

History and Future of Fenestration

Where Have We Been? Where are We Heading?

Stephen Selkowitz

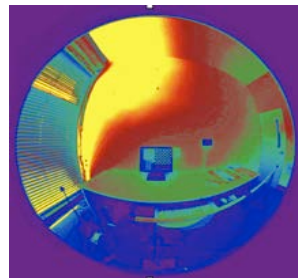
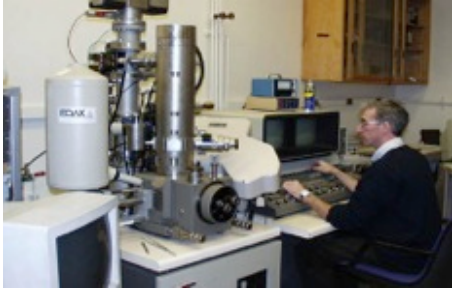
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*....If you don't know where you are going,
any path will get you there....*

.....It helps if you know where you've been...

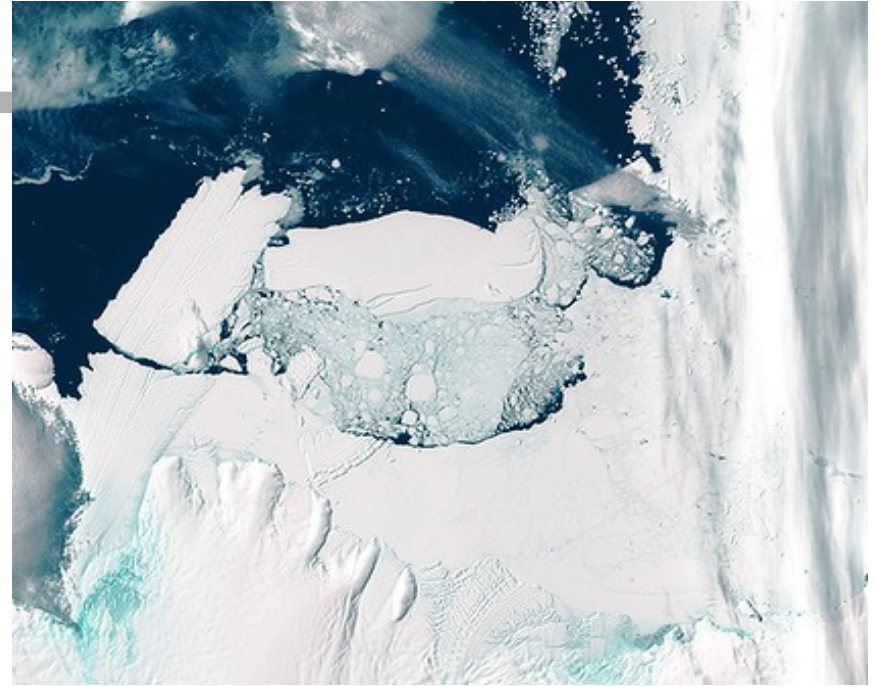
Insanity *is defined as taking the same action over
and over again, and expecting a different outcome.*

Trouble Ahead?



Greenland Glaciers

+



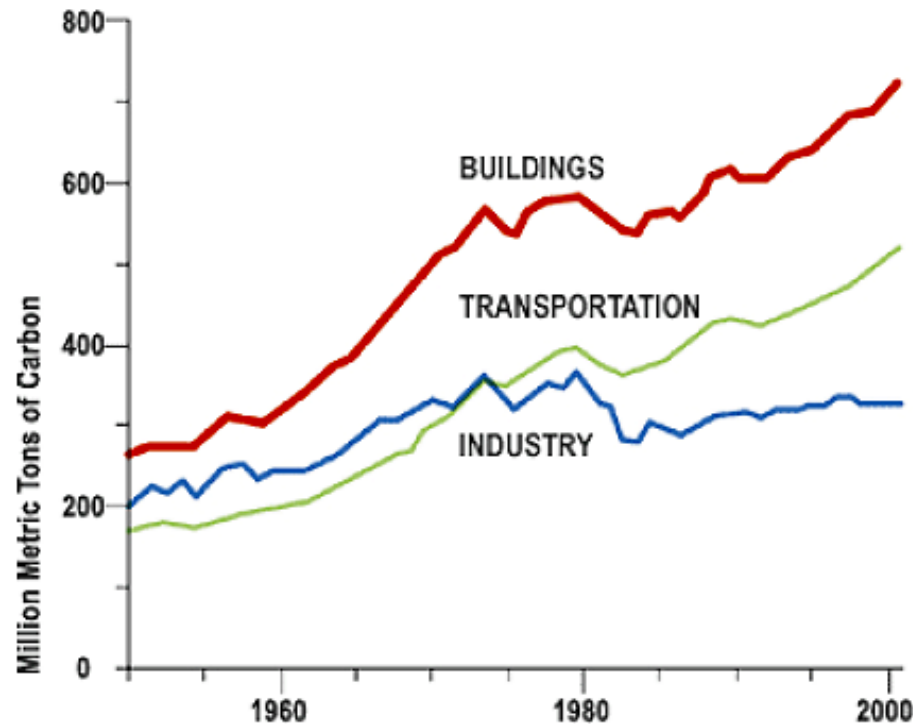
Antarctic Ice Shelf

Energy Use →
Carbon Emissions →
Climate Change →
Sea level rise →
????

Why Focus on Buildings - Fenestration??

Total Building Energy Use; End Use Consumption

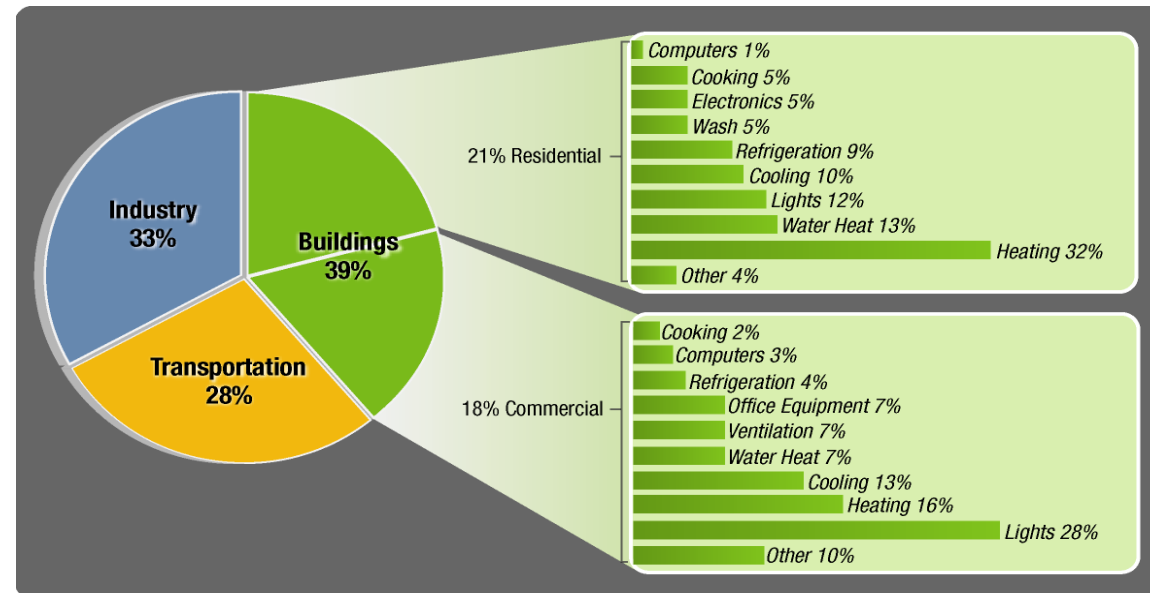
Building sector annual \$\$
Energy Use ~ \$500B
Construction ~ \$1T



Buildings consume 40% of total U.S. energy

- 71% of electricity
- 54% of natural gas

No Single End Use Dominates
Fenestration impacts ~ \$50B



50-80% Reduction in Carbon? Solution is Simple in Concept

- 1. Optimize “Lifestyle” to Minimize Energy Services and Needs**
 - Buildings...
 - Make cities walkable, food,...
- 2. Maximize Efficient Use of Energy**
 - e.g. LED light bulbs,.....
- 3. Decarbonize energy sources**
 - Solar energy, wind, biofuels.....

But more difficult to plan, execute and scale

Addressing the Building “Grand Challenge”

- Focus on **Life Cycle of the Building**
 - Design → Construction → Operations → Renovation → Decommissioning
- Focus on **Measurable, Documented Energy Impacts**
 - Make performance visible, understandable, actionable
- Focus on **Integrated Smart Building Systems**
 - Materials → Devices → Integrated Systems → Buildings
- Focus on **Buildings and the Grid**
 - Renewables, Storage, Microgrids, Neighborhoods, “Smart Grid”
- Focus on **People and Behavior**
 - Policy makers, Designers, Investors, Contractors, Occupants,...
 - Occupant behavior, life style, satisfaction, comfort,....
- Focus on **“Intersection” of Technology and Policy**
 - Incremental + Innovative, Disruptive technologies
 - Investment and Decision making

Whose Experience? Expertise?

“The first American house built in war-time Java completely bewildered natives there. Instead of building walls of local bamboo, which is closely spaced to keep out rain but admit light and air, the white men put up solid walls to keep out light and air, and then cut windows in the walls to let in the light and air. Next he put glass panes in the windows to admit light but keep out the air. Then, he covered the panes with blinds and curtains to keep out the light, too.”

Ken Kerr, 1978

LBNL Beam Daylighting Experiments ~1977



ional Laboratory

Energy Efficient Building in 2050 ??

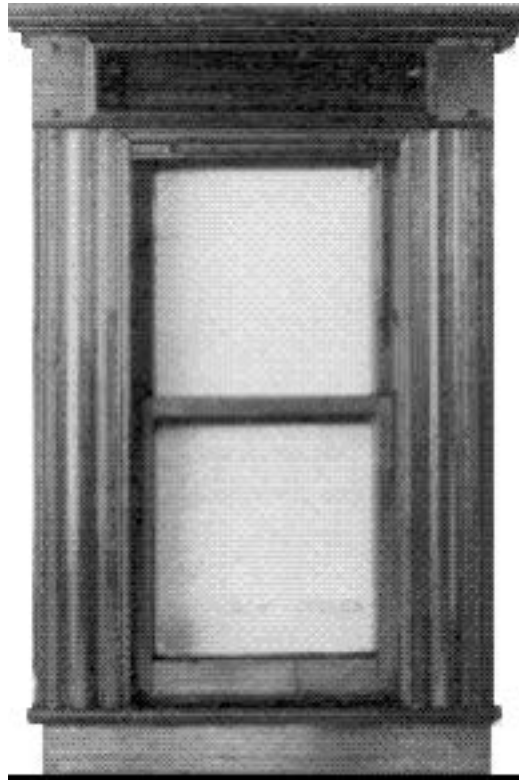




Window/Glazing Performance Needs

| Energy

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



- Daylight
- Aesthetics
- Weatherproof
- Cleaning
- Maintenance



Windows:

~ 10-12 % of Buildings

~ 4-5% of Total Energy

~ \$50 billion/yr

Need a New Vision for Window Performance:

Energy Losers --> Neutral --> Net Energy Suppliers

= “Net Zero Energy” Fenestration

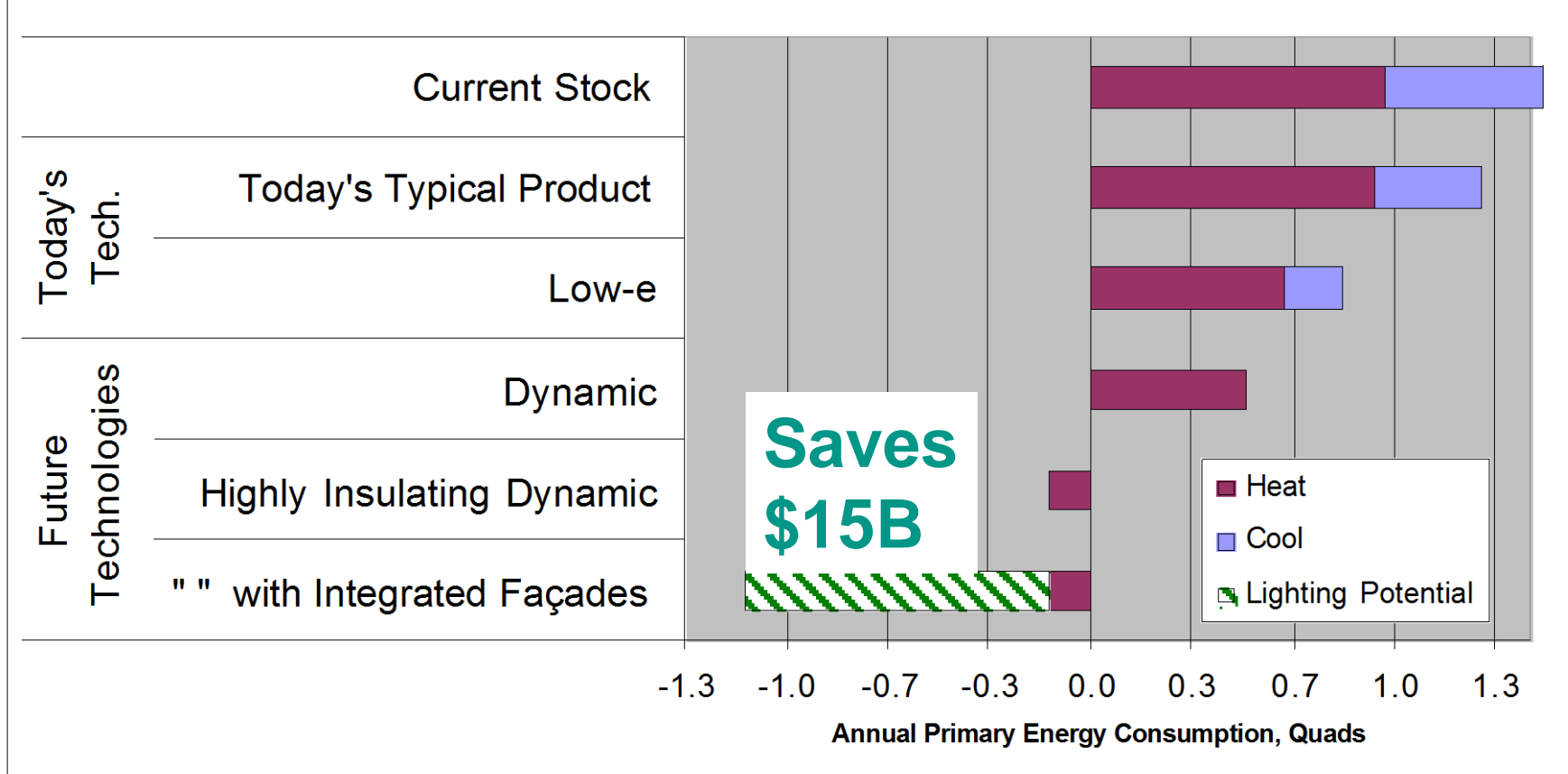
If we can create these solutions,
THIS IS A GAME CHANGER:

1. Design “Freedom”
2. Codes become “irrelevant”
3. Owners are happy: asset value
4. Occupants Benefit: View, Comfort,...
5. National: Large energy, carbon savings

Commercial Building Window Energy Use

2010 Cost
= \$20B

What if all windows in commercial buildings were replaced with...?



Challenge!

Energy and Carbon as Major Design Issues

Embodied energy, Operational Energy

Technology continues to evolve....

Design Strategy/Process Must Evolve Also
(Look for “technology” solutions in new places)

Trends → Salvation?

Components → Systems

Passive → Active

Robust → Resilience

Generalized → Granular

Building → Grid

Building → People

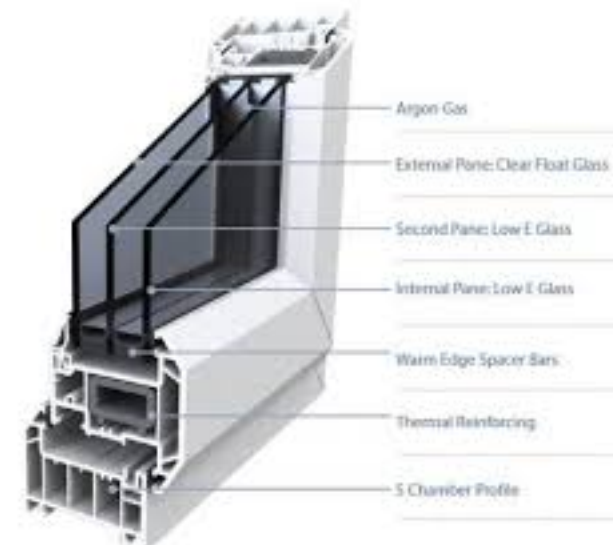
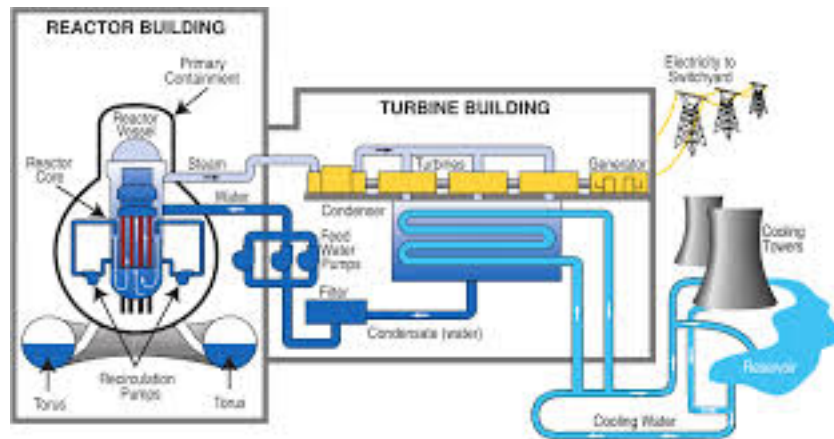
Health, Well-being, Comfort

Performance Transparency

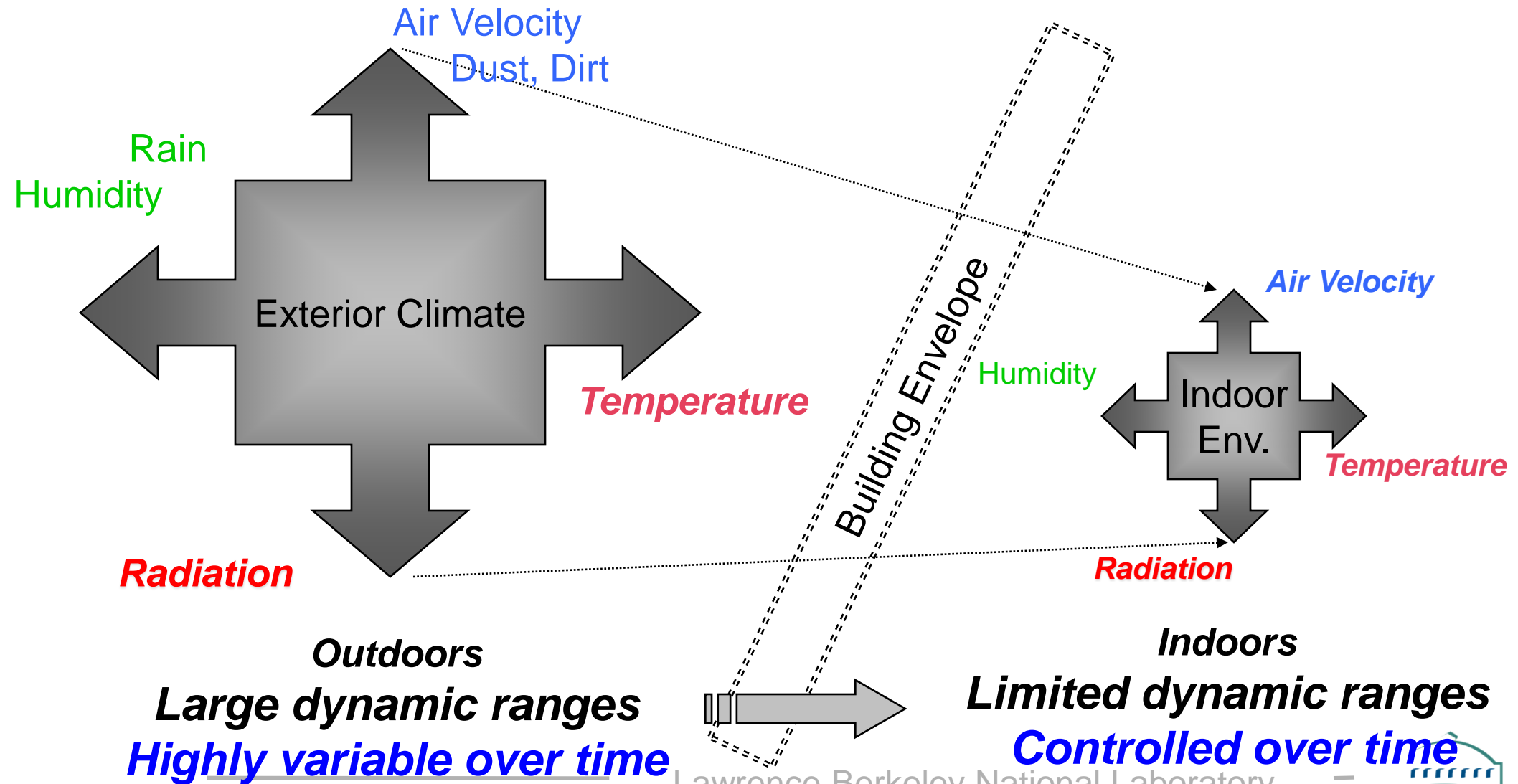
“Internet of Things”:

Cheap, fast, efficient Connectivity

Relative Cost and Complexity? Watts vs Negawatts

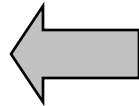


Building Envelope as Dynamic Filter

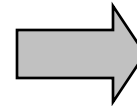


Glazing and Window Technology Landscape: Changing “Scale” and Function for R&D

**“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

Lawrence Berkeley National Laboratory



The “Battle for the Wall”: 3 Pathways

- **“Just meet the code”**
 - **Small Windows**, prescriptive properties, e.g. double
 - No special lighting, shading or daylighting
 - **Mainstream “good” solutions: (prescriptive packages)**
 - **Modest sized windows**, skylights
 - Double glazing, Spectrally selective glass
 - Manually operated Interior shading
 - “Daylight compatible” Lighting design; On-off/multistep lighting controls
 - **Architectural Solution: “Transparent Intelligent Façade”**
 - **Highly glazed façade**; extended daylighted zone
 - **Reliable tools reduce risk**
 - High Performance technology with **Systems Integration**
 - **Task/Ambient Lighting solution w/ Controls**
 - **Dynamic, smart control- automated shading, dimmable lights**
 - Economic from Life cycle perspective
 - Optimized for people (Comfort) and for energy, electric demand
-

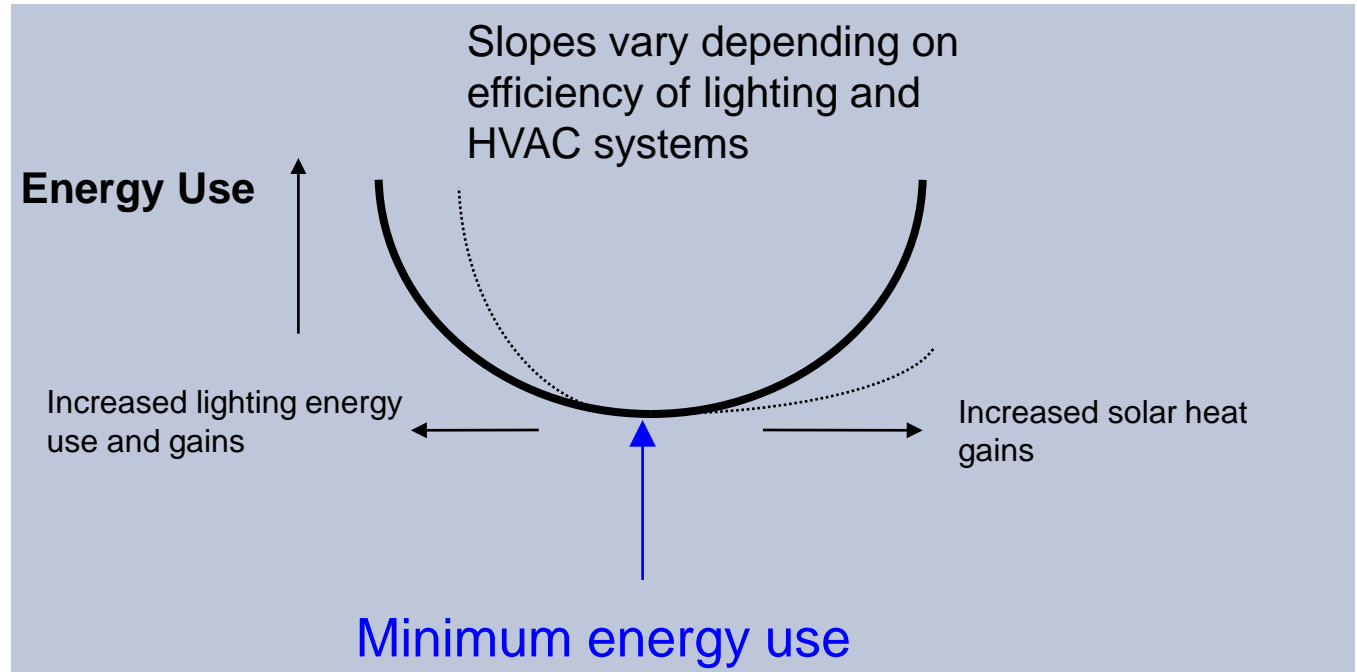
Challenge: Optimizing Energy in Integrated Facades

Dependent on a number of parameters

- Climate
- Orientation
- Building Type
- Fenestration area
- Glass type
- Operations
- Daylight
- Shading

Need to balance a number of issues

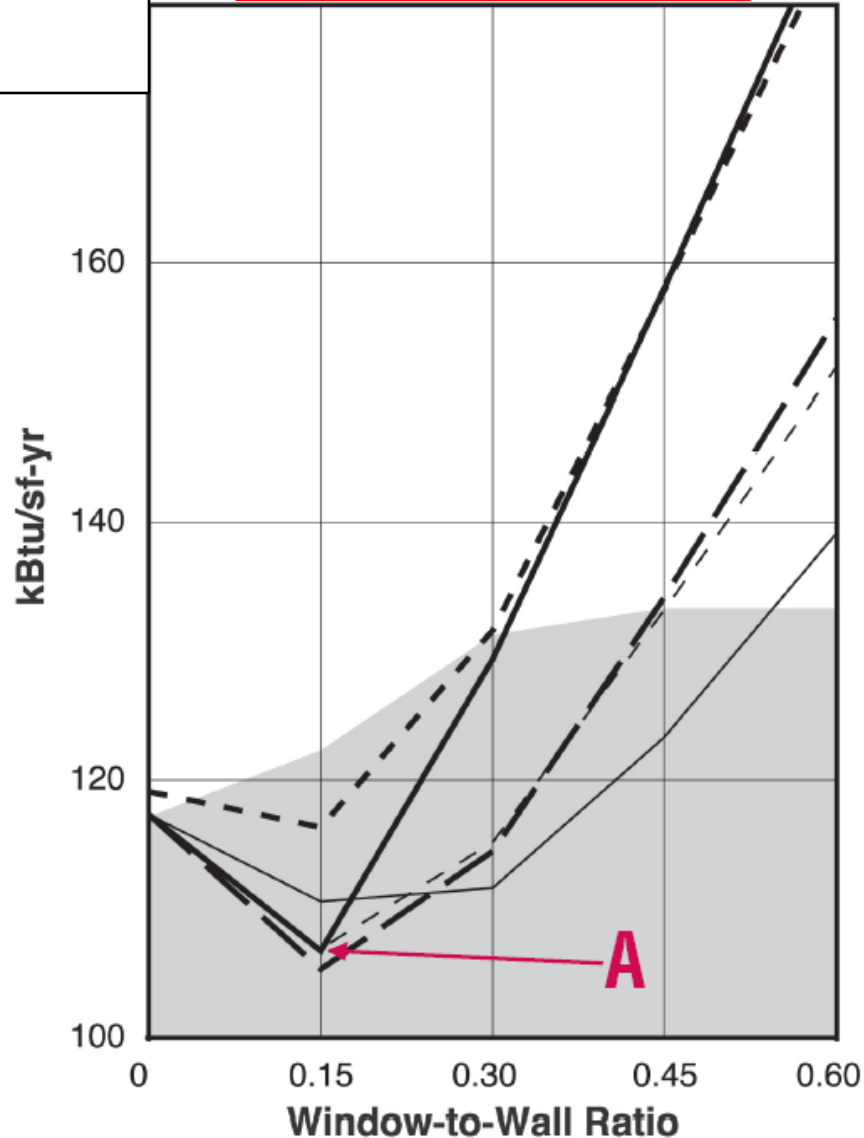
- Energy
- Demand
- Carbon
- Peak Cooling
- Comfort: visual/thermal
- View
- Appearance
-



- *Ideal:* Integrated approach to **façade-lighting-HVAC** building systems to achieve optimum energy-efficiency and comfort.

Window B

double glazing, clear
 $U=0.60$, $SHGC=0.60$, $VT=0.63$

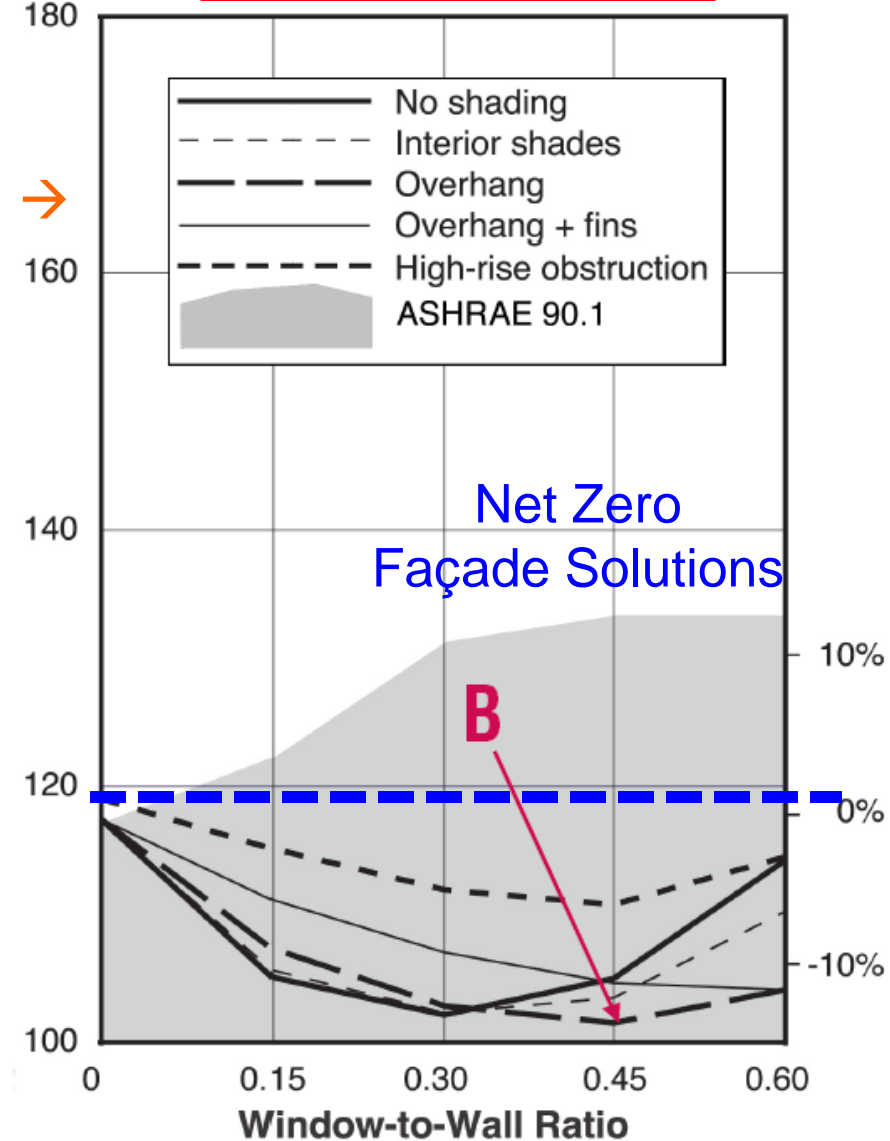


Grey: Code allowance

Shading Options →

Window H

triple glazing, 1 low-E layer, clear
 $U=0.20$, $SHGC=0.22$, $VT=0.37$



Cold Climates: Chicago, IL

al Laboratory

Vision: Windows for “Zero-Energy Buildings”?

Facades: Energy Losers --> Neutral --> Suppliers

Fenestration -> Net Zero Energy Impact

- 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

High Performance Fenestration might need....

1. High Performance Components and Systems

- Kit of Parts: heat loss, solar gain, daylight air, moisture

2. Integrated, Responsive, Intelligent Systems

- Links to other building systems: lighting, HVAC
- Responsive to occupant, owner, electric grid
- Smart: adaptive to changing needs

3. Follow-thru: Guaranteed Energy Performance

- Design, Construct, Operate to deliver on promises

4. Toolkits to Achieve #1-3

- Simulation tools
- Testing for Validation, Verification and Innovation

1. High Performance Components, Systems

- Insulating technologies
 - Solar control technologies
 - Daylight technologies
 - Ventilation technologies
-
- Heat Storage
 - Thermal capture
 - Energy generation

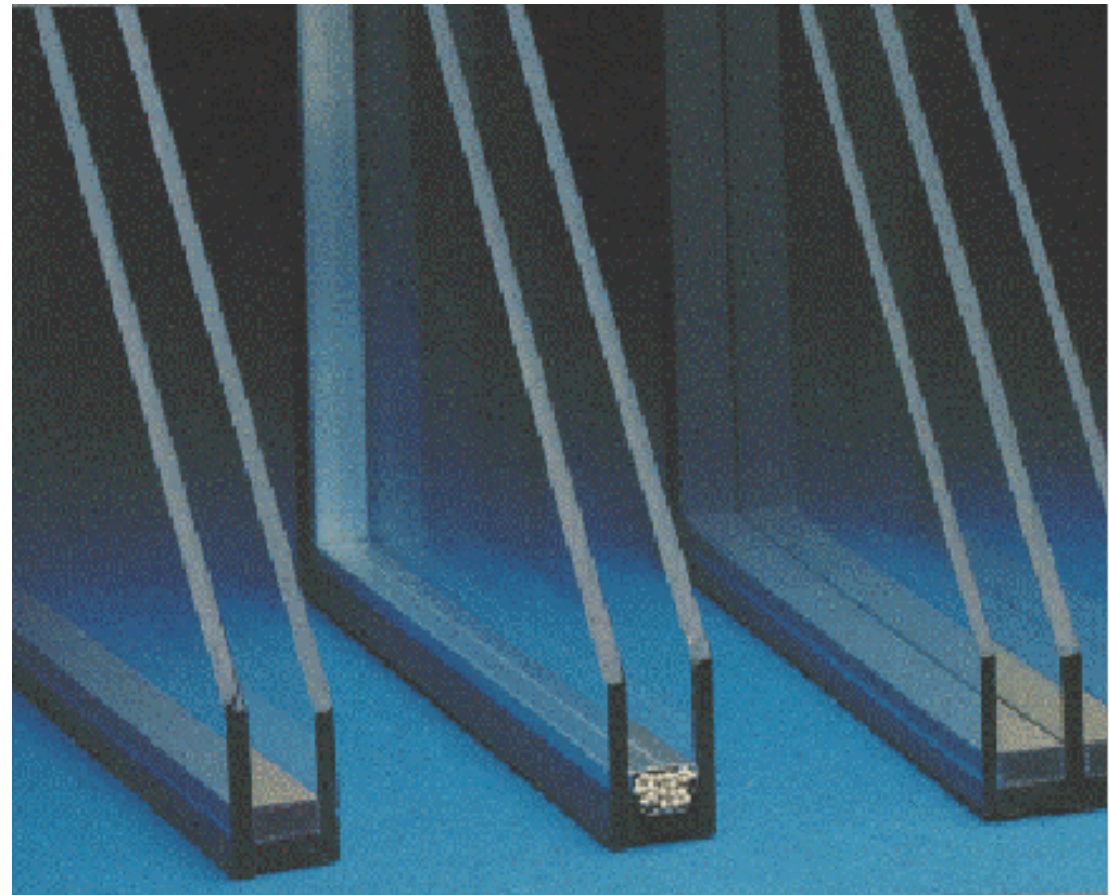
Highly insulating, low heat loss glazing

Nearer Term Objective: U-value < 1.0 W/m²-K

Long Term Target: U-value < 0.5 W/m²-K

Approaches:

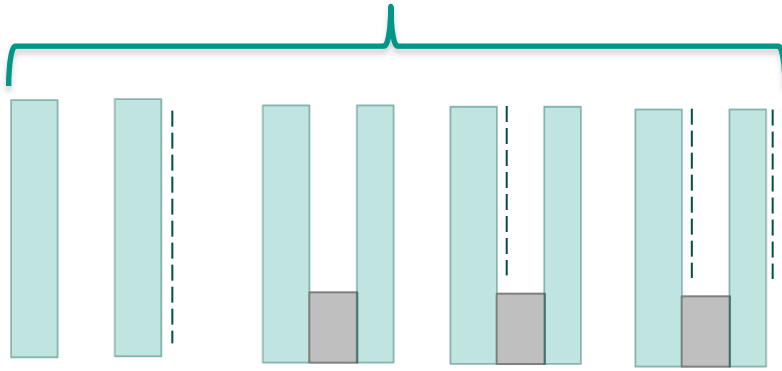
- Low-Emissivity Coatings
- Low Conductance Gas Fills
- “Warm edge” low conductance spacers
- Insulated Frame Systems



HIGHLY INSULATING GLAZING SOLUTIONS:

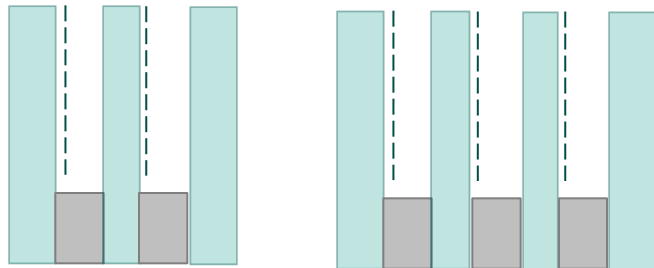
$U \sim .5 \text{ W/M}^2\text{-K}$

Market Today



Single

Double

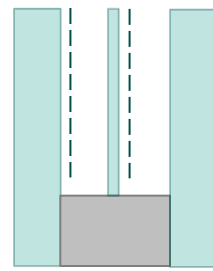


Two low-e

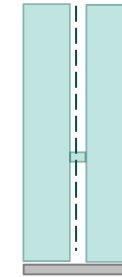
Three low-e

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

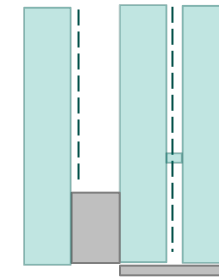
Emerging



Two low-e
Thin glass
single seal
Krypton

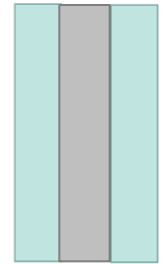


One low-e
Vacuum

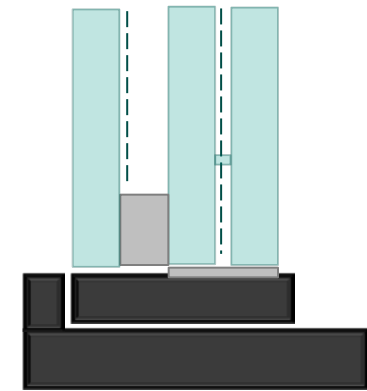
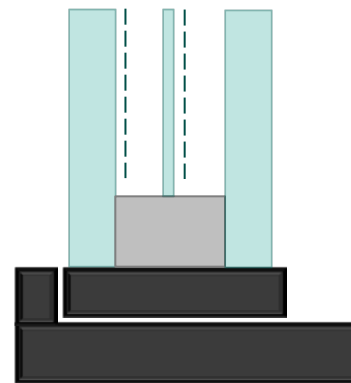


Two low-e
Vacuum Hybrid

Future



Aerogel

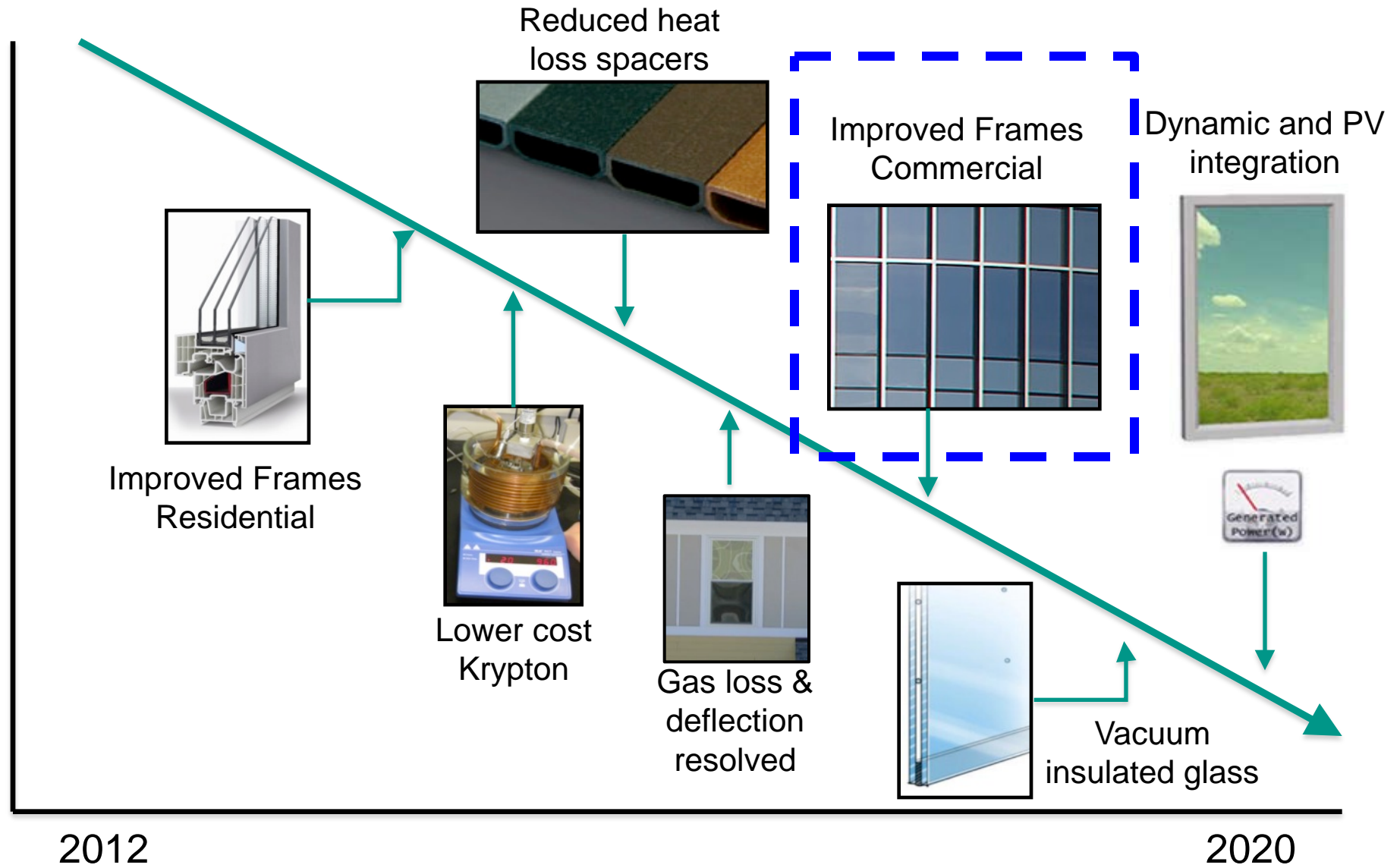


Super-insulating frame with highly insulated glazing

Hi-R Technology Track: FY12-20 Timeline

R5,
High
Cost

Net
Zero,
Low
Cost



Solar-Optical Properties of Windows

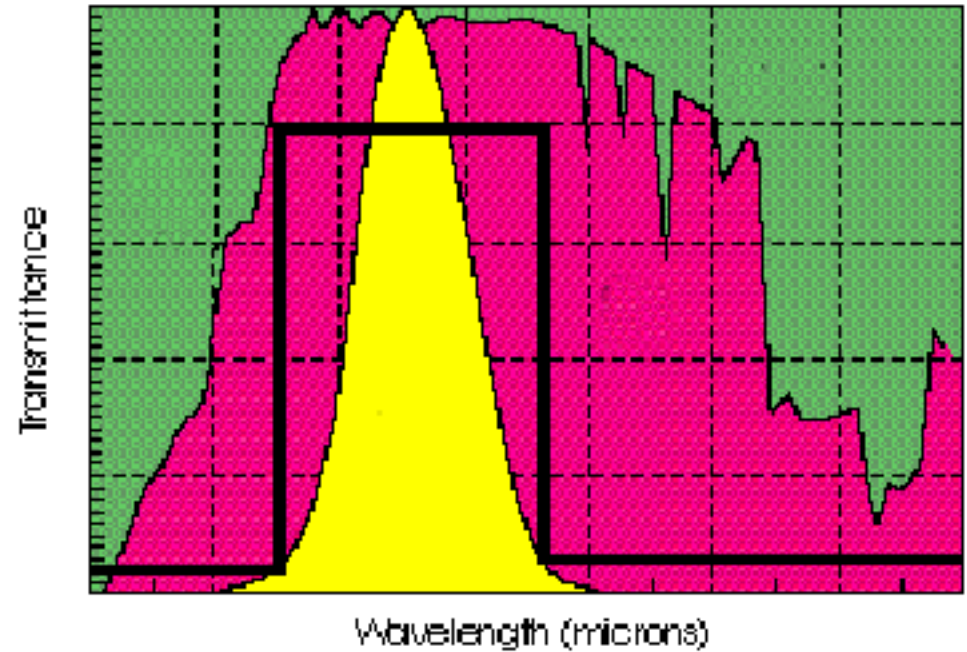
- **Highly Transparent**
 - View, Daylight
 - Passive solar gain in winter
- **Solar Protection**
 - Reduce Cooling energy
 - Minimize cooling system size and cost
 - Manage Glare
- **Control Options:**
 - Spectrum – “tuning”
 - Intensity – “dim”
 - Distribution into Room – “redirection”

Spectrally Selective “Cool” Glazings

- Spectral control- transmit light, reject near-IR heat
- Equal daylight with only 50% of solar gain

Technology:

- **Selective Absorbers**
 - blue-green tints
- **Selective reflectors**
 - modified low-E coatings
 - coated glass and plastic
 - Multilayer dielectric

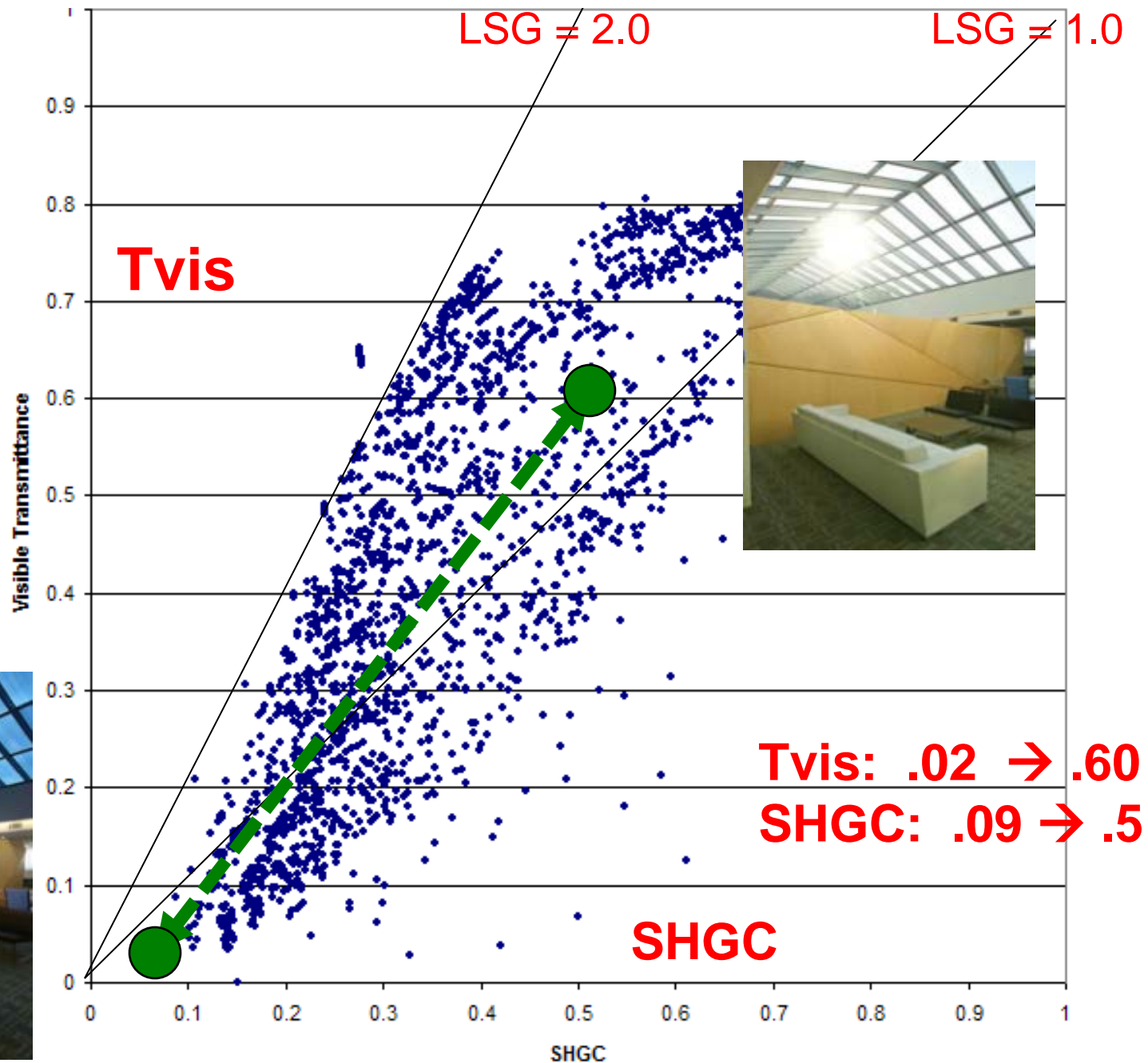


Transmittance -vs- Wavelength

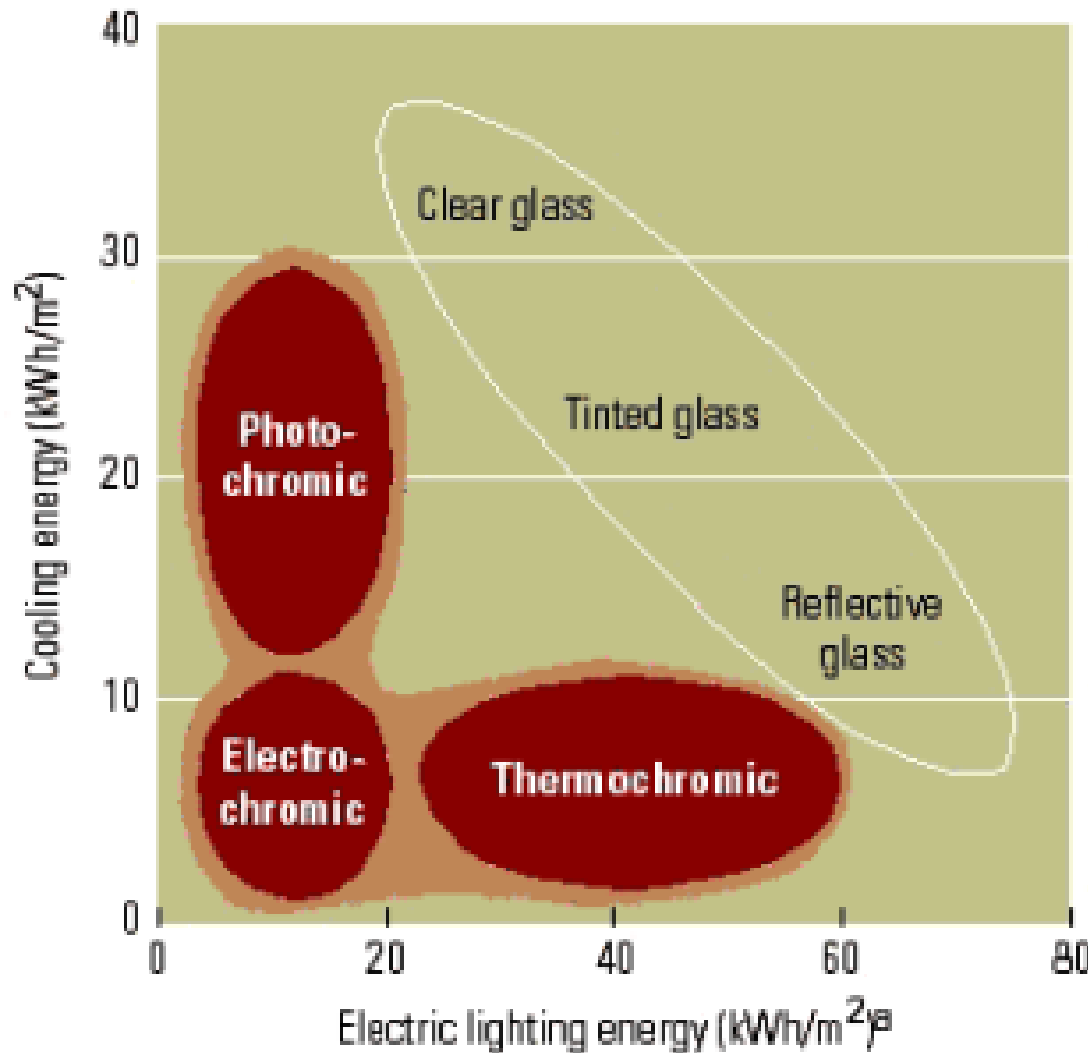
Light to Solar Gain Ratio = $T_{vis} / SHGC$

**SMART
GLASS:**

**Change
properties
based on
needs**



Static vs Active Glazings: Cooling vs Lighting Performance



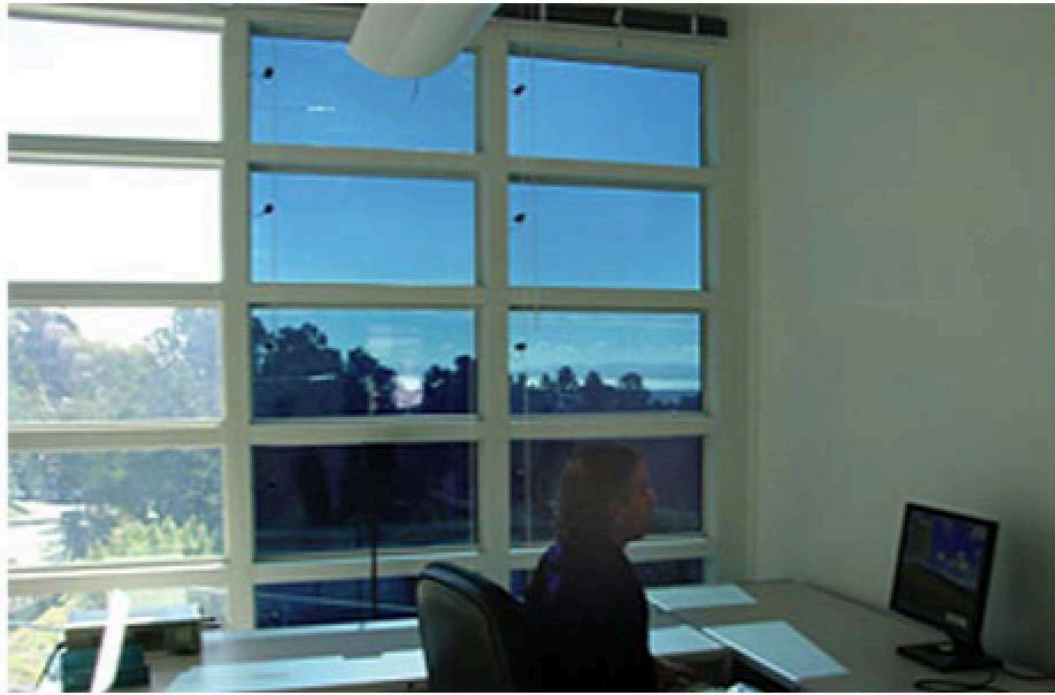
Cooling
Energy

Lighting Energy

Active control
preferred; but
requires “source” for
power and control

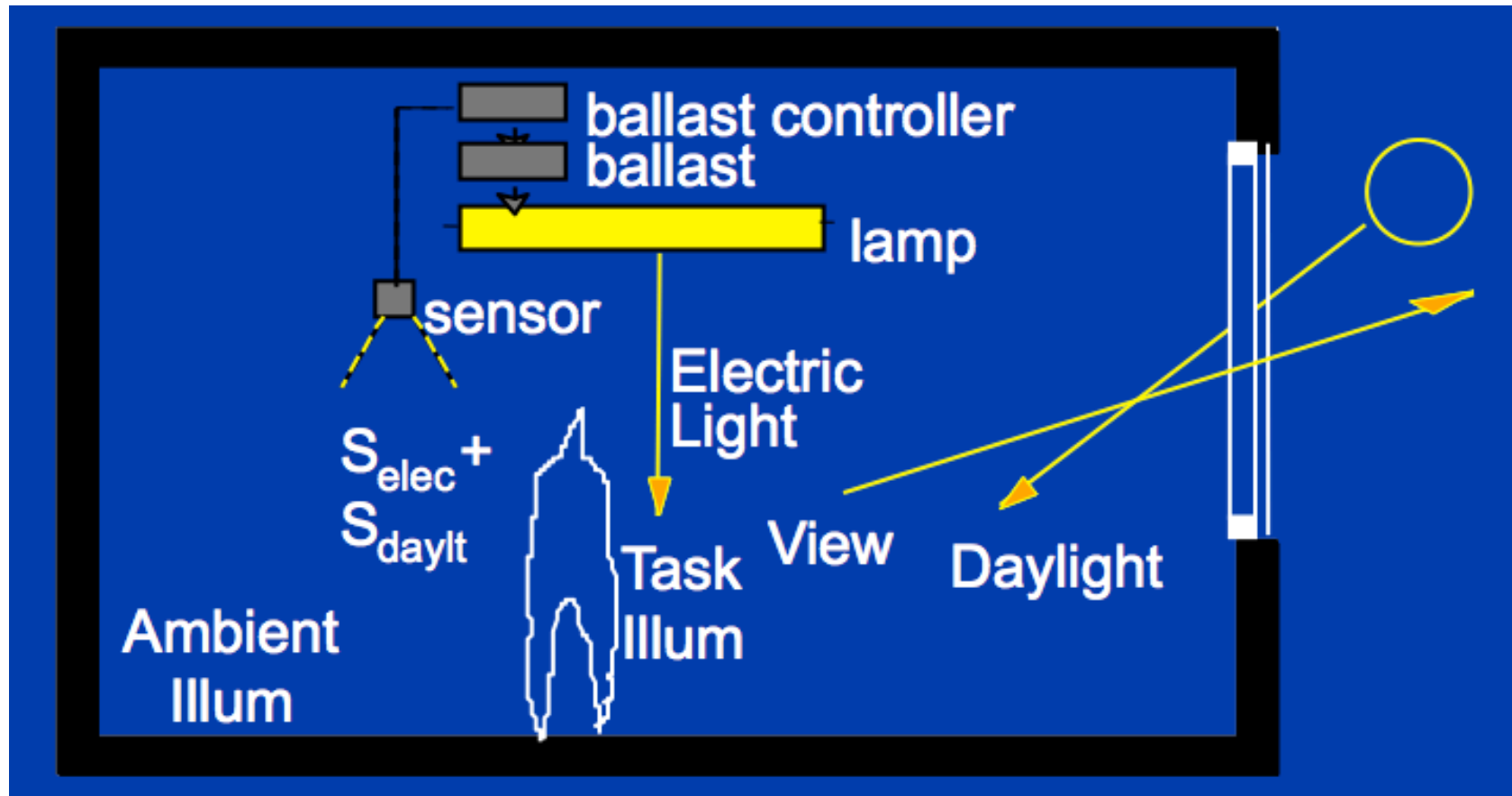
Automated shades
and blinds is a
mature market in EU

“Granular control” of light, view and glare, (occupant controlled)

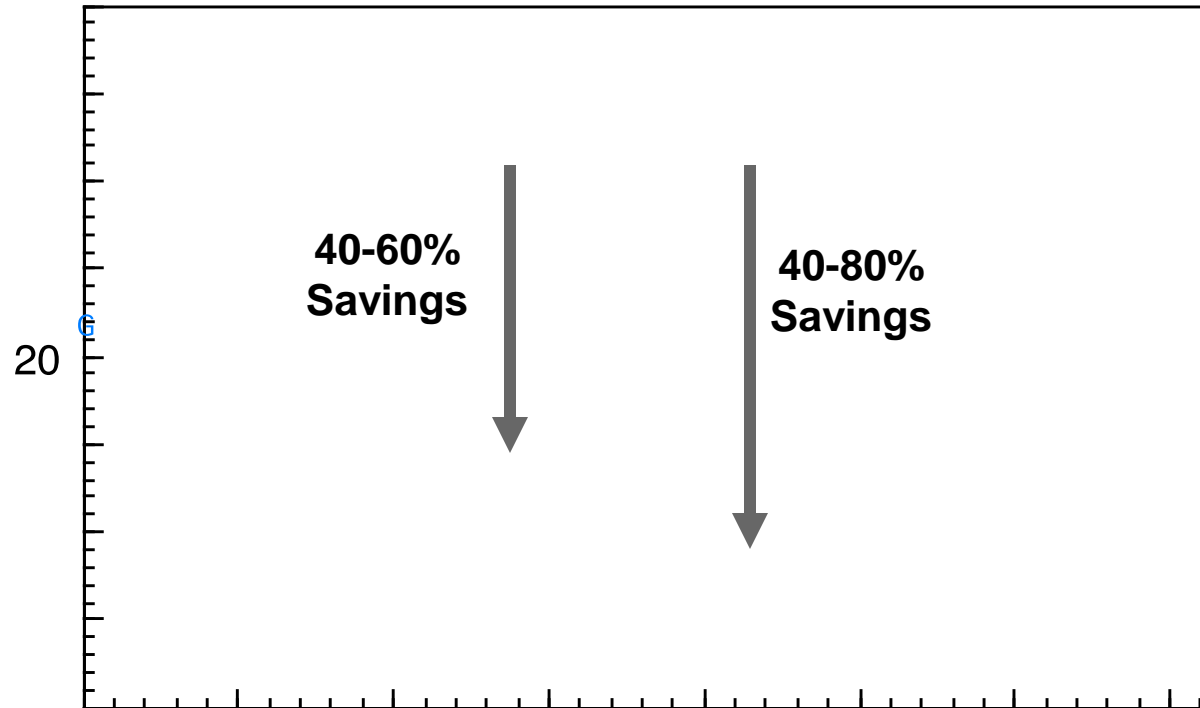


(Day)Lighting: 3 challenges

1. A Daylighted Building Doesn't Save Energy if the Lights are On
2. Why Do We Only Daylight Outer 3-4 M of space
3. Glare vs Light- Occupant Control of Shades, blinds



Good Lighting Controls (Daylight Dimming) Work



Data from
advanced
lighting controls
demonstration
in Emeryville, CA
(1990) ← !!!

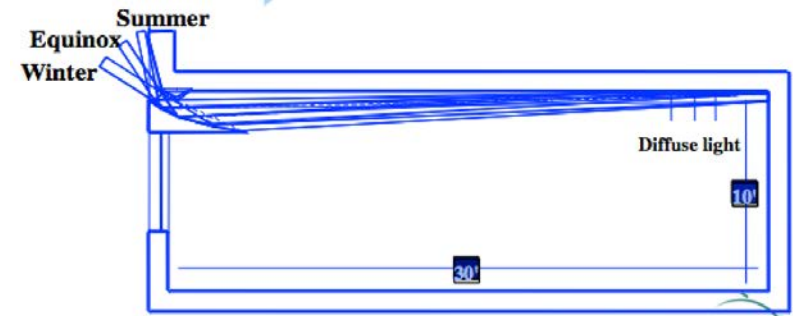
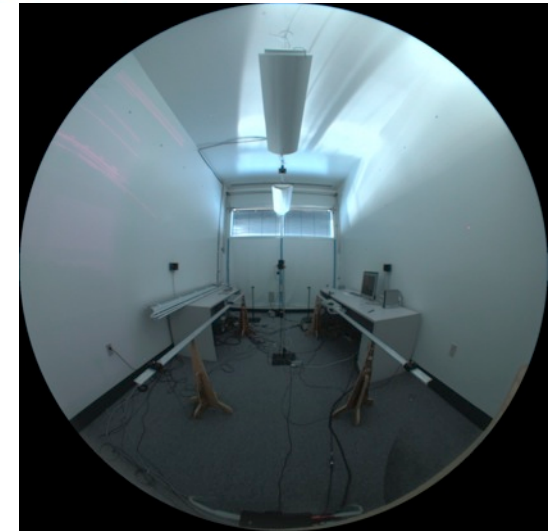
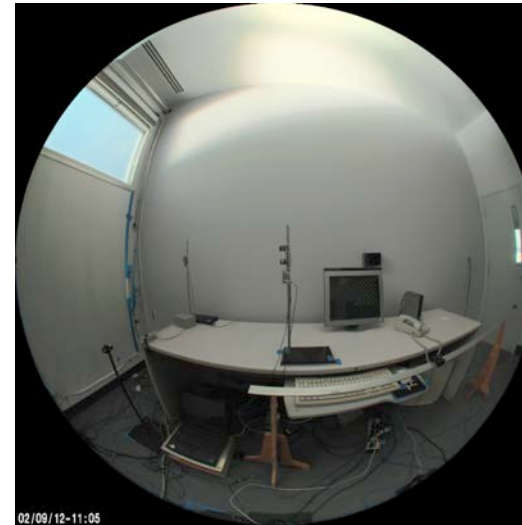
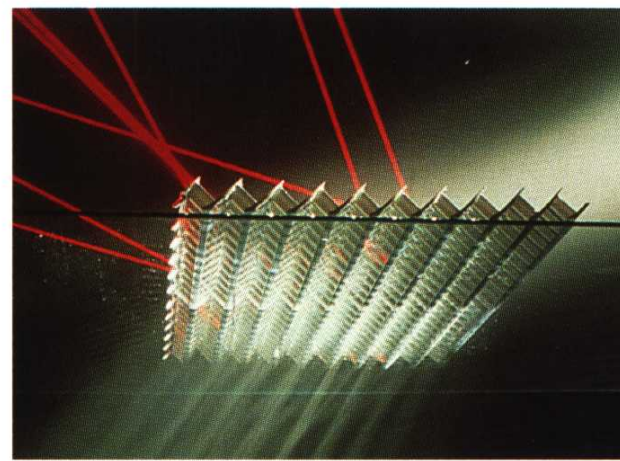
Energy Use
before retrofit: 

After retrofit:
South zone: 
North zone: 

But Dimming is only
3% of lighting sales!

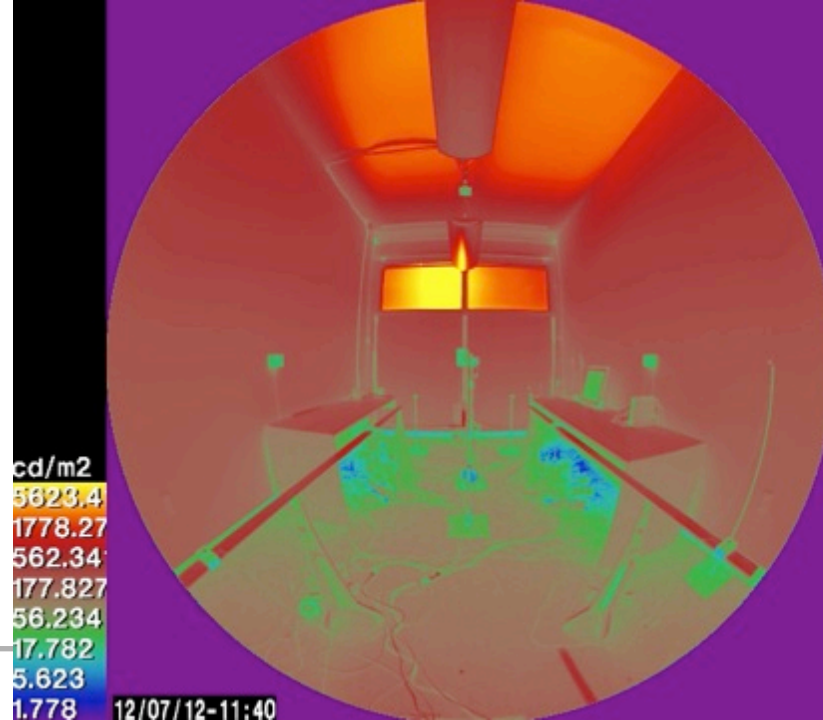
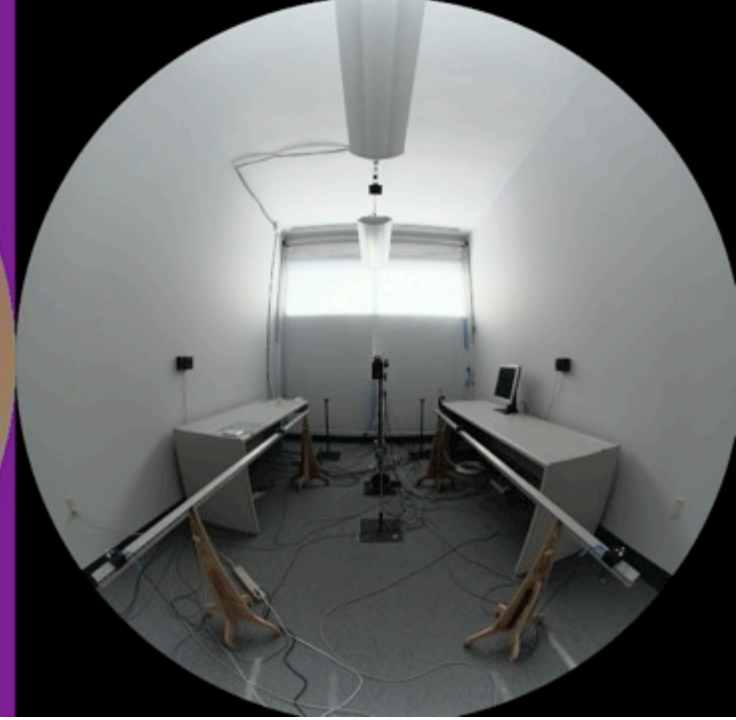
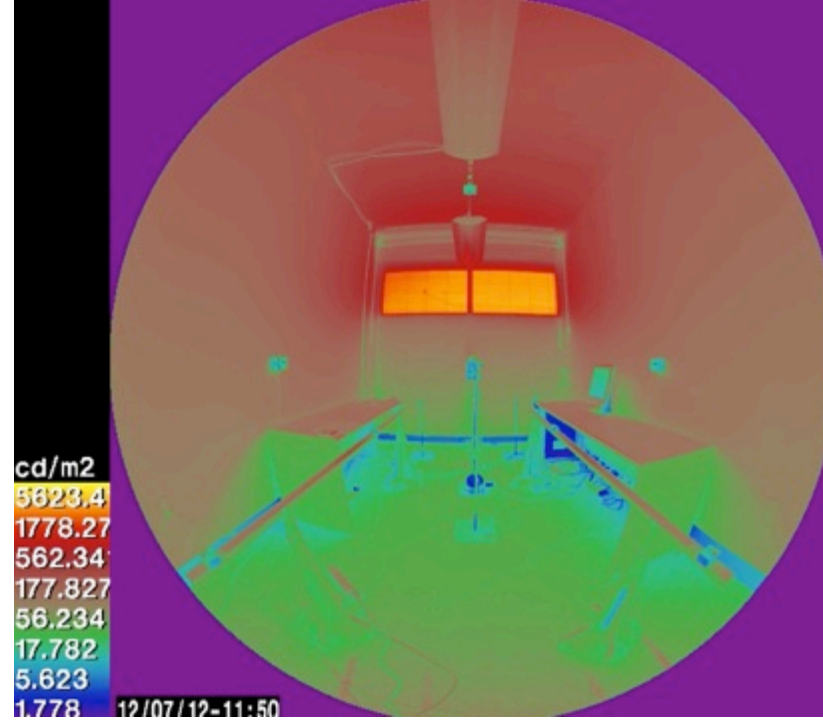
New Technology for Light Control

- Conventional Directional control
 - glass block, fritted glass, diffusers
 - shading systems
- New Options
 - Special blinds
 - Prismatic glazings
 - Holographic materials
 - Laser cut panels
 - Light pipes and Fiber optics
- Emerging Options
 - Nano- based optical control
 - Static → dynamic control of light
- Challenges
 - Fabrication at affordable cost
 - Characterization - how do they perform?



Venetian blind;
Noon

Light Redirecting Coatings



2. Integrated, Responsive, Intelligent System

1. Create Integrated Façade from Components

2. Link Façade to other building systems:

- Lighting
- HVAC
- Building-wide automation
- Responsive to:
 - Occupant - comfort
 - Owner – energy
 - Electric grid – resilience, stability
- Integration can lower net cost
- Smart: adaptive to changing needs
- Reliable operation....

What Happens When You Don't Get Integration Right?

Bloomberg BusinessWeek Magazine 2/27/2012

[Bloomberg.com](#) [Business Exchange](#)

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Automatic Shades Inspire Office Frustration

Smart blinds cut power use, but workers find them maddening

By Karen Weise

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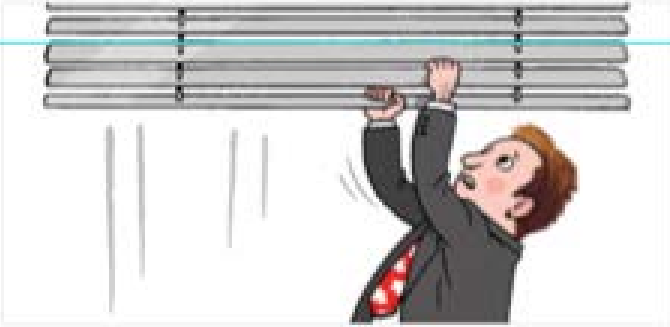


Illustration by Scott Garnett

The Seattle building Brent Rogers designed for his architecture firm, NBBJ, has won awards for its natural light, flexible workspace, and sustainability. Yet when Rogers moved in, he soon grew frustrated by a key element of the green design: the automated window blinds, which went up and down with little apparent reason. "At times it seemed random," recalls Rogers. "And at times it was random."

— Maximizing daylight can cut a building's lighting bill by as

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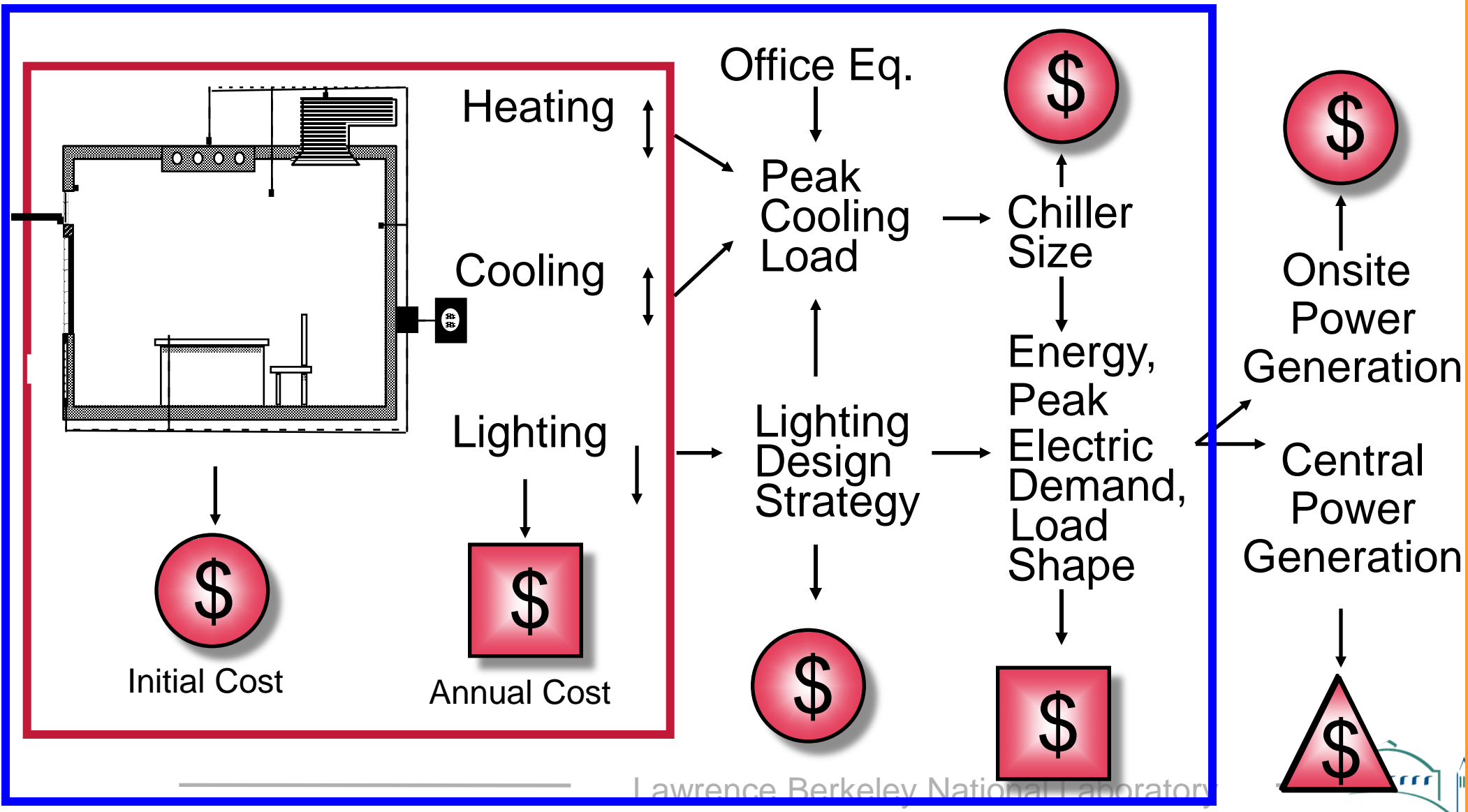
THIS WEEK



February 27, 2012
Scorned in the USA

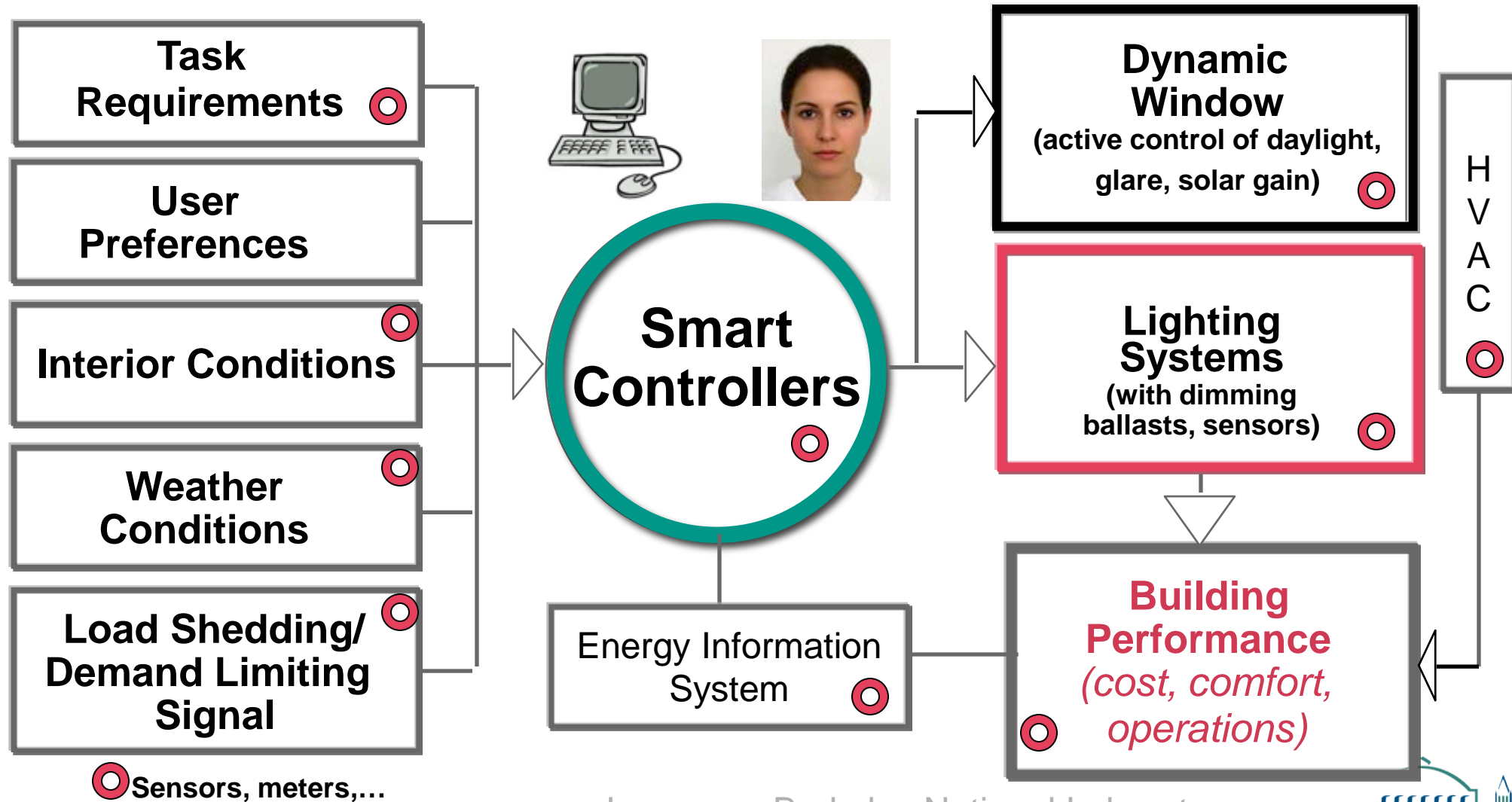
Levels of System integration → Cost tradeoffs

Buildings ↔ “Smart Grid”



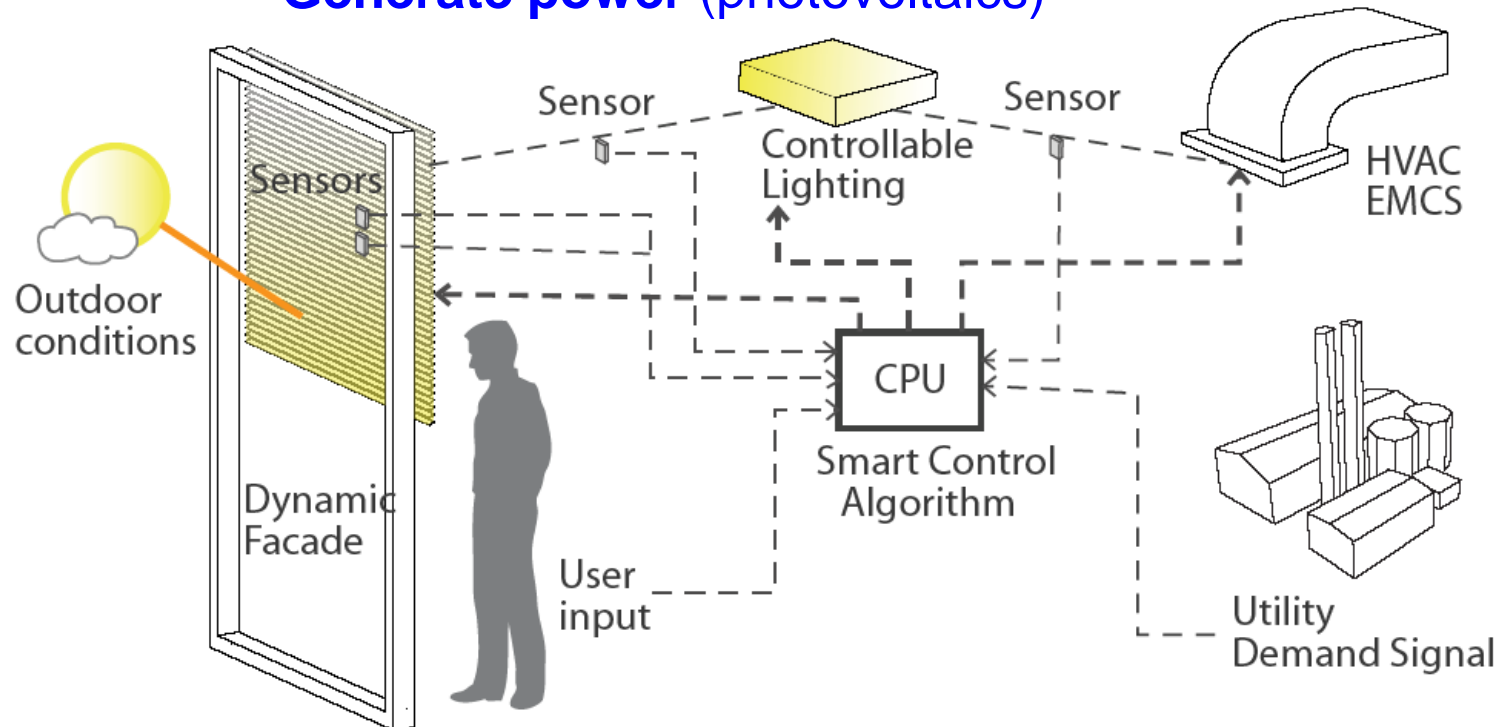
Exploring Intelligent Control Systems:

Maximum performance requires full integration with all building systems (manual control??)



An “Intelligent” Envelope/Lighting System might.....

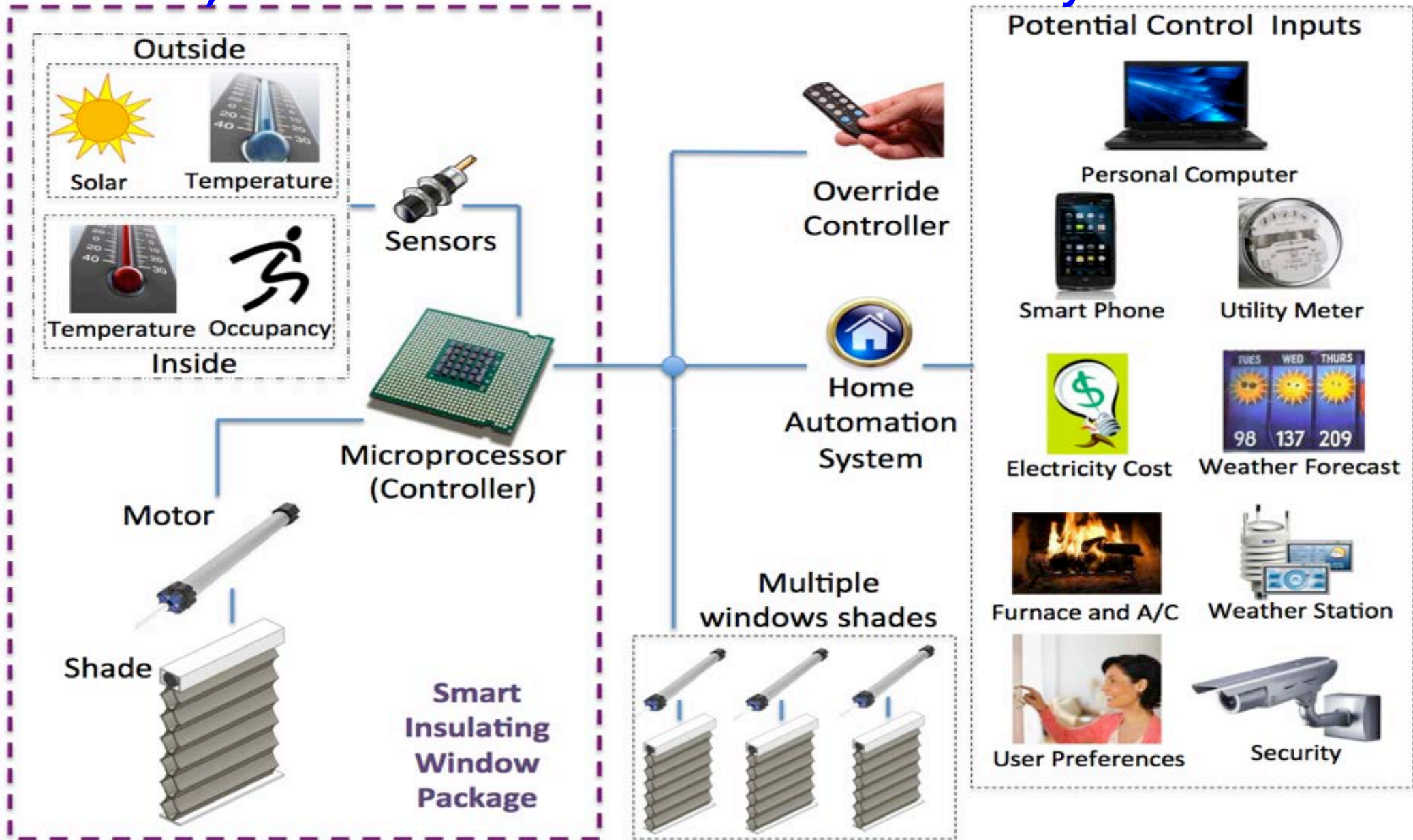
- Manage **thermal loss and gain**
- Provide dynamic **solar control**:
- Provide glare-free **daylight**
- **Manage electric light distribution, intensity, power**
- Provide **fresh air** to interior, minimize noise
- **Enhance occupant health, comfort**
- **Reduce demand** on utility
- **Generate power** (photovoltaics)



1) Who Integrates? 2) Levels of Integration and Responsiveness:

1) Autonomous package 2) Multiple Levels of Integration

2) Window → Room → House → Community/Grid



To Reliably Achieve Scalable Savings We Need....

1. Glazing, Shading and Light Redirecting Technologies

- Kit of Parts: with glazing and framing, shading, thermal and solar gain control,...

2. Adaptive, Responsive (Dimmable) Light Source

3. Smart Sensors

4. Robust Wireless Communications

5. Real time and Archival Performance Data

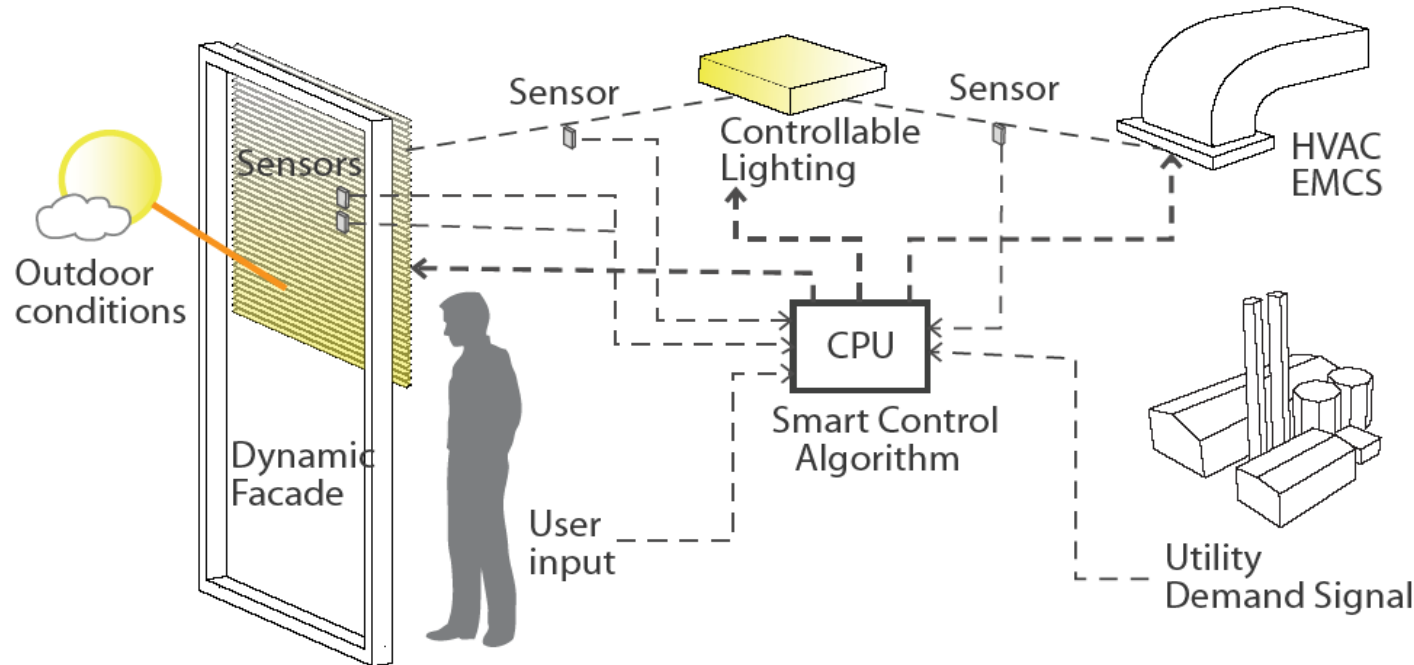
6. Foolproof Installation and Commissioning

7. Occupant savvy operational modes

8. Links to Building Automation, Grid,...rest of the world...

“Active Integrated Perimeter Building Systems”

Optimal Performance of Dynamic Systems Requires Integration



Goal: Plug and Play, Flexible, Responsive, ...

Today's Reality: Multiple, incompatible systems, lack of standards

Challenges: Interoperability, Open Systems, Robustness, Low Cost, Resilience,

Build on “The Internet of Things” platform to integrate and link systems

3 year Program: 1) Specs, 2) Testbed, 3) Owner demonstration

3. "Guaranteed" Energy Performance

- Can a Design Team Guarantee Energy Use target?
- Design – Bid – Build – Operate....??
- Need new metrics and business practice
- New Market Drivers:
- Outcome based codes: **Carrot**
 - “build anything you want but prove that the building energy use is lower than target level after occupancy...”
- Energy Disclosure laws: **Stick**
 - Publicly disclose your annual energy use!
 - European Union
 - US: 29 Cities and States now have disclosure laws

NY Times: Intelligent Lighting, Shade Control, UFAD

(Field Energy Measurement Study Completed 2013)

- Automated Shaded
(Multifunctional)



Occupied 2007

- Dimmable lighting
 - Addressable
 - (Multifunctional)



New York Times office with dimmable
lights and automated shading

The “Headlines” from The New York Times Building

46

- **2003-2006: Building designed to save energy as well as satisfy occupants**
- Shading systems and lighting control systems were rigorously developed and evaluated in a full scale test bed
- Owners engaged key systems suppliers via performance specs
- **2013: Over ~ 5 years, the systems (dimming, shading, UFAD) worked well;**

Compared to a similar Code-compliant building:

- 56% lighting energy savings
- 24% total energy savings
- 21-25% reduction in summer peak demand
- Economic Paybacks appear very reasonable
- Overall Occupant Satisfaction is high; some areas need help

PS- this is an all-glass building!

Annual Energy Costs in Perspective

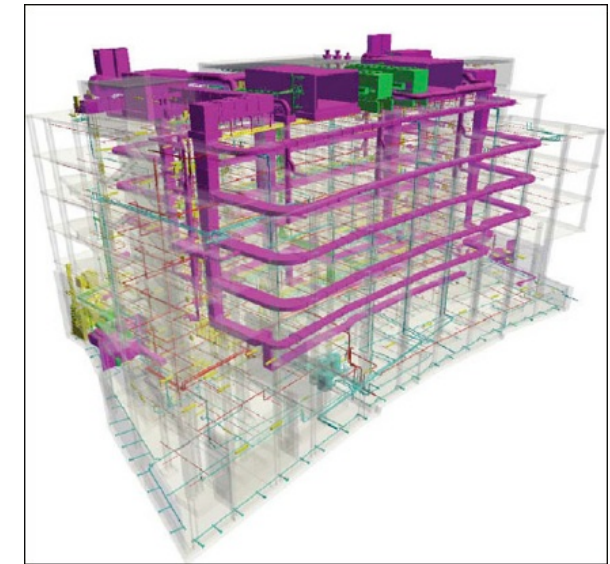
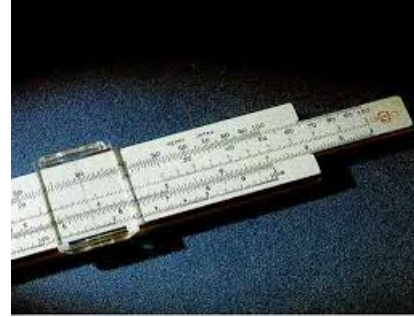
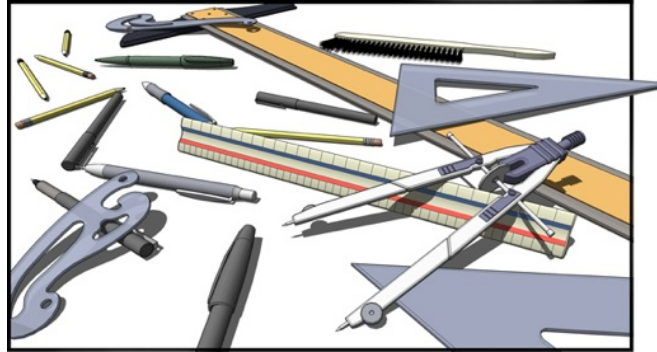
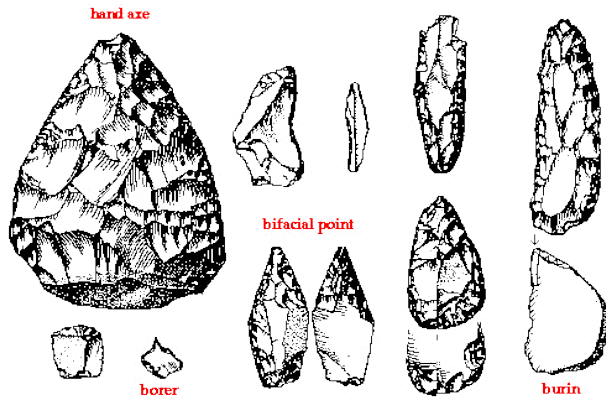
Cost / Sq. M. Floor -Year

- Energy Cost: \$30.00
- Maintenance: \$30.00
- Taxes: \$30.00
- Rent: \$300.00
- “Productivity” \$3000.00+



4. Simulation and Testing Toolkits

- **Simulation tools**
- **Testing for**
 - **Tool Validation**
 - **Performance Verification**
 - **Risk Reduction**
 - **Innovation/R&D**



Tools are constantly evolving, getting more powerful...

**“All Simulation Models are Wrong,
But Some are Useful”**

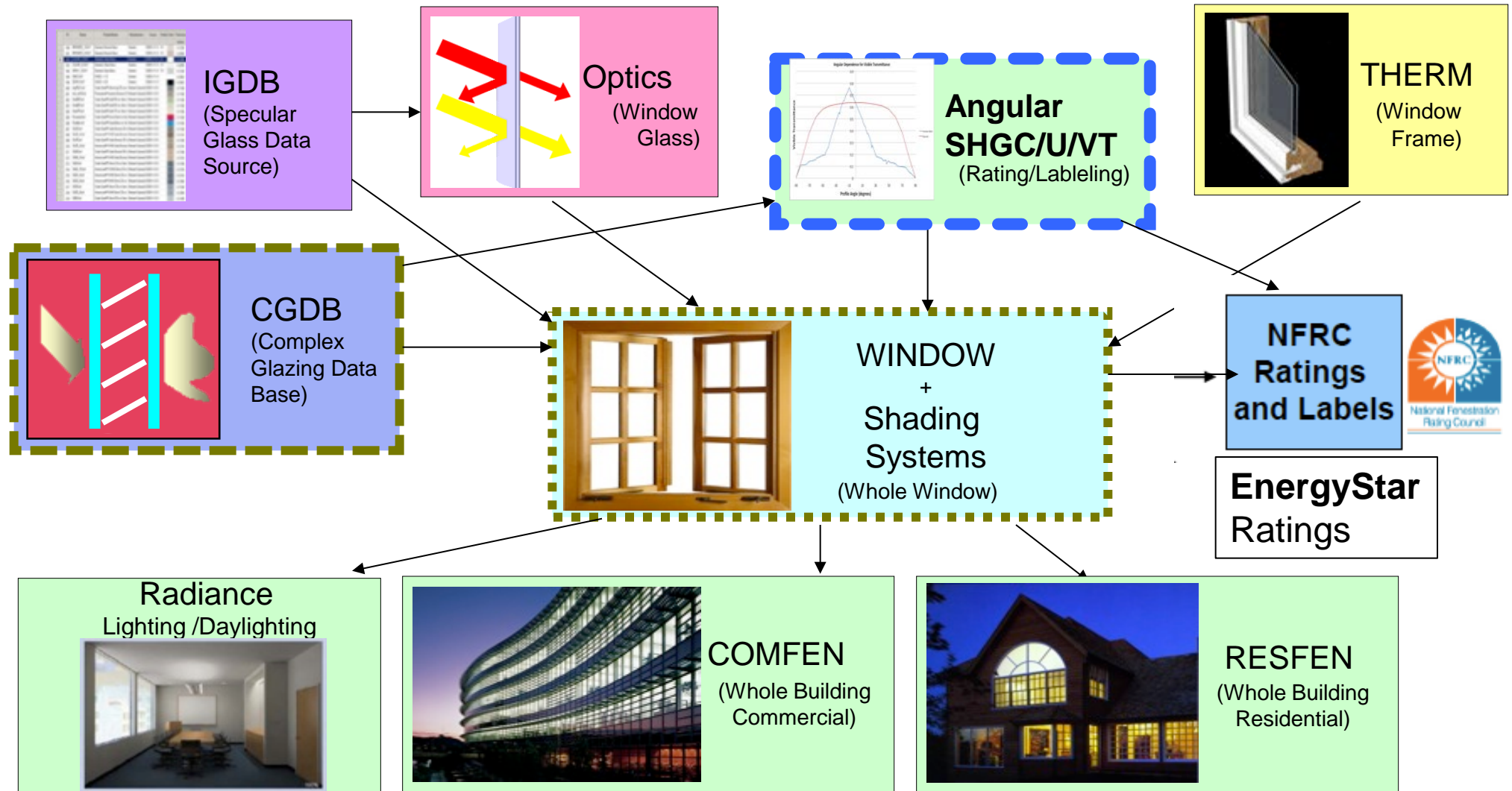
How do we ensure our tools are useful?

Glazing and Façade Simulation Tools

- **Design Guides, Selection tools**
 - Homeowners
 - Builders, contractors
 - Point of sale
- **Building Design Tools**
 - Allow integration strategies to be explored
 - Allows façade performance to be optimized
 - HVAC – Façade - Lighting tradeoffs
 - Explore commissioning and operational issues
- **Glazing, Window and Façade Tools - Manufacturers**
 - Essential for design of new products
 - Supplement, replace testing - virtual product development

Glazing and Façade Decision-Support Tools

Download <http://windows.lbl.gov/software/> 2014 ~ 40,000 Downloads



Commercial Windows Website

Efficient Windows Website

Design /Simulation Tools



COMFEN: Façade Early Design Tool

Download: windows.lbl.gov/software

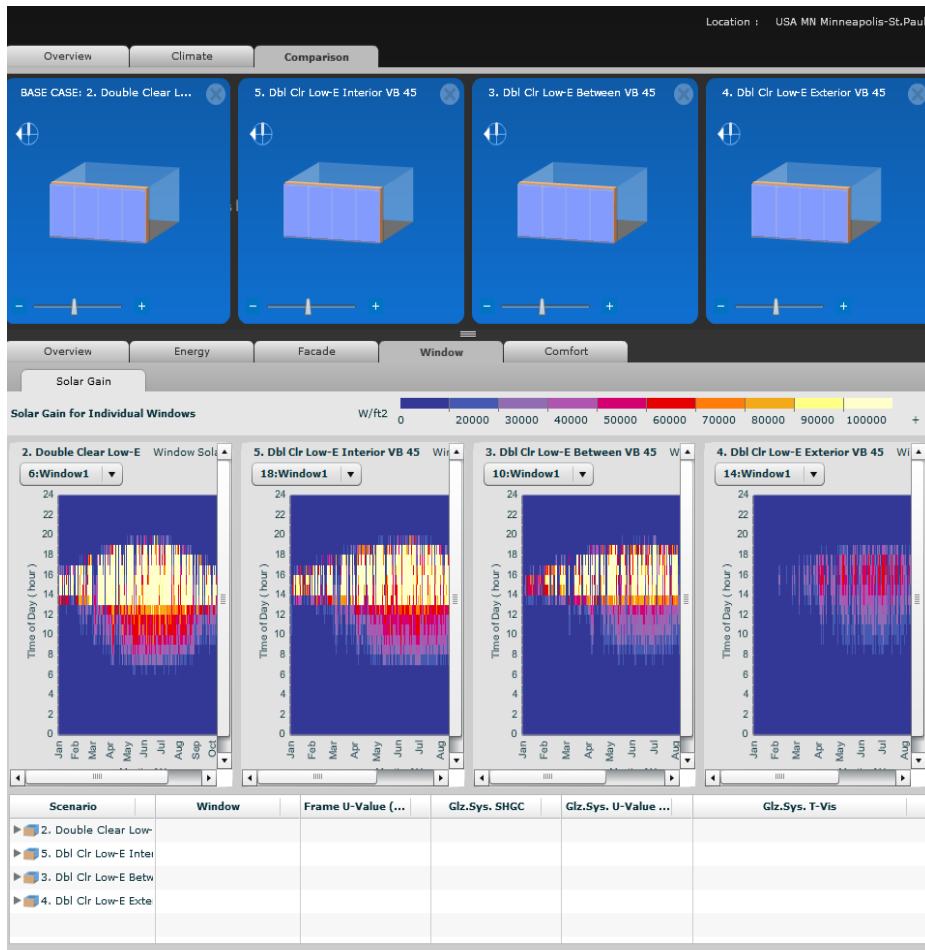
- Early Design Tool for Façade Systems: Thermal and Daylighting Impacts
- A tool to Optimize Energy Use, Carbon, Comfort...



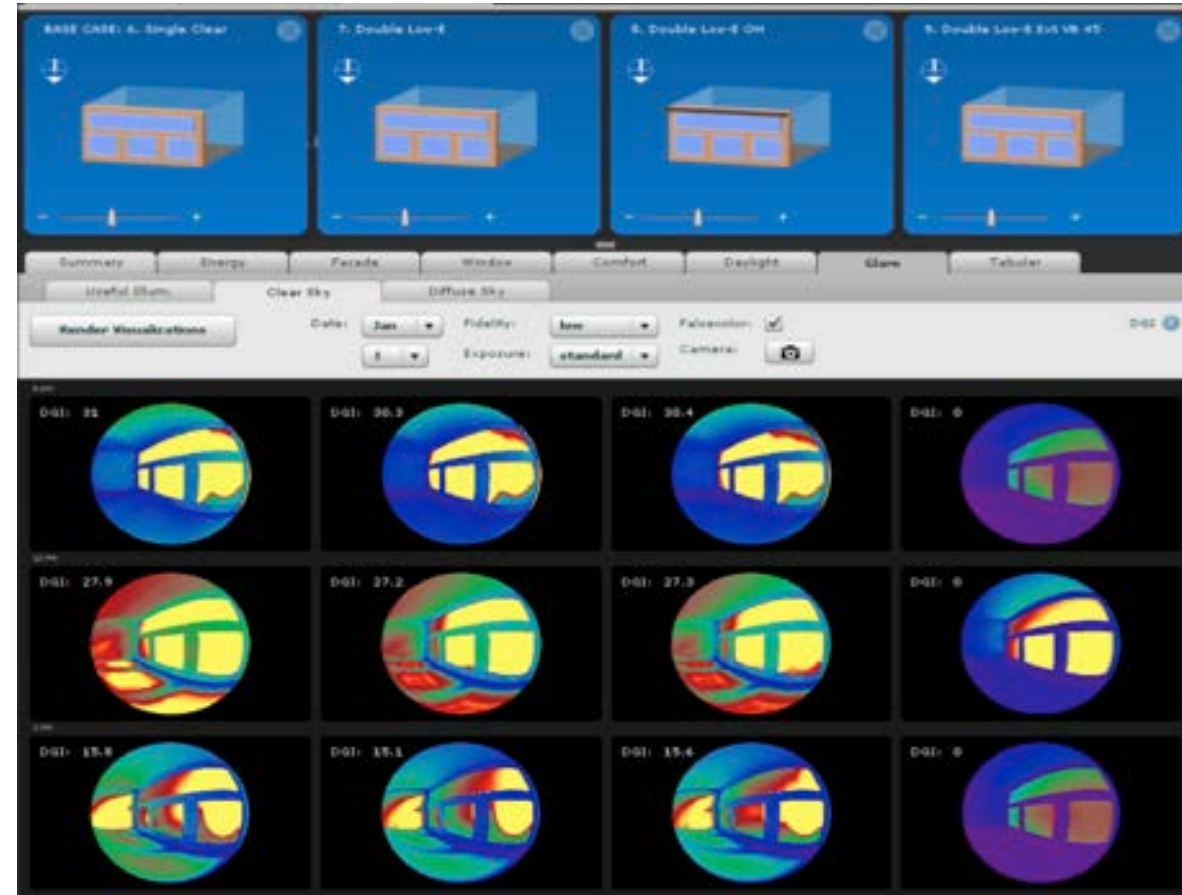
Diving Deeper: Exploring Performance Details

Solar Gain/Daylight/Glare Results

Window solar gain



Glare Assessment w/ Radiance



New Features: 5.0: Natural Ventilation, Cost Database; 5.1: Electrochromics

Lawrence Berkeley National Laboratory

MoWiTT: Mobile Window Thermal Test Facility

Reno, NV, 1985-2000; 2012+



Side-by-side test rooms:

- Heavily instrumented
- Changeable Facades
- Changeable skylights
- Variable operating condition
- Variable orientation
- High Accuracy
- No Occupants
- Small Rooms

Explored:

- Net Energy Balance
- Technology impacts
- System tradeoffs
- Climate effects
- Control impacts

LBNL Advanced Façade Testbed Facility

2003-2006

**Electrochromic
windows**



**2007-2015
Automated
Shading;**

**Daylight
Redirecting;**



- Berkeley, South facing
3 Rooms
- Changeable façade
- Lighting, HVAC
- Heavily instrumented
- Static/Dynamic
- Occupant Studies
- Controls/Automation

**Integrated PV
and storage**

What Do We Learn from the “Real World”?

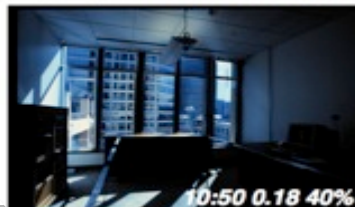


DOE/CBI
Living Laboratory
New York City
Bank of America
Goldman Sachs

NY Times
Mockup and
Test bed
2003-2007



DOE/CEC/PG&E
Electro-chromic
Daylighting Testbed Oakland
CA, 1999



Lawrence Berkeley National Laboratory

FLEXLAB: 2014+ Facility for Low Energy Experiments in Buildings



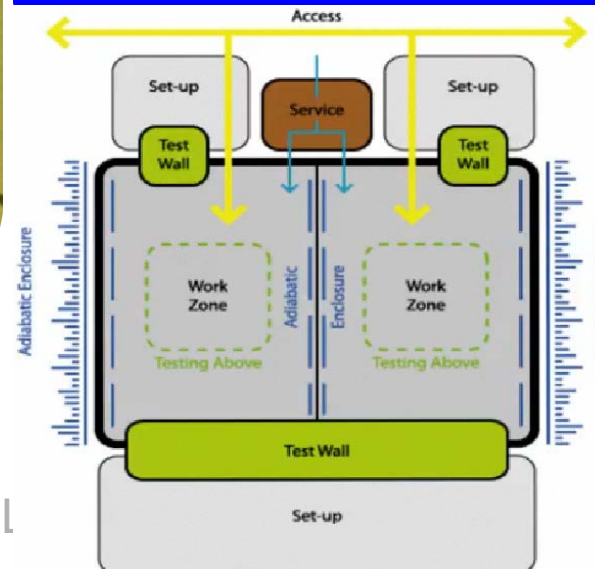
4 Outdoor Testbeds:

- 3 1-story
- 1 2-story

3 Indoor Testbeds

Lighting/Plug Load
Sensors/Controls
Design Lab

**Data Acquisition,
Monitoring, Control
System**



FLEXLAB

FACILITY FOR LOW ENERGY EXPERIMENTS IN BUILDINGS

**Exterior View
Rotating Testbed**



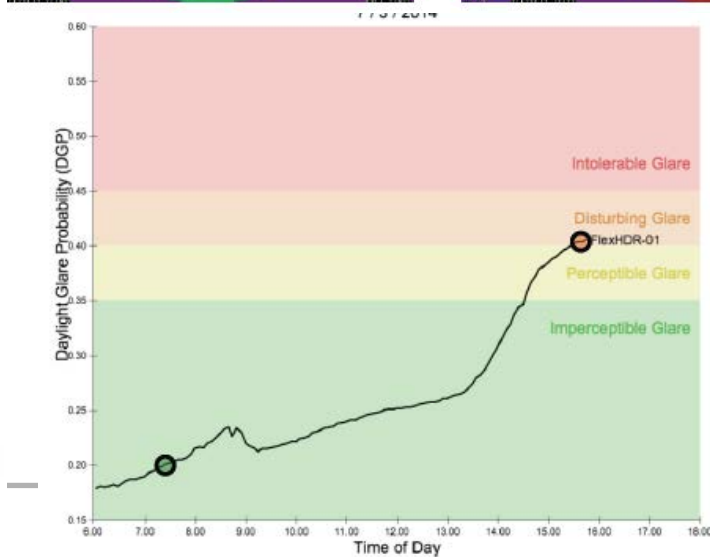
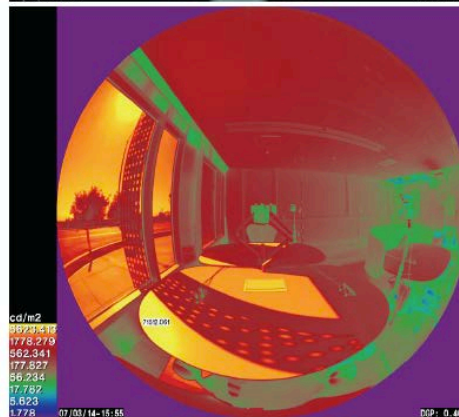
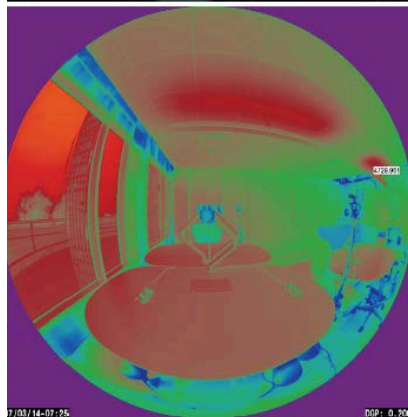
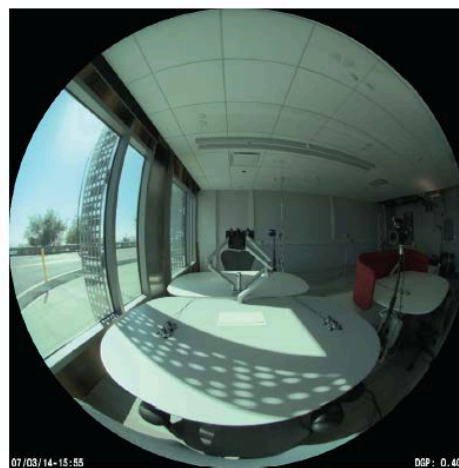
Interior View of Testing



Webcor/Genentech Test Program

3 Exterior Fixed Shading Designs Tested





© Berkeley



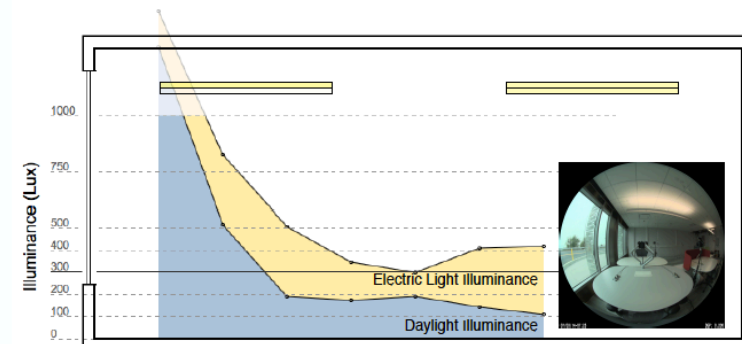
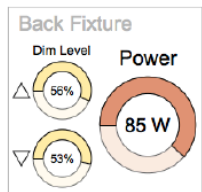
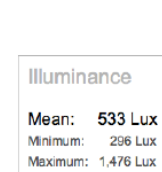
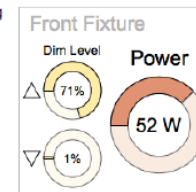
Glare Assessment

Can we Recapture floor space adjacent to curtain wall!

Lighting Energy

7:25 am

An overcast morning with electric lighting on to supplement daylight.



Challenge and Opportunities for Advanced Facades

- **Make high performance and energy efficiency a market advantage, not an extra cost or a risk**
- **Must Deliver Measured Savings!**
- **New Technology, Smarter Design → Win-Win**
 - **New Business Opportunities** → **Manufacturer**
 - **Design freedom and flexibility** → **Architect**
 - **Value-added benefits, e.g. better acoustics** → **Occupant**
 - **New performance benefits: e.g. comfort** → **Occupant**
 - **Modest/no extra first costs and large annual savings** → **Owner**
 - **Lower impact on global environment** → **Society**

April 20: Progress- 45 Years Since “Earth Day”

- **Technology Advancement -> Integrated Systems**
 - Glazing, coatings, shading, daylighting,....
 - Merge with Lighting, HVAC, building automation
 - Static → Dynamic, Integrated Systems Performance; IoT
- **Set New Design Expectations And Deliver Performance**
 - Building ratings, disclosure laws → “Guarantee”??
 - Shift from “payback” to broader owner “value proposition”
- **Field Test Data Critical to Building the Performance Case**
 - **Net Zero Facades Outperform Insulating Walls...**
 - Validate Tools with Measured Data
- **New Business Models- Public/Private Partnership, Collaboration**
 - Collaboration Risk but Huge Opportunity
- **Less Than 45 Years To Get It Right !**



Benefits of High Performance Building Facades

Improve
Occupant Comfort,
Satisfaction and
Performance



Occupant

Add Value,
Reduce Operating
Costs



Building Owner

Reduce Energy,
Greenhouse Gas
Emissions



Planet

More Information

Stephen Selkowitz

E-mail: SESelkowitz@lbl.gov

Current information and downloads at:

<http://buildings.lbl.gov>

<http://flexlab.lbl.gov>

<http://facades.lbl.gov>

<http://windows.lbl.gov/resources/LBNLresources.pdf>

<http://wem.lbl.gov>

http://windows.lbl.gov/comm_perf/newyorktimes.htm

