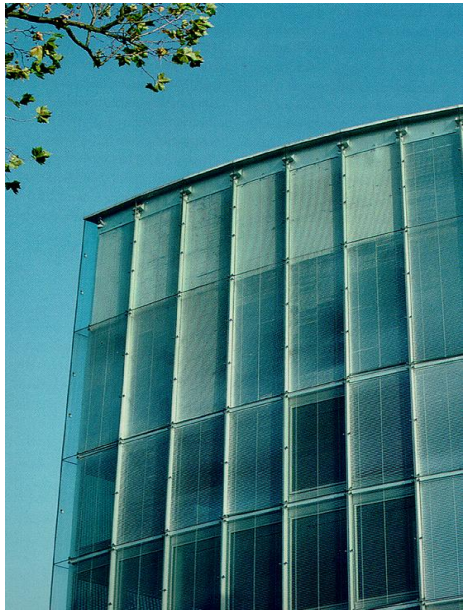
IEA Building Envelope Technologies and Policies Workshop,
Paris, 17/11/2011

High Performance Windows and Glazings
Technologies, Systems and Tools in the U.S.

Stephen Selkowitz
Windows and Daylighting Group
Building Technologies Department
Lawrence Berkeley National Laboratory



Business and Policy Context

- Severe downturn in Construction Markets
- Future energy costs unclear, policy on carbon??
- Continued Globalization of Markets
  - Investment, China, ….
- "Technologies" reaching inflection points
  - E.g. Double glazing → Triple: new factory investment
  - New technologies: "smart glass"
  - Shift from "Components" to focus on "Integrated Systems"
- Updates to Mandatory Codes and Standards
- Updates to Voluntary Programs: e.g LEED, EnergyStar
- New State, Federal Energy Savings Requirements
  - E.g. California: "all new buildings net-zero by 2030"
- New Performance Disclosure requirements like EPBD
  - City, State now; will likely spread; How is Envelope Assessed?

Windows Overview

- **Context** (1 Quad = 10^{15}Btu = 1.05x 10^{9} GJ; US Energy Use = ~100 Quads)
  - Windows are a 4-5 Quad/yr energy cost (~$50B/yr) -- 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
Cooling	1.02	0.52
Total	*2.67*	*1.48*

Daylight: +1 Q

- **Needs**
  - 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

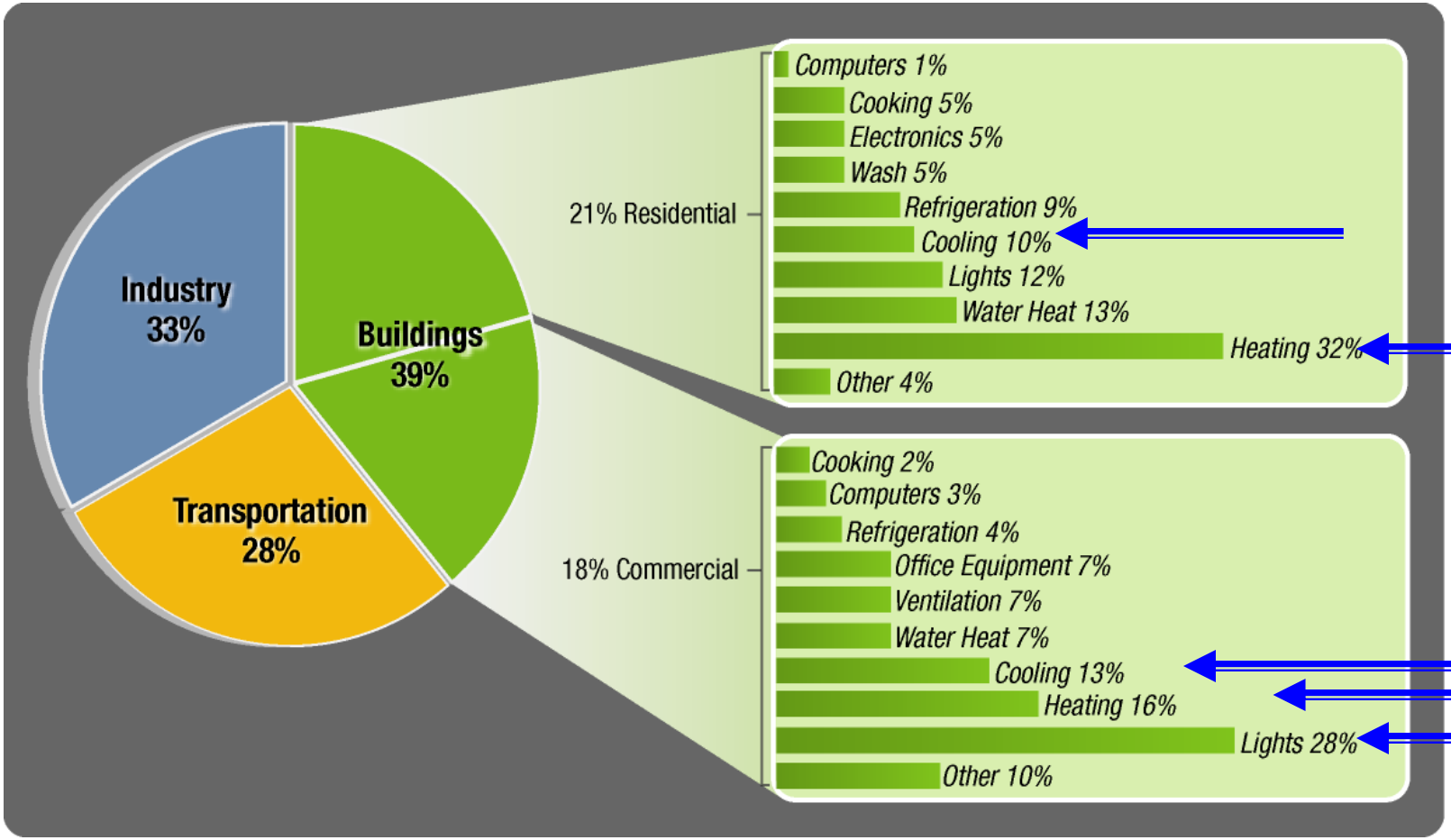
Fenestration Impacts on Building Energy Consumption

Buildings consume 40% of total U.S. energy

- *71% of electricity and 54% of natural gas*

Windows Do Not Directly Consume Energy

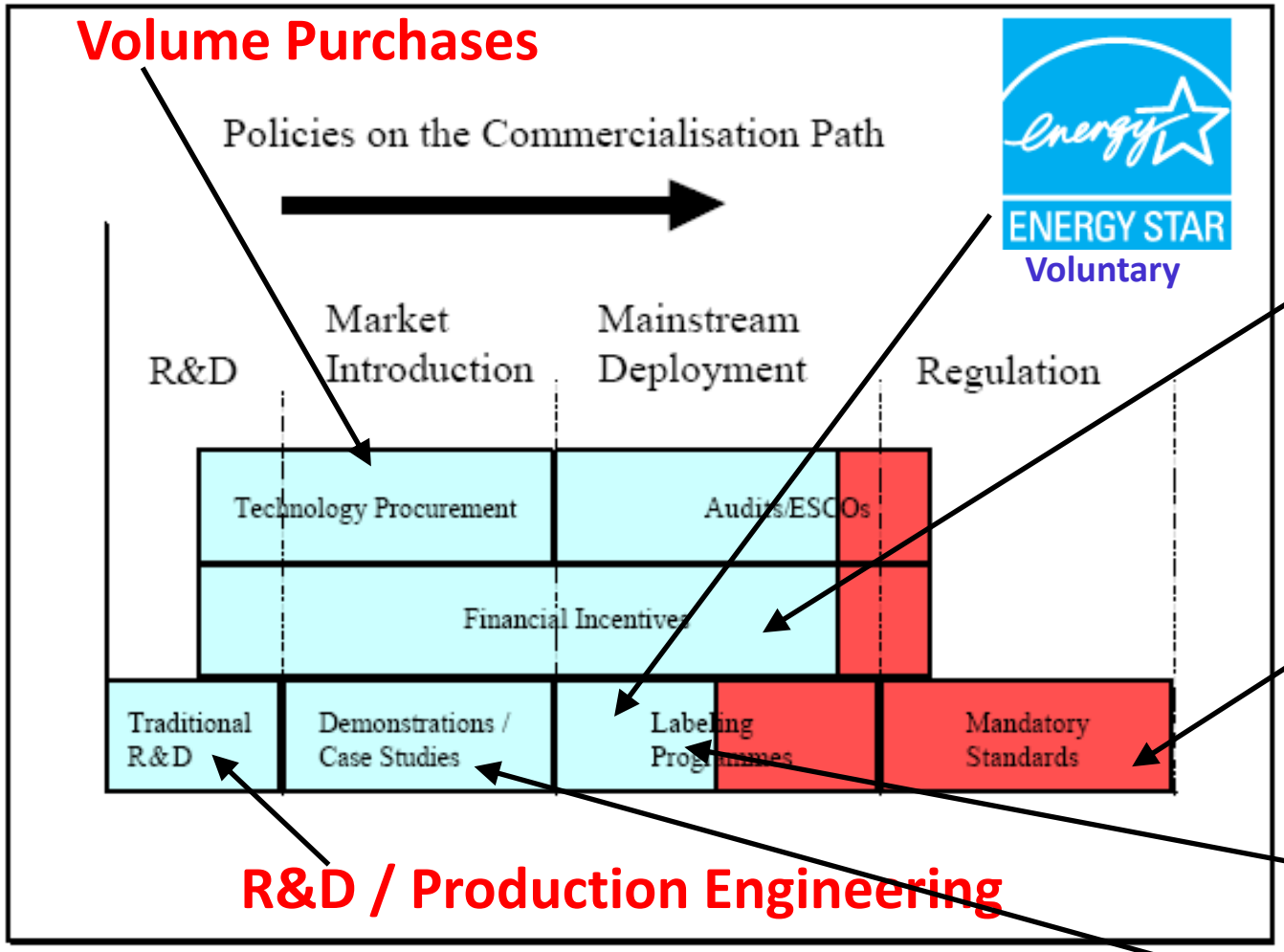
- ***Allocating Impact on End Use Energy is a** Challenge*



R&D Breadth Reflects Diverse Markets, Diverse Efficiency Opportunities

- **Markets: New ↔ retrofit**
- **Building Type: Residential ↔ Commercial**
- **R&D Scope: Short term ↔ Long Term**
  - Full spectrum: Research, Development, Demonstration
    - "Valley of Death" for Innovation and Technology Development
  - Supports Short-term Deployment programs
  - Fill the "innovation pipeline" for longer term success
- **R&D → Deployment**
  - Federal Deployment Programs – DOE, other agencies
  - State and Regional Programs
  - Utilities, NGOs, Private programs

Efficiency Policies for Windows



Tax Credits/ Utility Rebates

Building Codes

Nat'l Fenestration Rating Council

Building America; Commercial Bldg Partnerships

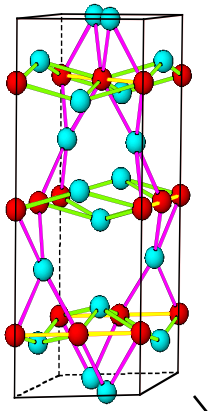
These Activities at Federal, State and Local Levels

Diverse Technical Program Areas needed to Capture Savings

- Reduce thermal losses
- Manage dynamic solar gain and glare
- Control and redirect daylight
- Air flow and Natural Ventilation

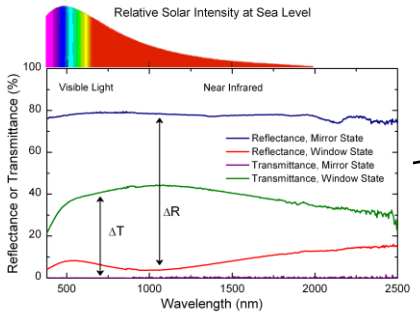
- Components → Integrated, automated façade systems
- Enabling technologies for performance simulation and measurement

Integrated R&D Strategy: e.g. Electrochromic Devices

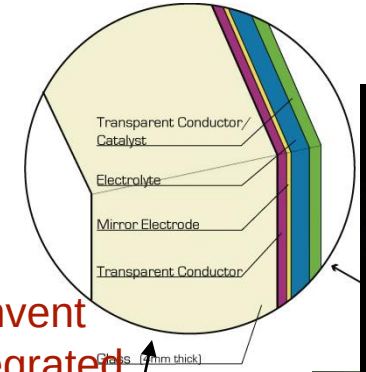


Mg_2Ni

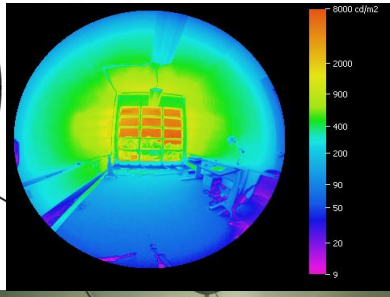
Invent New Materials



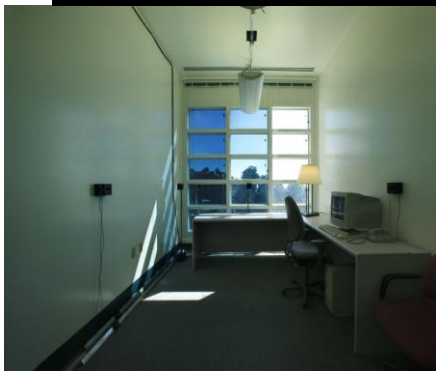
Characterize Coating Performance



Invent Integrated Window

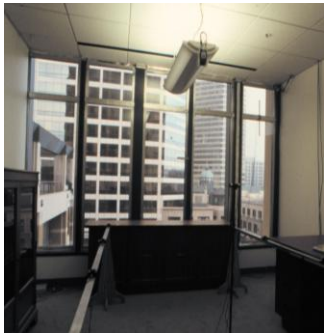


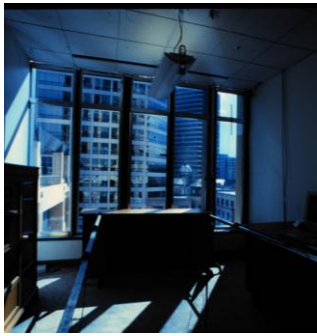
Assess Human Factors



Assess Savings

Invent Innovative Manufacturing Process





Invent/Test Integrated Systems

Program Vision: "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**
  - **Static control -> dynamic control**
- **All climates**
  - **Replace electric lighting with daylight**
- **Electricity supply options**
  - **Photovoltaics-building skin as power source**

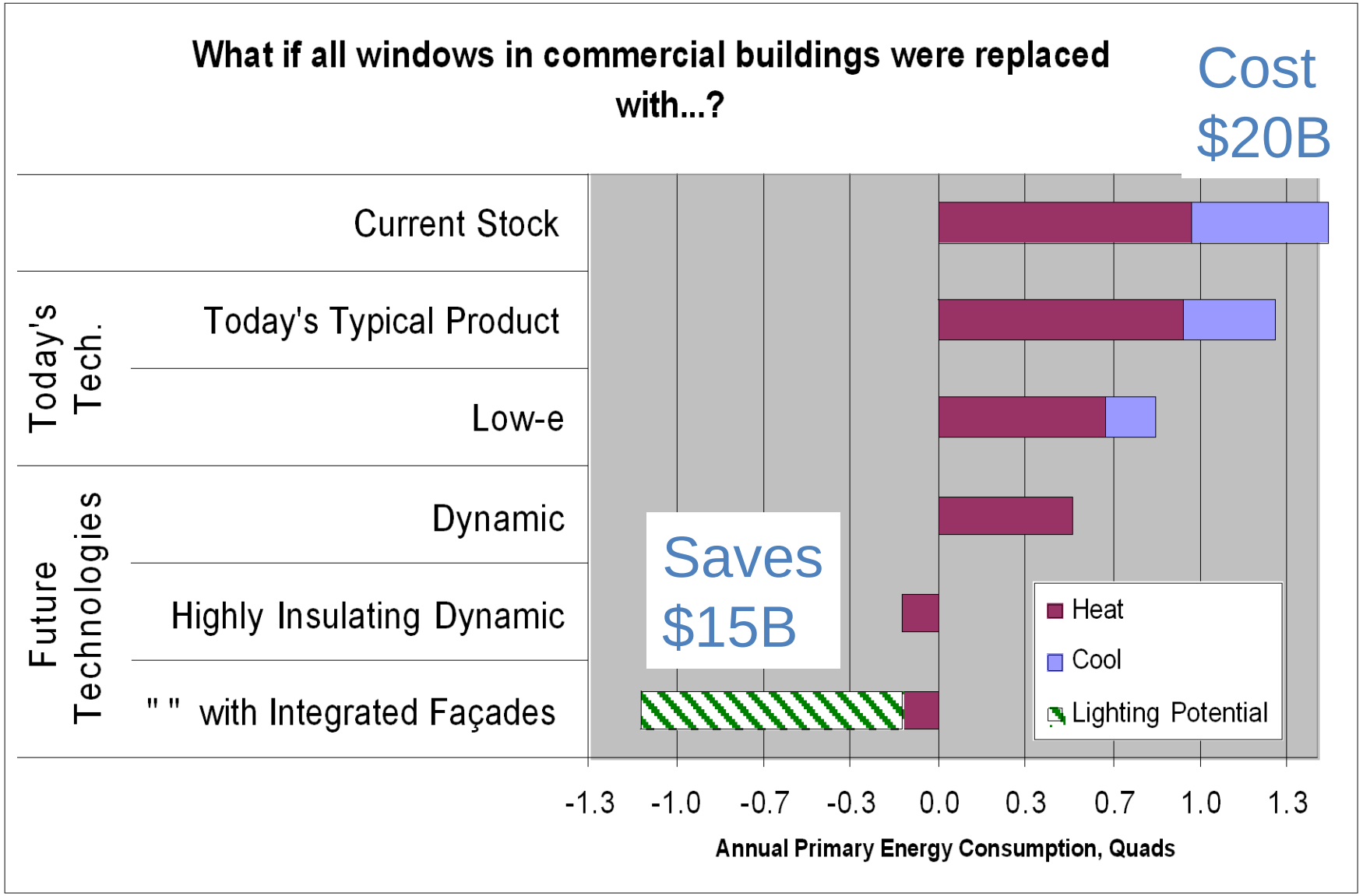
Advanced Window Energy Savings in Homes

Scenario	Energy Savings over Current Stock		
	Heat, quads	Cool, quads	Total, quads
Sales (Business as usual)	0.49	0.37	0.86
Energy Star (Low-e)	0.69	0.43	1.12
Dynamic Low-e	0.74	0.75	1.49
Triple Pane Low-e	1.20	0.44	1.64
Mixed Triple, Dynamic	1.22	0.55	1.77
High-R Superwindow	1.41	0.44	1.85
High-R Dynamic	1.50	0.75	2.25

Windows account for 1.65Q heating; 1.02Q Cooling = 2.67Q

Conclusion: ideal windows save 80% of total current window energy use

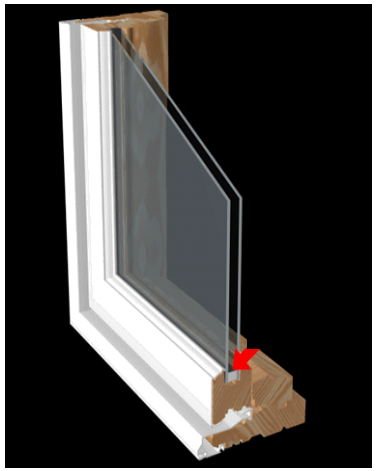
Commercial Building Window Potentials



Successes in U.S. Window Markets

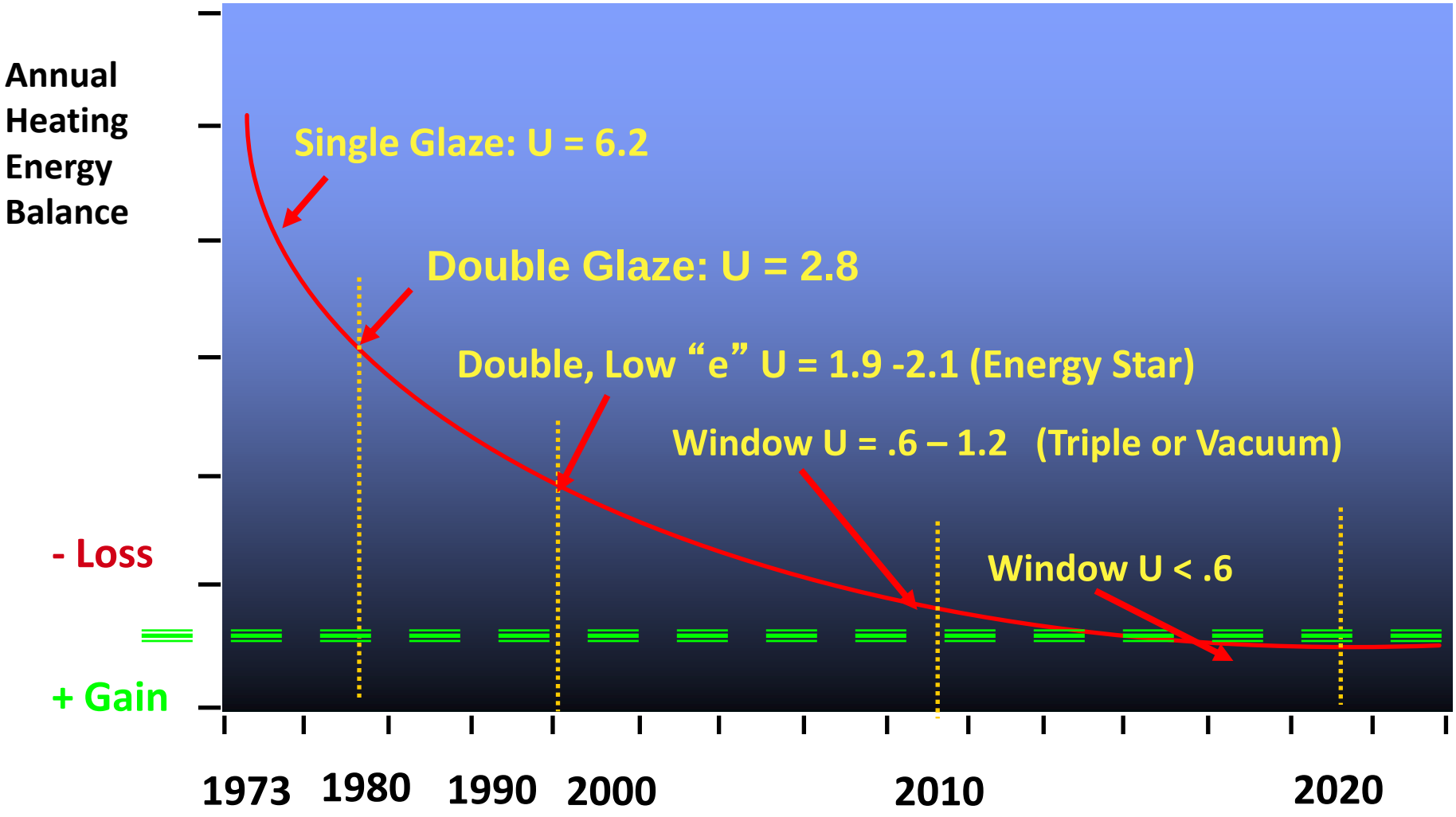
(Example: Improved Insulating Properties in Residential market)

- **1973: Typical Window:**
  - clear, single glazed,
  - double or storm window in north,
  - $U_{average}$ = 4.8 W/m²-K
- **2003: Typical Window:**
  - 95% double glazed
  - 50% have a low-E coating
  - 30-65% energy savings vs. 1973
  - $U_{average}$ = 2.5 W/m²-K
- **2030: Future Window:**
  - Zero net energy use (typical)
    - Net winter gain; 80% cooling savings
  - $U_{average}$ = .6 W/m²-K
  - Dynamic solar control



Insulating Windows Can Become Energy Producers

In cold climates, solar gain can exceed losses through highly insulating windows



Annual Heating Cost simulated for a heating climate

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

Double Glazed, **$1218**

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

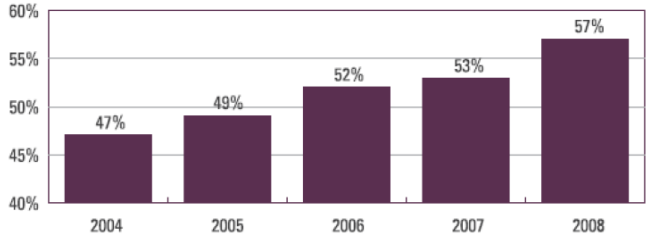
House with no windows, **$1000**

"SuperWindow", **$960**

Energy Star Program Enhancements

- Energy Star has helped push better technology to mainstream markets
- Complex program because of regional dependence
- Codes and Standards have surpassed EnergyStar- needs to be tightened
  - Market share is saturating in some markets- 2010 Tax Credits helped
  - Incremental or disruptive changes re: product lineups
  - "Most Efficient" alternative?– top 5%
- New Options?: Promote Window Coverings/Solar Shading Attachments
- Dynamic/Operable systems
  - How to credit operator impacts

Figure 1. ENERGY STAR Market Share, 2004–2008

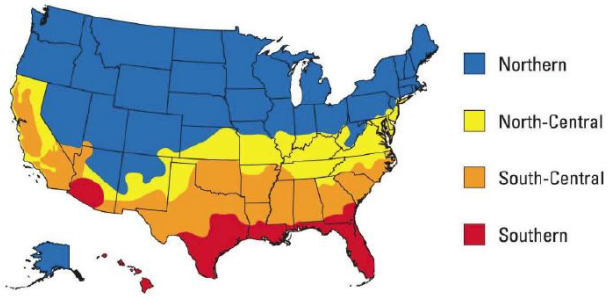


Source: ENERGY STAR 2009 http://www.energystar.gov/ia/partners/manuf_res/downloads/PartnerResourceGuide_LowRes.pdf

Table 1. Summary Results (simple average)

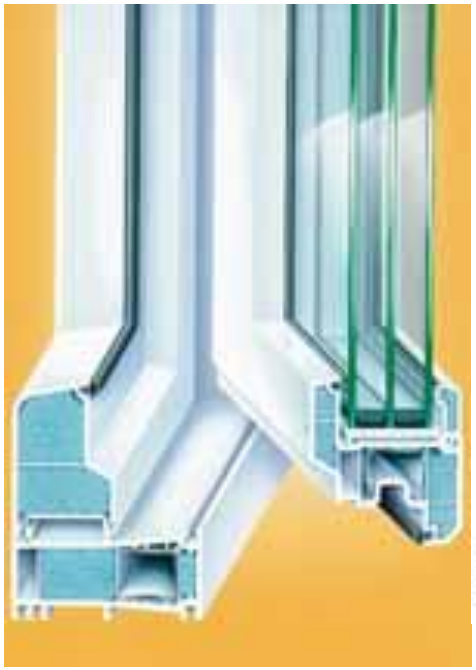
ENERGY STAR Windows Region	Metro Area	2010 % ENERGY STAR	2011 % ENERGY STAR
North (East)	Milwaukee/Madison, WI	98%	99%
North (West)	Portland, OR	89%	81%
North-Central (East)	Washington DC	95%	91%
North-Central (West)	San Francisco, CA	85%	76%
South-Central (East)	Atlanta, GA	96%	93%
South-Central (West)	Tulsa, OK	93%	91%
South (East)	Jacksonville, FL	87%	80%
South (West)	Houston, TX	99%	98%
Average		**93%**	**89%**

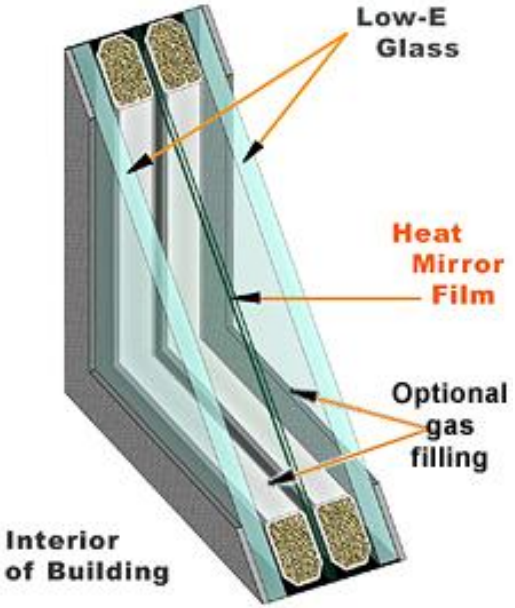
Figure 2. ENERGY STAR Windows Regions

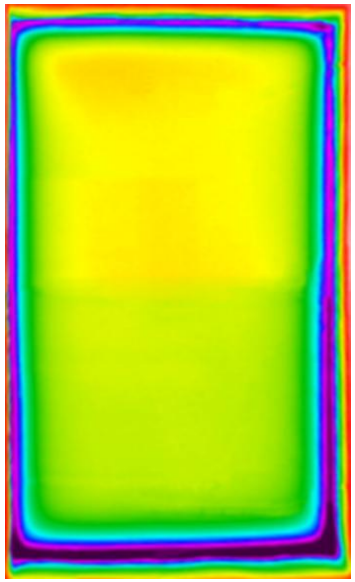


Transforming Markets Toward Highly Insulating Windows

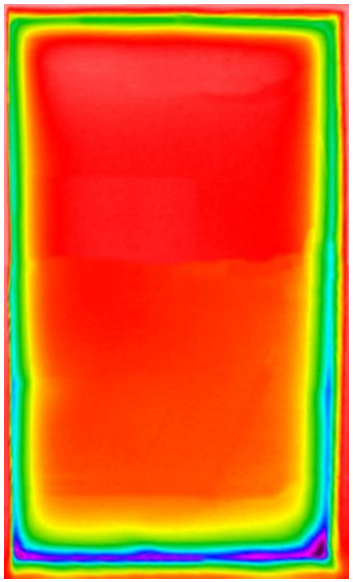
- Three panes or two panes and suspended film
- Substantially outperform ENERGY STAR criteria
- Present market share only around 2-3%



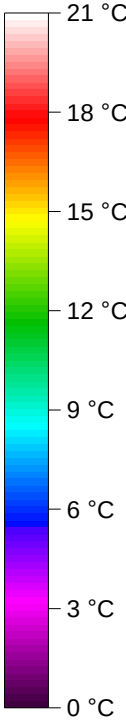




Double Glazed Low-e



Triple Glazed Low-e, Krypton



Building America demonstrations/ production housing

High-performance specs in LEED for Homes & NGBS

Production Engineering RFP – 50% Cost Share

Technology Procurement/Volume Purchases –
Multifamily/Public Housing/Condo, Builders, etc

Develop advanced utility program specs

Utility programs for advanced windows

ENERGY STAR spec revision

New ENERGY STAR / Phase II

A highly-insulating building envelope not only saves substantial energy… but can allow for up-front savings in HVAC system costs.

- High-performance windows are a critical link in the Building Envelope

Windows Area: 30 m^2
Incremental Cost for R .9 Windows: *$50/$m^2$
Total Cost: $1500

Cost: $1500
Savings: $1000
Total: $500
6-12 yr simple payback

*Consumer price premiums are $20-$40 per sq m, but wholesale base cost to builders may he lower

Reduced Duct Savings: $450

Reduced HVAC Savings: $550

200 m^2 Home

Integrated R&D Program

Advanced Facades and Daylighting:

Program Goals:

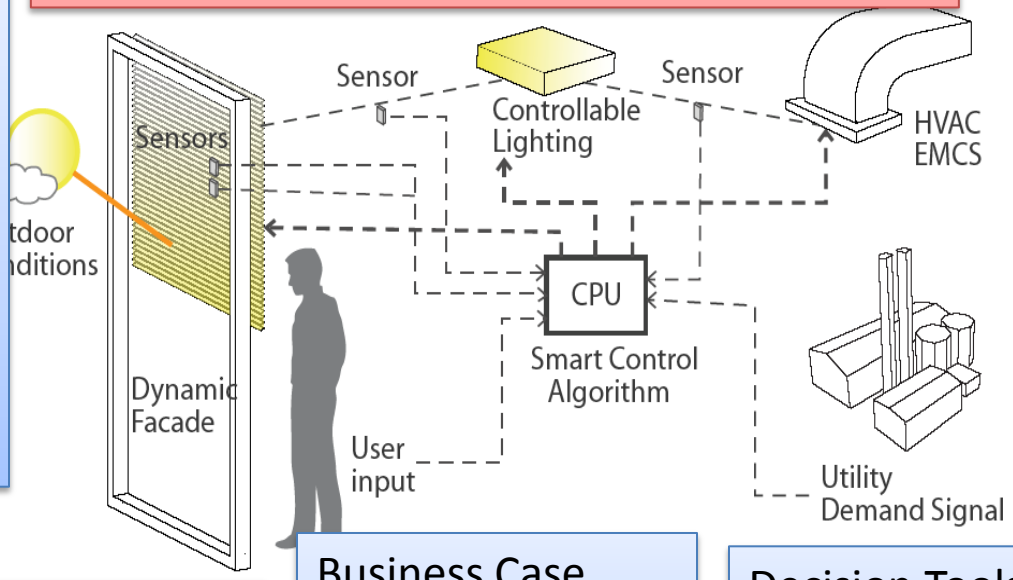
Net Zero Energy Balance for New and Retrofit
Enhanced View and Thermal Comfort
Reliable, cost effective operations
Tools to design, optimize, specify, control
Adoption/diffusion throughout industry

Application:

All climates
All Building types
New-Replacement-Retrofit

Advanced Technologies:

Sensors;
Controls;
Hi R windows,
Cool coatings;
Switchable coatings;
Automated Shading;
Daylight-redirecting
Operable windows,



Program Activities:

Simulation
Optimization
Lab test
Field Test
Demonstrations
Standards

Human Factors:

Thermal comfort
Visual comfort
Satisfaction
Performance

Business Case

Manufacturing
Installation
Commissioning
Reliability
Cost

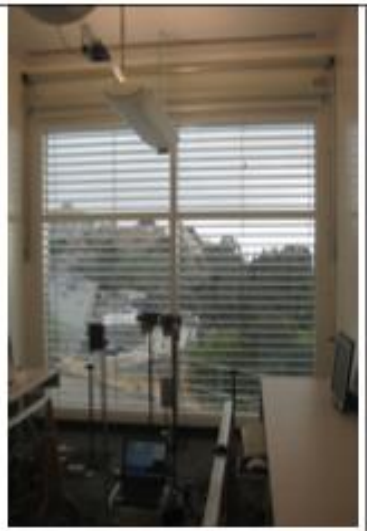
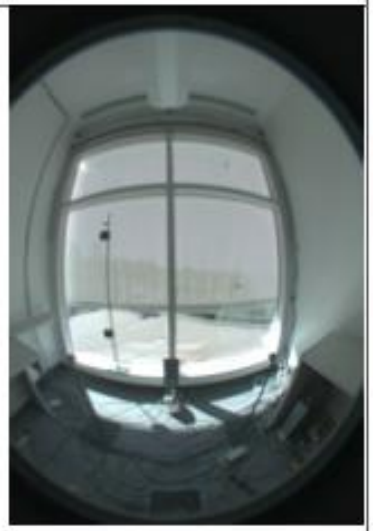
Decision Tools

Books, Guides
Websites
Simulation Tools
Testbeds

Partners

Manufacturers
Owners
Architects
Engineers
Specifiers
Code officials
Contractors
Utilities

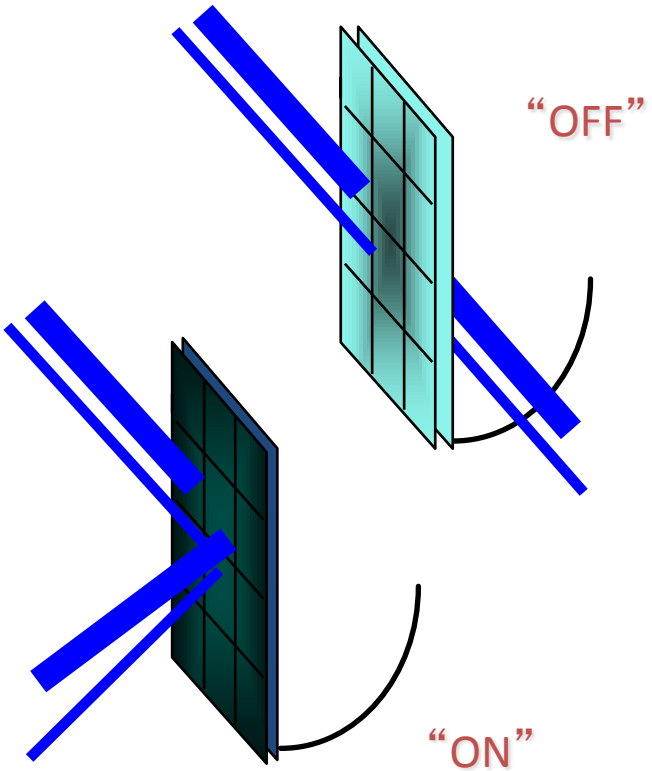
Comparative Shading System Performance

			
VB-E1n (exterior)	VB-E1n (interior)	VB-E3opt (exterior)	VB-E3opt (interior)
			
VB-E2n (exterior)	VB-E2n (interior)	RS-E-autol1 (exterior)	RS-E-autol1 (interior)

Smart Coatings for Windows

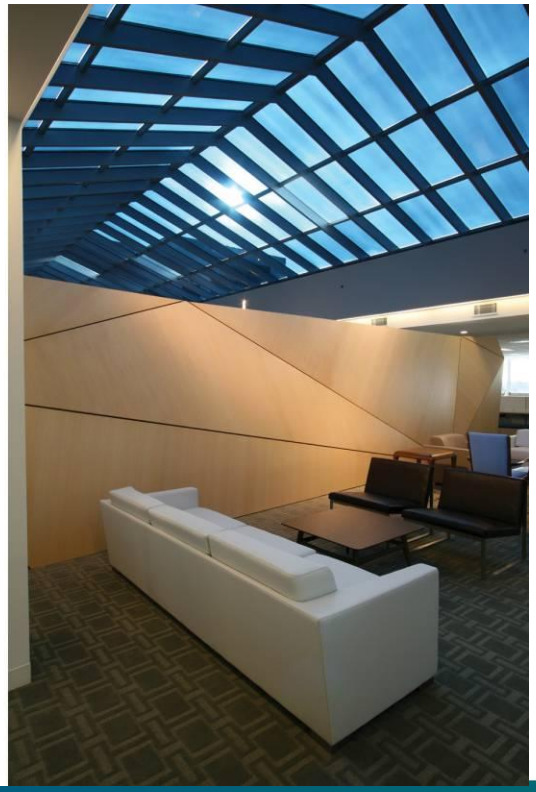
Need Dynamic Control of Window Properties To Balance Cooling, Daylighting, Glare

- Flexible, optimized control of solar gain and daylight
- **Passive control**
  - **Photochromic - light sensitive**
  - **Thermochromic - heat sensitive**
- **Active control**
  - **Liquid Crystal**
  - **Suspended particle display (SPD)**
  - Electrochromic
- Active control preferred; but requires wiring windows for power and control



Progress with Electrochromic Windows

Early manufactured products in buildings now; New production facilities on-line in 2012 with larger, better quality at lower cost.

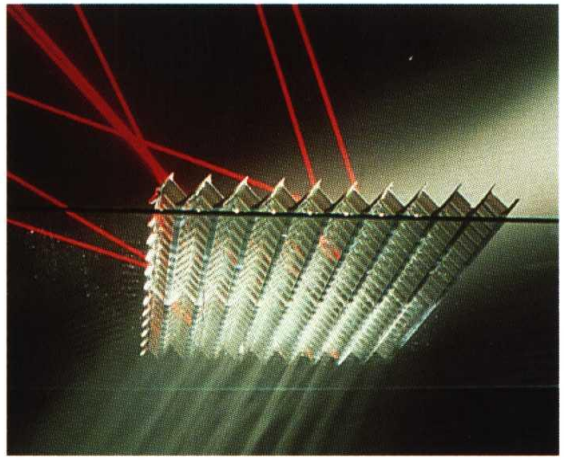


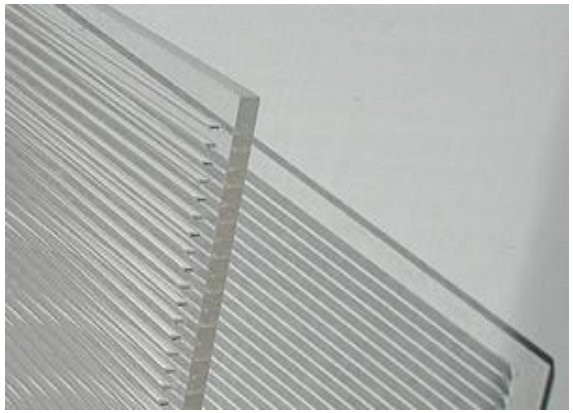
New Technology for Daylighting

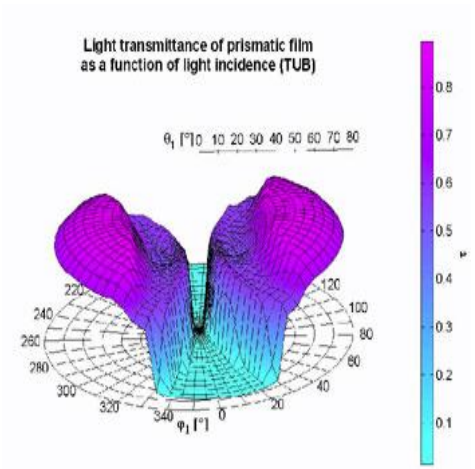
- Two Strategies for Increased Energy Savings
  - Better glare control
  - Deeper daylight penetration

- Conventional Options for Directional Control
  - **glass block**
  - **fritted glass**
  - **diffusers**
  - **shading systems**
- New Options
  - **Special blinds**
  - **Prismatic glazings**
  - **Holographic materials**
  - **Laser cut panels**
  - **Light pipes**
  - **Fiber optics**
  - **Nanotech- dynamic coatings**

- Challenges
  - Fabrication at affordable cost
  - Durability, lifetime
  - Characterize them - how do they perform?







2010+: New Program Directions

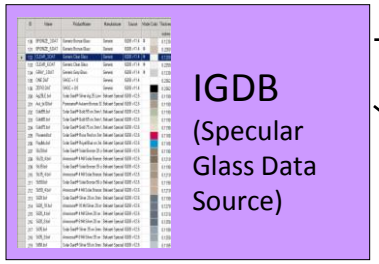
- **Expansion from residential to commercial research**
  - New R&D focus on daylighting since Lighting is major commercial load.
    Daylighting issues:
    - Lighting/cooling load tradeoffs
    - Manage intensity, control glare
    - Understand occupant behavior
    - Sensors, controls, systems integration
  - NFRC program for rating commercial products
  - New tools, websites for Commercial e.g. COMFEN
- **Expansion from "New" markets to "Retrofit"**
  - Different companies and new market pathways
  - New systems: **Windows → Attachments**
  - "Attachments" = blinds, shades, shutters, storm windows,….
  - "How do they perform?"
  - **International Collaboration**: ESSO- European Solar Shading Organization

Major New Program Directions

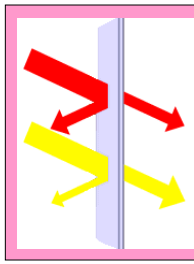
- **New Investment in Technology R&D**
  - "High R" windows; Electrochromic glass and Automated Shading
  - New activity, interest, opportunity in Daylight control
- **More Aggressive Partner Engagement in Deployment**
  - Tighter building codes and standards, tax incentives,…
  - New Update for EnergyStar (may require triples in 2013)= Technology drivers
  - Utility programs as partners, voluntary programs as market drivers
  - New Market Pull from LEED and Green/Sustainable Design
- **New, Enhanced "Tools" for decision making**
  - Product Design: WINDOW, THERM, Optics, etc
  - Façade Design: COMFEN
  - Daylighting: Radiance
  - Whole Building Design: EnergyPlus with new GUI

Glazing and Façade Decision Support Tools

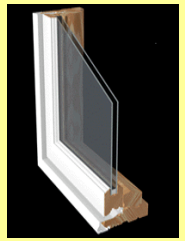
Download http://windows.lbl.gov/software/ FY10 ~ 37,000 Downloads



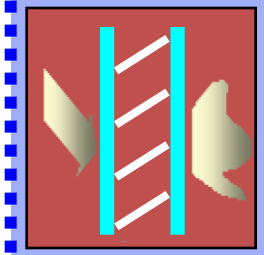
IGDB
(Specular Glass Data Source)



Optics
(Window Glass)



THERM
(Window Frame)



CGDB
(Complex Glazing Data Base)

WINDOW
(Whole Window)

NFRC Ratings and Labels

Radiance
Lighting /Daylighting

COMFEN
(Whole Building Commercial)

RESFEN
(Whole Building Residential)

Commercial Windows Website

Efficient Windows Website

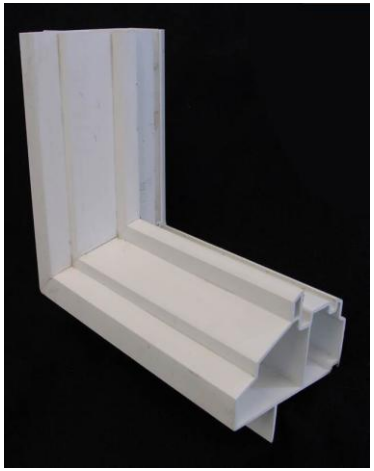
Design /Simulation Tools

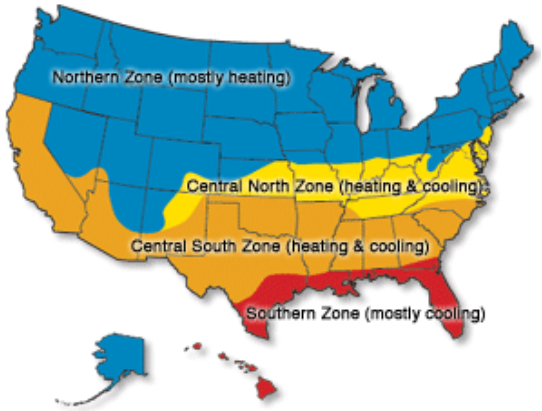
Tools Support R&D and Deployment

How are Tools Used?

- Design of new products
- Guidelines for Product Selection
- Energy Star Compliance and Analysis
- NFRC Ratings

R&D: New Product Design





Energy Star Map

Efficient Windows Collaborative

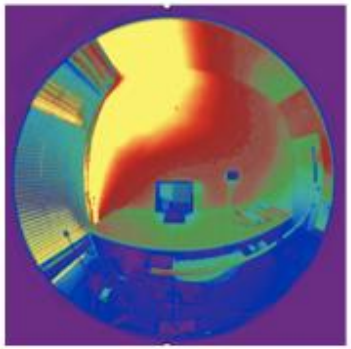
Product Selection Guidelines

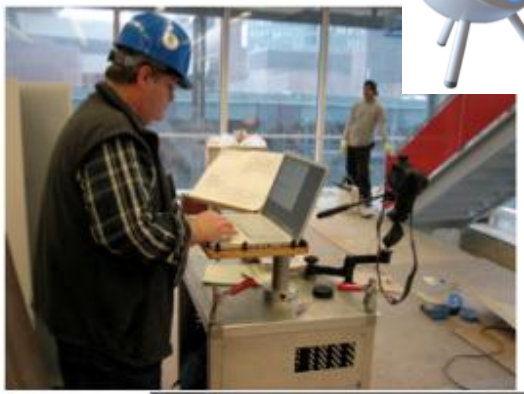
NFRC Label

Glazing/Shading/Daylighting Measurement and Validation

Environmental Energy Technologies Division

BERKELEY LAB



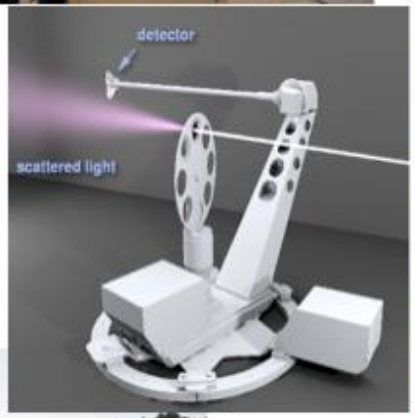


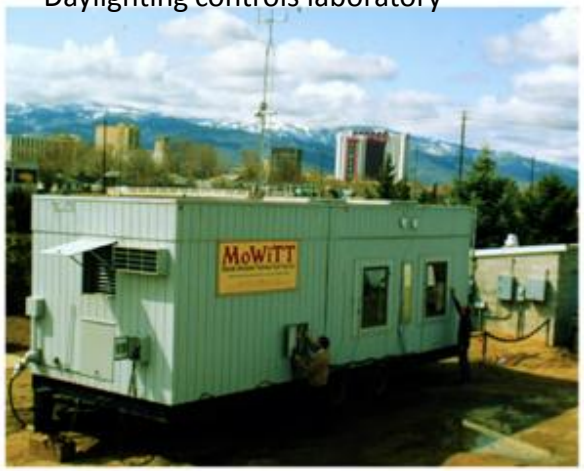
Façade/daylighting test facility
Integrated Systems testbeds
Mobile Thermal Test Facility
IR Thermography chamber

Large integrating sphere
Optics laboratory

- **Scanning Goniophotometer**
- HDR Imaging
- Field Data Collection systems
- Commissioning systems

- Virtual Building Controls Testbed
- Daylighting controls laboratory





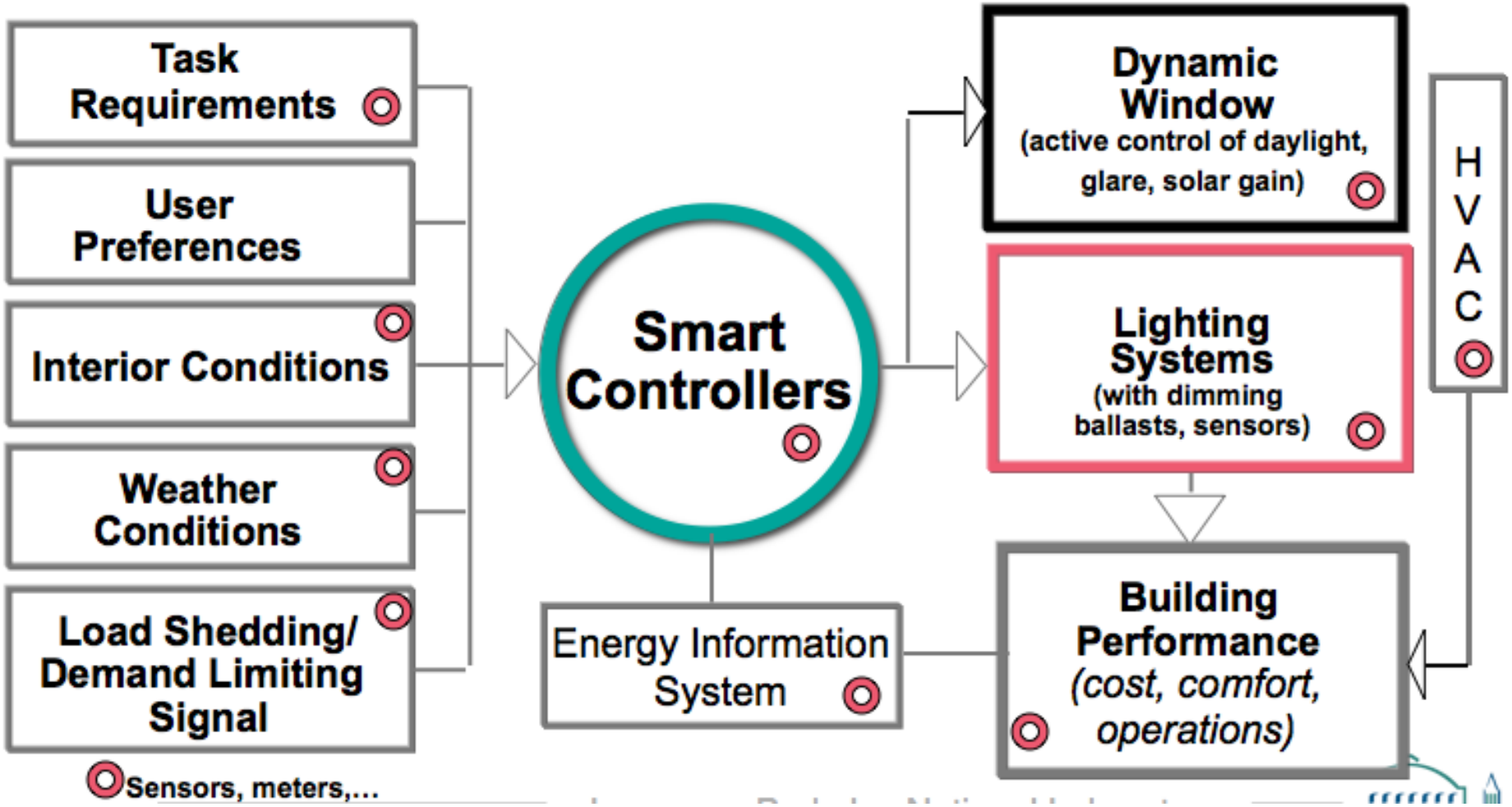
Next Steps? Collaboration?

- **Enhanced deployment of Proven technology**
  - Mandatory and voluntary programs
  - Ratings and Labels: Properties → Performance
  - Financing, Education, Training,…..
- **Collaboration and Harmonization in a Global Era**
  - Standards- ongoing issues- ASTM, ISO, CEN, ASHRAE, Green buildings
  - Collaborative R&D: IEA BCS/ SH&C Annexes, Tasks
- **Collaborative R&D for Pre-competitive Topics? IP Challenges?**
- **Sharing Best Practice**
  - Technology --- > Systems, Building Practice
  - Design→ Construction → Operations
  - Measured Data
- **Example: Solar Shading collaboration**
- **Examples: Windows and Integrated Building Systems**
  - **Extracting best performance**
  - **Measuring impacts → System Tradeoffs, e.g. better windows → smaller HVAC**

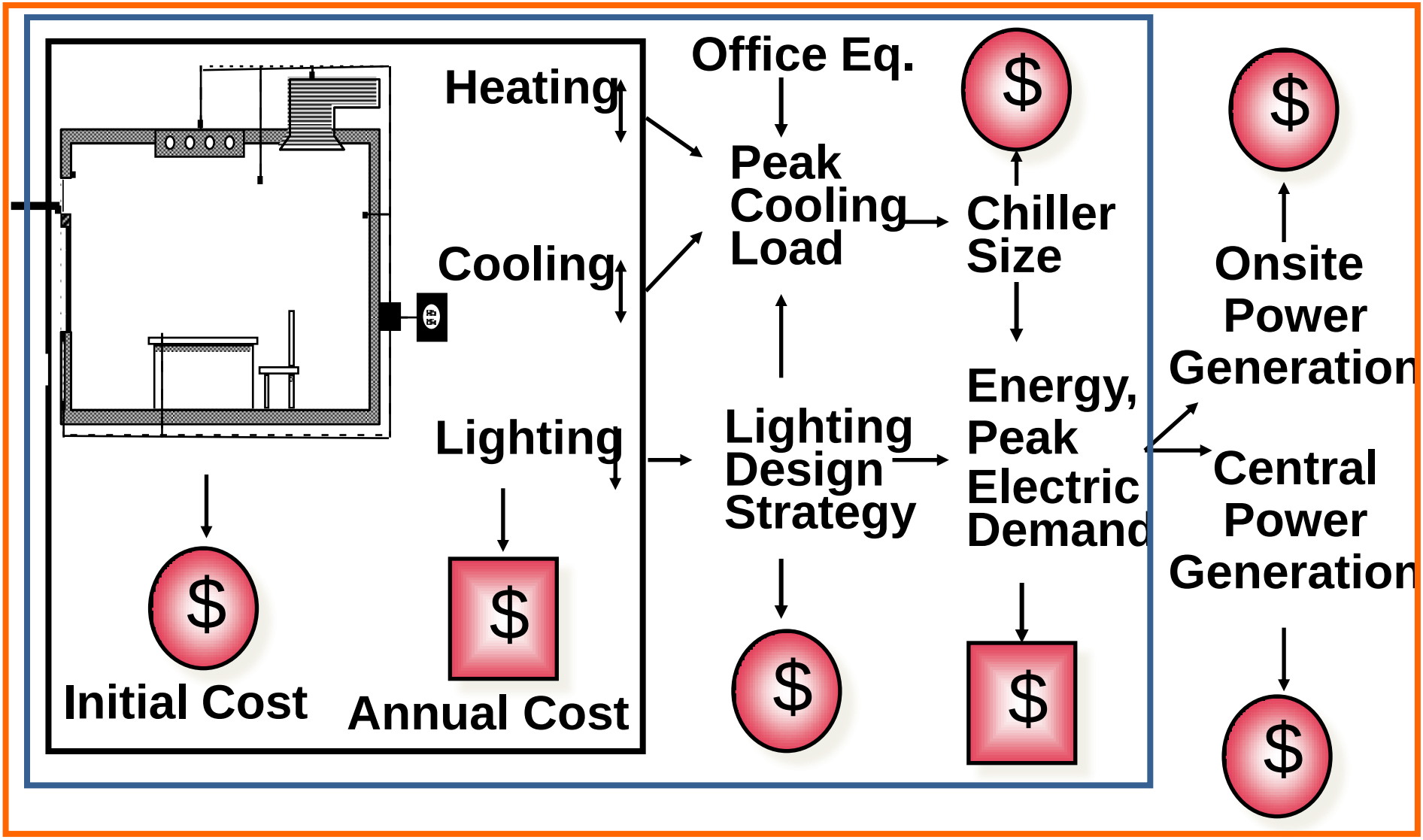
U.S.: New Window Retrofit Initiative

- **Context**
  - New Construction: Slow stock turnover; worse with recession
    - Renovation/Additions adds "new" windows
  - Window Retrofit/Replacement rarely done for "payback"
  - Large, thriving, fragmented industry – **"window attachments"**
    - Focus is privacy, fashion, comfort…….. sometimes Energy
  - **Global interest- Europe is driver, established markets**
    - External Shading is Common practice without AC
    - Collaboration with European Solar Shading Organization
    - Potenial IEA Annex?
  - Lack of "accurate" tools to characterize products and performance
    - Utilities cannot launch incentive programs if they can't estimate savings
- **Opportunity**
  - **Harness latent industry interest to focus on energy efficiency**
  - **Dual program: "Applications Now"/"Innovation tomorrow"**
- **Needs/Scope**
  - **"Applications Now"**
    - Tools, guides to characterize products; select best/better solutions (smart phone)
    - Channel, marketing program
  - **"Innovation Tomorrow"**
    - New materials
    - Automated control/integration

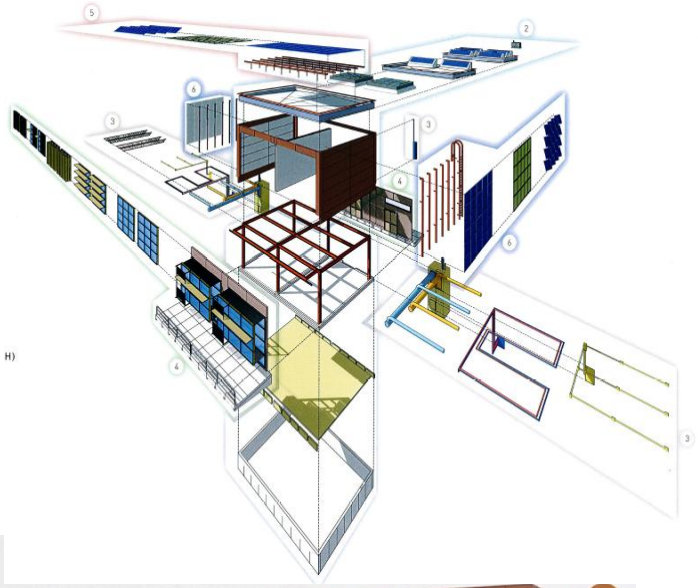
Maximum performance requires full integration with building systems



System Integration: Investment Tradeoffs



Commercial Building Integrated Systems testbeds: Envelope, Lighting, Plug Load, HVAC interactions (w/ and w/o occupants)



Construction: 2012
Operations: 2013

5 New Façade Testbed Facilities

- Multiple comparative experiments
- Interface with public and private test sites
- Link and share experimental data sources
- Objective, "third party" data

- **What works? How well? Why? Why Not?**
- **Integrated building systems performance**
- **Occupant behavior and energy impacts**
- **Validation of design tools**