickness: 11.3 mm

Curvature: 0.000 mm

of segments: 5

Comment:

Protected



Ucenter: 1.771 W/m2

SC: 0.574

SHGC: 0.499

Vtc: 0.721

Glass Library (C:\Program Files\LBNL\WINDOWS\w51b-SimMan.mdb)

File Edit Libraries Record Tools View Help

Detailed View

Calc

New

Copy

Delete

Find ID

Advanced...

1035 records found.

Import

Export

Report

Print

NFRC only

ID	Name	ProductName	Manufacturer	Source	Mode	Color	Thickness mm	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Ttr
100	BRONZE_3.DAT	Float Glass	Generic	Optics 5 v11.4	#		3.124	0.646	0.062	0.063	0.680	0.065	0.066	0.000
101	BRONZE_6.DAT		Generic	Optics 5 v11.4	#		5.740	0.486	0.053	0.053	0.533	0.056	0.056	0.000
102	CLEAR_3.DAT		Generic	Optics 5 v11.4	#		3.048	0.834	0.075	0.075	0.899	0.083	0.083	0.000
103	CLEAR_6.DAT	Float Glass	Generic	Optics 5 v11.4	#		5.715	0.771	0.070	0.070	0.884	0.080	0.080	0.000
104	GRAY_3.DAT		Generic	Optics 5 v11.4	#		3.124	0.609	0.060	0.061	0.617	0.062	0.063	0.000
105	ONE.DAT		Generic	Optics 5 v11.4	#		6.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000
106	ZERO.DAT		Generic	Optics 5 v11.4	#		6.000	0.000	1.000	1.000	0.000	1.000	1.000	0.000
700	B120.AFG	Silver-Blue on Clear	AFG Industries	Optics 5 v11.4	#		5.639	0.140	0.399	0.204	0.205	0.323	0.217	0.000
701	B130.AFG	Silver-Blue on Clear	AFG Industries	Optics 5 v11.4	#		5.613	0.227	0.319	0.141	0.307	0.275	0.152	0.000
702	B140.AFG	Silver-Blue on Clear	AFG Industries	Optics 5 v11.4	#		5.639	0.319	0.248	0.092	0.410	0.219	0.097	0.000
703	B220.AFG	Silver-Blue on Green	AFG Industries	Optics 5 v11.4	#		5.791	0.091	0.401	0.102	0.178	0.326	0.162	0.000
704	B230.AFG	Silver-Blue on Green	AFG Industries	Optics 5 v11.4	#		5.842	0.140	0.320	0.087	0.260	0.277	0.129	0.000
705	B240.AFG	Silver-Blue on Green	AFG Industries	Optics 5 v11.4	#		5.766	0.199	0.249	0.060	0.355	0.225	0.079	0.000
706	B320.AFG	Silver-Blue on Gray	AFG Industries	Optics 5 v11.4	#		5.598	0.079	0.400	0.096	0.105	0.324	0.088	0.000
707	B330.AFG	Silver-Blue on Gray	AFG Industries	Optics 5 v11.4	#		5.598	0.130	0.317	0.074	0.160	0.273	0.072	0.000

For Help, press F1

Mode: NFRC | NUM



Ultimately Any “Product” will Need NFRC Data and Ratings....

	Best Window Wood Ultimate Double Hung Low-e / AIR	
ENERGY PERFORMANCE RATINGS		
U-Factor (U.S./I-P)	Solar Heat Gain Coefficient	
0.27	0.36	
ADDITIONAL PERFORMANCE RATINGS		
Visible Transmittance	Air Leakage (U.S./I-P)	
0.38	0.2	
<p>Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. www.nfrc.org</p>		

RESFEN Window Selection Tool: Annual Energy Calculator

Annual energy vs properties, location, orientation, orientation, shading, house type, etc

RESFEN - Example3-1.RSF

File Edit Library Calculate View Options Help

House Data

Location: MO Kansas City

House Type: 1-Story New Frame

Foundation Type: Basement

HVAC System Type: Gas Furnace / AC

Total Area Floor (ft2): 2000

Window (%): 13

Elec Cost: \$/kWh: 0.086

Gas Cost: \$/Therm: 0.40

Description: Example #3 -- Case 1

Window Data

	North	East	South	West	Skylight
Window Type	User spec				
Window (% Flr Area)	3.00	2.00	5.00	3.00	0.00
U-factor	0.90	0.90	0.90	0.90	1.31
SHGC	0.63	0.63	0.63	0.63	0.74
Cfm/ft2	0.56	0.56	0.56	0.56	0.00
Solar Gain Reduction	None	None	None	None	None

Results

Whole House | Window Annual Energy | Window Energy Cost | Window Peak Energy

	Energy Totals		Total Cost
Cooling	2648 (kWh)	Cooling (\$)	227.75
Heating	61.92 (MBtu)	Heating (\$)	247.68
		Total (\$)	475.43

Energy per ft2

Cooling	1.32 (kWh/ft2)
Heating	30.96 (kBtu/ft2)

The bar chart displays the energy costs for cooling and heating. The cooling cost is represented by a blue bar, and the heating cost is represented by a red bar. The total energy cost is shown as a combined bar.

RESIDENTIAL EFFICIENT WINDOWS COLLABORATIVE

www.efficientwindows.org



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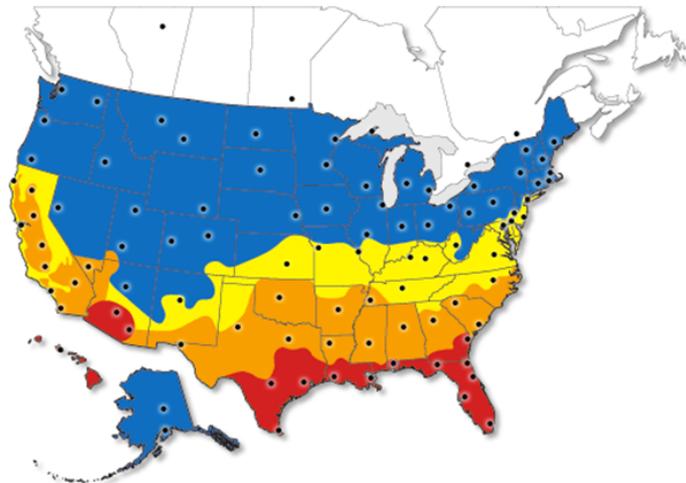
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WINDOW SELECTION TOOL			WINDOW TECHNOLOGIES			BENEFITS		

Window Selection Tool

Compare Annual Energy Cost

- Compare how various window or skylight types affect estimated energy cost for a typical house in your location;
- Find manufacturers who offer windows and skylights within the categories shown;
- Learn more about manufacturers' specific product options.

These comparisons assume average conditions. The effect of windows on your specific home's heating and cooling costs may vary depending on [glazing area](#), [shading](#), and [orientation](#), but also on thermostat setpoints, equipment efficiency, etc.



Other Factors to Consider

In addition to energy use, you may also want to consider the non-energy benefits of

Select a condition:

- New Construction
- Existing Construction

Select a type:

- Windows
- Skylights

Select a city:

MN Minneapolis

Compare Energy Costs

American Architectural Manufacturers Association (AAMA):
AAMA is the premier source for performance standards, product certification and educational programs. AAMA's over 250 members represent both the residential and commercial window, door and skylight industry. The AAMA online [Certified Products Directory](#) is a resource for locating products to achieve air, water, structural and forced entry resistance code compliance.



Window & Door Manufacturers Association (WDMA):
WDMA is a trade association



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WINDOW SELECTION TOOL			WINDOW TECHNOLOGIES			BENEFITS		

Minneapolis, Minnesota

Energy Costs
 Natural Gas: \$0.991/therm
 Electricity: \$0.097/kWh



[Minnesota Factsheet](#)
[State Code Information](#)

Window Search

Select Glass:

Select Frame:

ENERGY STAR®: Yes

Construction Type: New Existing

Product Type: Windows Skylights

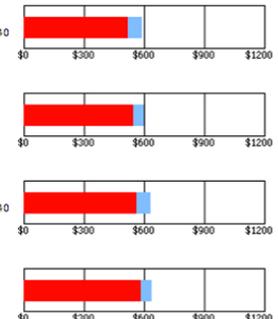
Window Types

	Window 28 Triple-glazed, Medium-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved
	Window 29 Triple-glazed, Low-Solar-Gain Low-E Glass, Argon/Krypton Gas Non-metal Frame, Thermally Improved
	Window 23 Triple-glazed, Medium-solar-gain Low-E Glass, Argon/Krypton Gas Non-metal Frame
	Window 24 Triple-glazed, Low-Solar-Gain Low-E Glass, Argon/Krypton Gas Non-metal Frame

Properties

U = ≤0.20 SHGC = 0.26-0.40 VT = 0.41-0.50
U = ≤0.20 SHGC = ≤0.25 VT = ≤0.40
U = 0.21-0.25 SHGC = 0.26-0.40 VT = 0.41-0.50
U = 0.21-0.25 SHGC = ≤0.25 VT = ≤0.40

Annual Energy Use



ENERGY STAR®
 Manufacturer Information
 Qualified

Products	yes

WEB-BASED QUANTITATIVE PRODUCT SELECTION TOOL

- Example of Window Selection Tool (efficientwindows.org)

Window Types

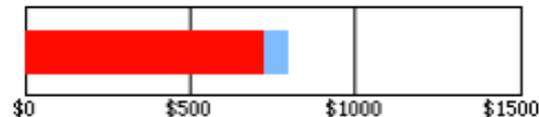


Window 27
Double-glazed, Low-solar-gain
Low-E Glass, Argon/Krypton Gas
Non-metal Frame, Thermally Improved

Properties

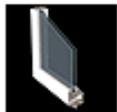
U = 0.26-0.30
 SHGC = ≤ 0.25
 VT = 0.41-0.50

Annual Energy Use



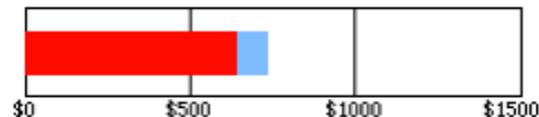
Window 22
Double-glazed, Low-solar-gain
Low-E Glass, Argon/Krypton Gas
Non-metal Frame

U = 0.31-0.40
 SHGC = ≤ 0.25
 VT = 0.41-0.50



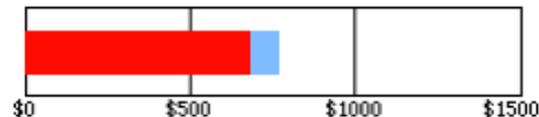
Window 29
Triple-glazed, Low-Solar-Gain
Low-E Glass, Argon/Krypton Gas
Non-metal Frame, Thermally Improved

U = ≤ 0.20
 SHGC = ≤ 0.25
 VT = ≤ 0.40



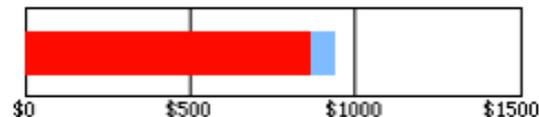
Window 24
Triple-glazed, Low-Solar-Gain
Low-E Glass, Argon/Krypton Gas
Non-metal Frame

U = 0.21-0.25
 SHGC = ≤ 0.25
 VT = ≤ 0.40



Window 14
Double-glazed, Low-solar-gain
Low-E Glass, Argon/Krypton Gas
Metal Frame with Thermal Break

U = 0.41-0.55
 SHGC = ≤ 0.25
 VT = 0.51-0.60



Summary: Trends and Needs....

- **Tremendous energy savings potential with single glazing retrofits**
- **Challenging markets-**
 - must balance technical performance vs cost, installation, aesthetics, view, Tv clarity, comfort, durability, house ownership, etc vs climate, orientation
 - Cost is a major limitation; product OEM cost \leftrightarrow Installed cost
- **Applications Targets:**
 - Glass focus, but consider sash +/- or frame
 - Interior or exterior “attachments”
 - Existing products and markets: int/ext retrofit panels; glue-on films
 - Sunbelt challenge: dynamic solar control
- **Technical challenges/opportunities**
 - **Heat Loss in cold climates** – minimize heat loss, but manage SHGC; optimal option might not be the lowest U
 - Increase of “only” R2-3 at low cost might be good starting option
 - New high R, transparent materials and coating options
 - **Solar Gain control in southern climates** – minimize solar gain
 - Static solutions exist
 - New Low Cost Dynamic control options?
 - All Climates: Higher cost options need higher performance to justify cost
 - Or- provide other important market value, e.g comfort, security

Benefits of with High Performance Windows

Improve
Occupant
Comfort,
Satisfaction and
Performance



Occupant

Add Value,
Reduce Operating
Costs



Building Owner

Reduce
Energy,
Greenhouse
Gas Emissions



Planet

Available Information Resources

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E-mail: SESelkowitz@lbl.gov

More Info:

<http://wem.lbl.gov>

<http://facades.lbl.gov>

Software Tools
<http://windows.lbl.gov/software/>

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