High Rise Northern Exposure

Helsinki, June 12, 2023

Glass and Facades–

Challenges and Opportunities in a Carbon-Constrained World

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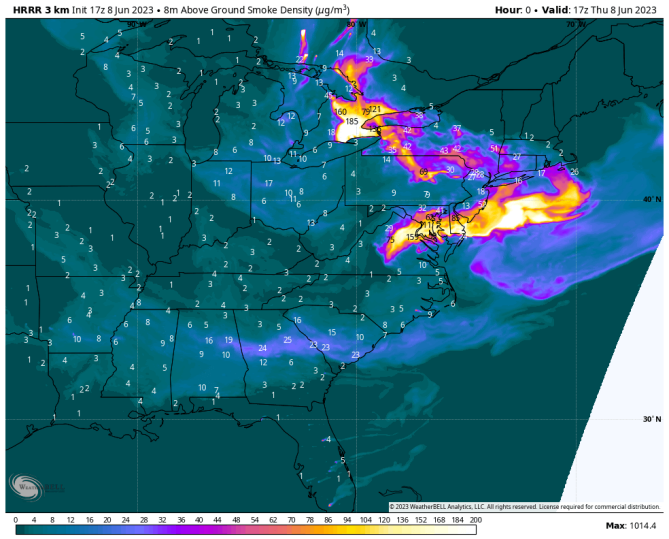
Façade Challenges, Risks and Opportunities

Trends and Issues that are Shaping, Reshaping the Glass/Building Facade Landscape

- Framing the Problem: Global Carbon Challenge
- Review Glazing/Façade Technology Options
- Explore Integrated Facade Systems
- Deploying building scale workable solutions
- Decarbonizing the Grid
- Reinventing the Building Industry
- Renovate/Retrofit

Carbon and Climate Change



“In order to change an existing paradigm, you do not struggle to try and change the problematic model.

***You create a new model and make the old one obsolete*.”**

Buckminster Fuller

Vision and Goals:
Potential Benefits of Advanced Facades

Improve Occupant Comfort, Satisfaction and Performance

Occupant

Add Value, Reduce Operating Costs

Building Owner

Reduce Greenhouse Gas Emissions

Planet

What's *Driving* High-Performance Buildings Today?

Energy efficient

Demand responsive

GHG/ Sustainable

Resiliency

Decarbonize

Economic competitiveness

Reduce Carbon/Energy Use?

Comfort

IAQ

Natural daylight

Outdoor views

Health + well-being

Productivity

Add Market Value?

How Do We Design/Redesign with "Net Zero" Glass/Windows/Facades…?

When Energy and Carbon Matter?
When People Matter?

New Construction
Retrofit/Renovation
Speed and Scale

Predicting the Future: From My Paper at GPD 1999:

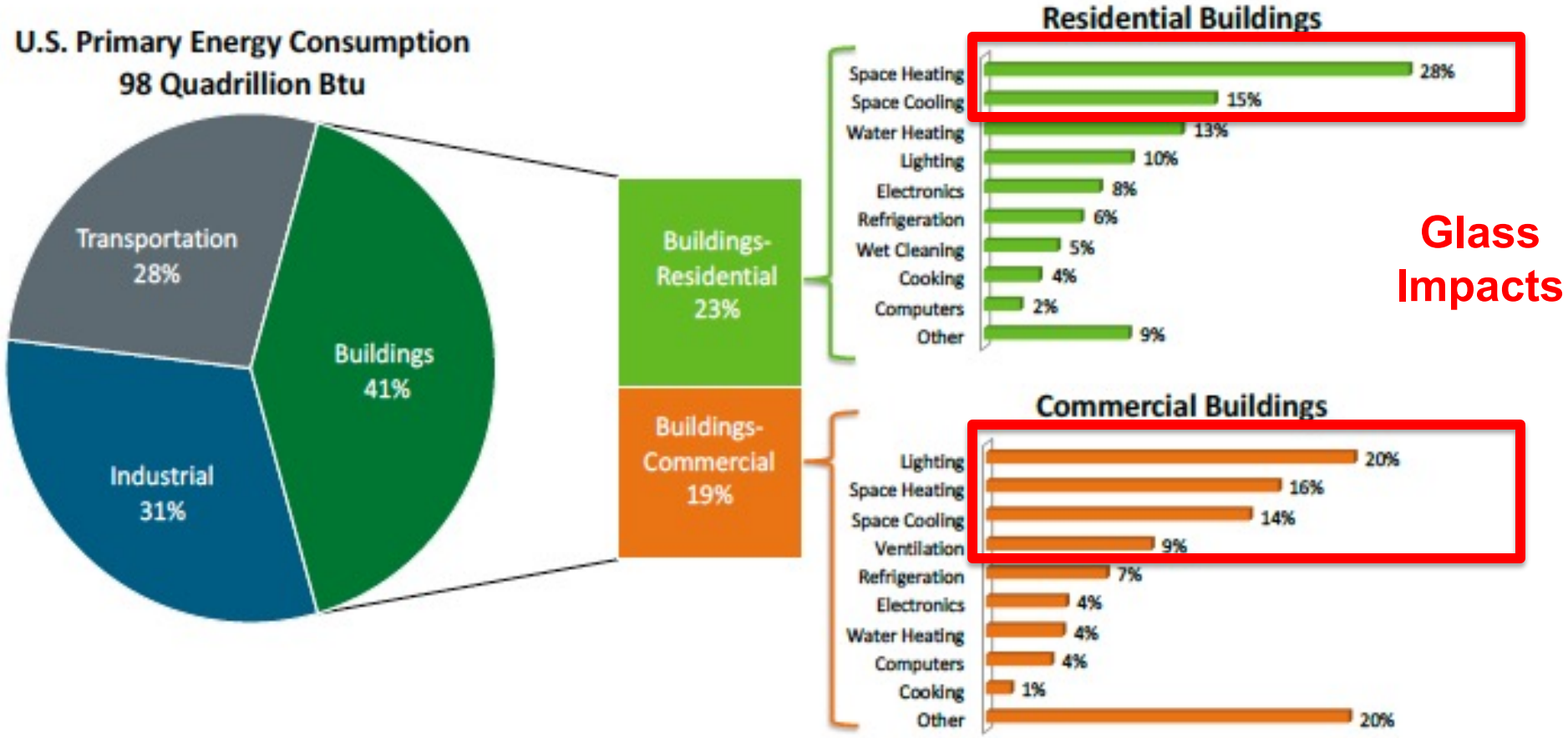
"Eight Factors Driving Glazing and Façade Design for the Next 20 Years"

- ***#1: Technology Improvements Will Continue to Enhance Glazing Performance.***
- ***#2. Glazings will become "Energy Suppliers" as well as "Energy Managers"***
- ***#3. Facades will be optimized for Daylighting and Natural Ventilation, …***
- ***#4. Glazings will be viewed as dynamic building elements rather than static components, and will function as an element in integrated building systems.***
- ***#5. As buildings become more complex, better computer tools will be developed for both design and operations.***
- ***#6. Changing business perspectives: occupants demand better work environments***
- ***#7. Utility restructuring will impact the way buildings are designed, built and operated.***
- ***#8. Global environmental concerns will play a larger role in public and private decisions.***

*"As new, highly innovative systems are tried on leading-edge buildings, **the experimental systems of the last decade will be refined and become the mainstream solutions in the years ahead."***

Business-as-Usual Isn't Working
Disturb, Disrupt Status Quo ...
Constructively Transform the Building Industry?

Role of Buildings and Energy Use in U.S.



Glass Impacts

Window "impact" on building loads ~ heating, cooling, lighting = ~40%

~ $50B /yr

CRITERIA/METRICS

For Selecting Glass, Windows and Optimal Facades

- Energy/Carbon
  - Operating
  - Embodied
  - Electric grid
- Occupants
  - Biophilia
  - Comfort
  - View/Privacy
  - Productivity
  - Daylight spectrum
  - Health
- Circular Economy
  - Recycled Materials

- Affordability
- Aesthetics
- Security
- Fire
- Acoustics
- Structure
- Weatherproof
- Maintenance
- Durability
- …

High Performance, Net Positive Energy Façade??
My Hypothesis:

- **It is "possible" to design a glass/façade system that will "outperform" an insulated, opaque wall,**
  - For **"any climate"**
  - For **"any glass area"**

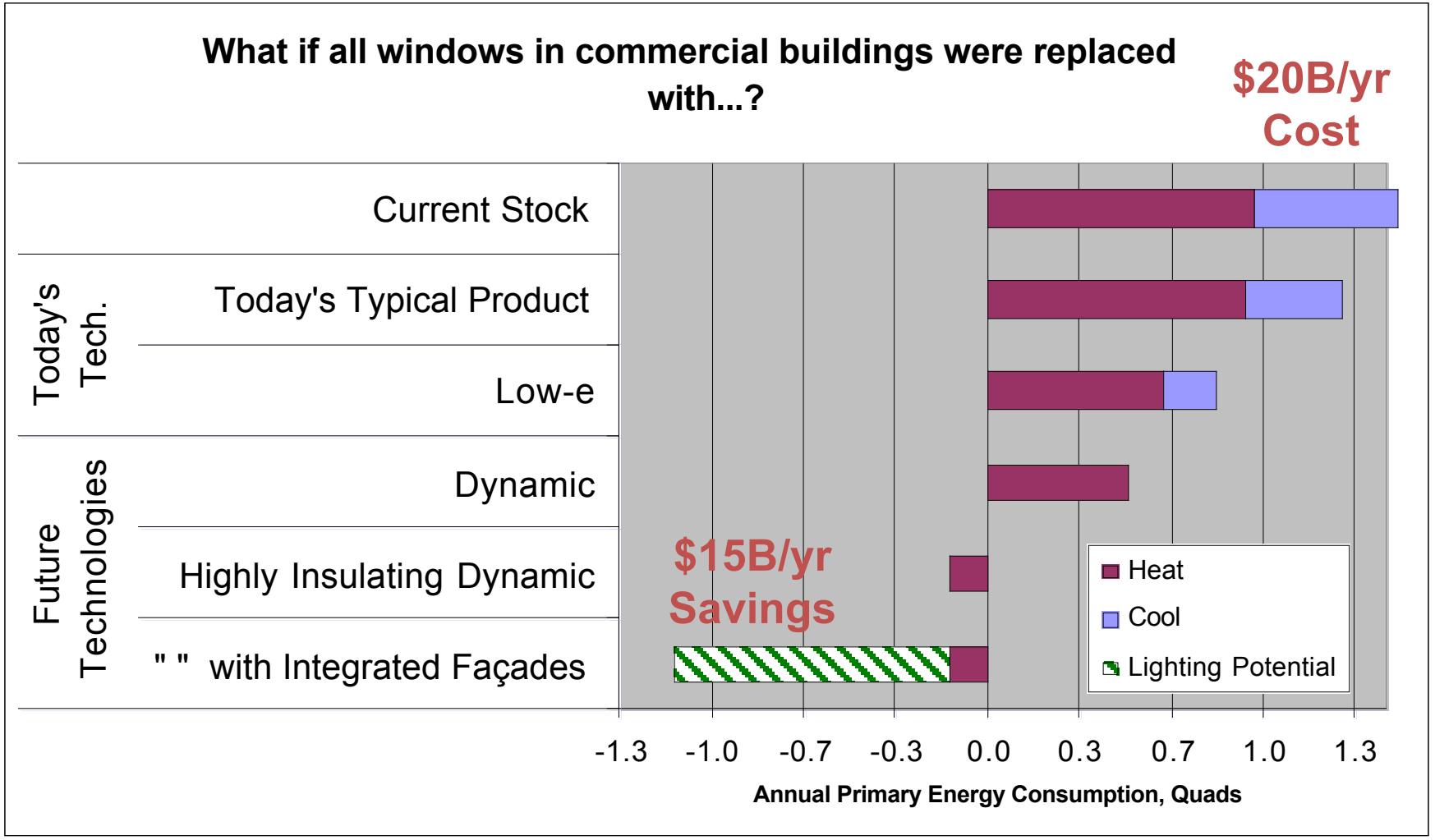
BUT
today

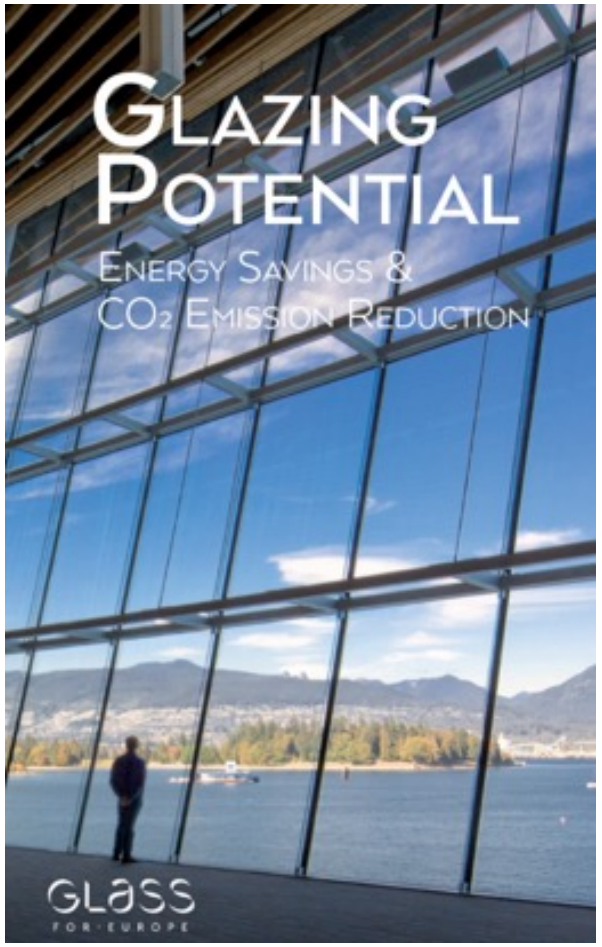
- **Not easy to design;**
- **Difficult to construct and commission**
- **A challenge to operate effectively**
- **May Cost More…**

- **Rethink everything, to do this at scale…**

U.S. Commercial Building Window Energy Use

Converting a $20B/yr cost to a $15B/yr Net Surplus





EU Glazing Energy Study

Technical Vision for Window/Façade Energy Impacts

Net Loss -> Neutral/"Net Zero" -> "Net Positive"

"Double glazing – Triple Low-E Glazing – Double Envelope Façade"

Energy → peak demand, carbon, $$

Business Vision for "Net Zero"Window/Façade

New Business Opportunities

More Value Added Product Sales

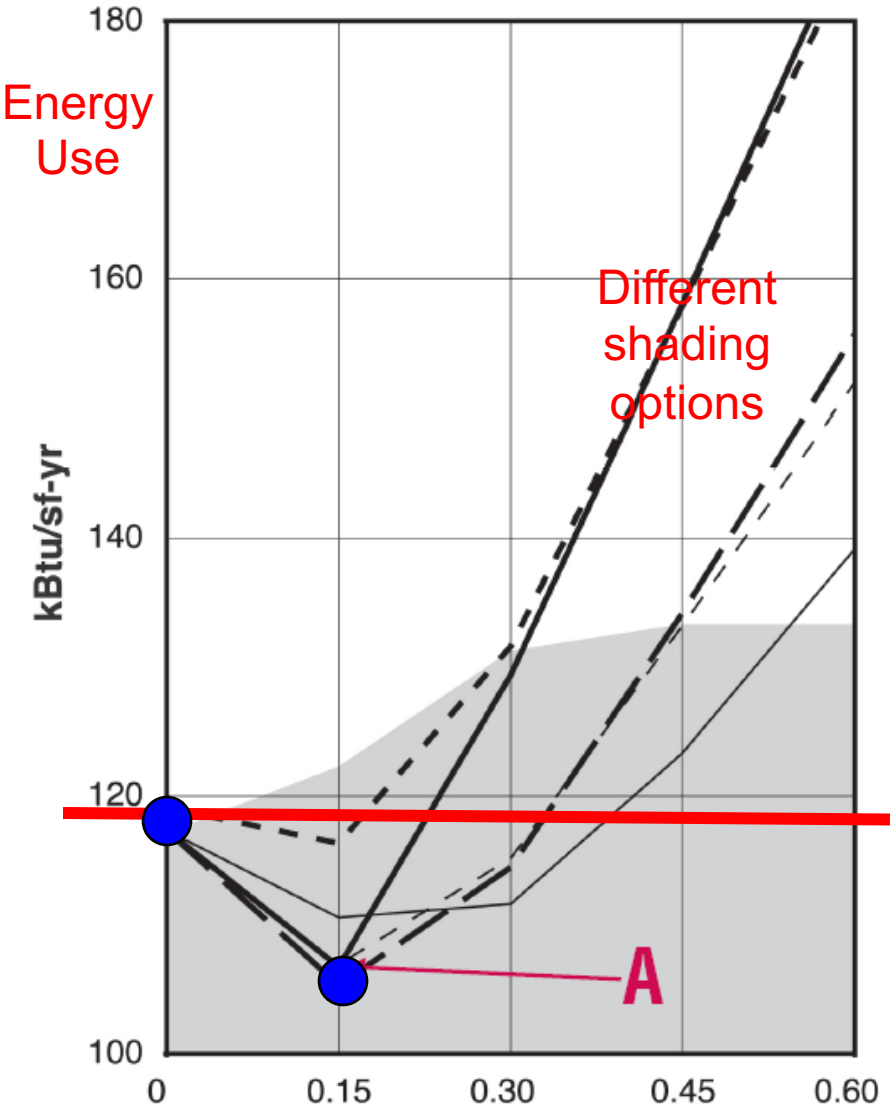
Design Freedom → WWR → Building Codes

Occupant Benefits: View, Comfort, Health

Increased Real Estate Market Value

Code Compliant, double glazing

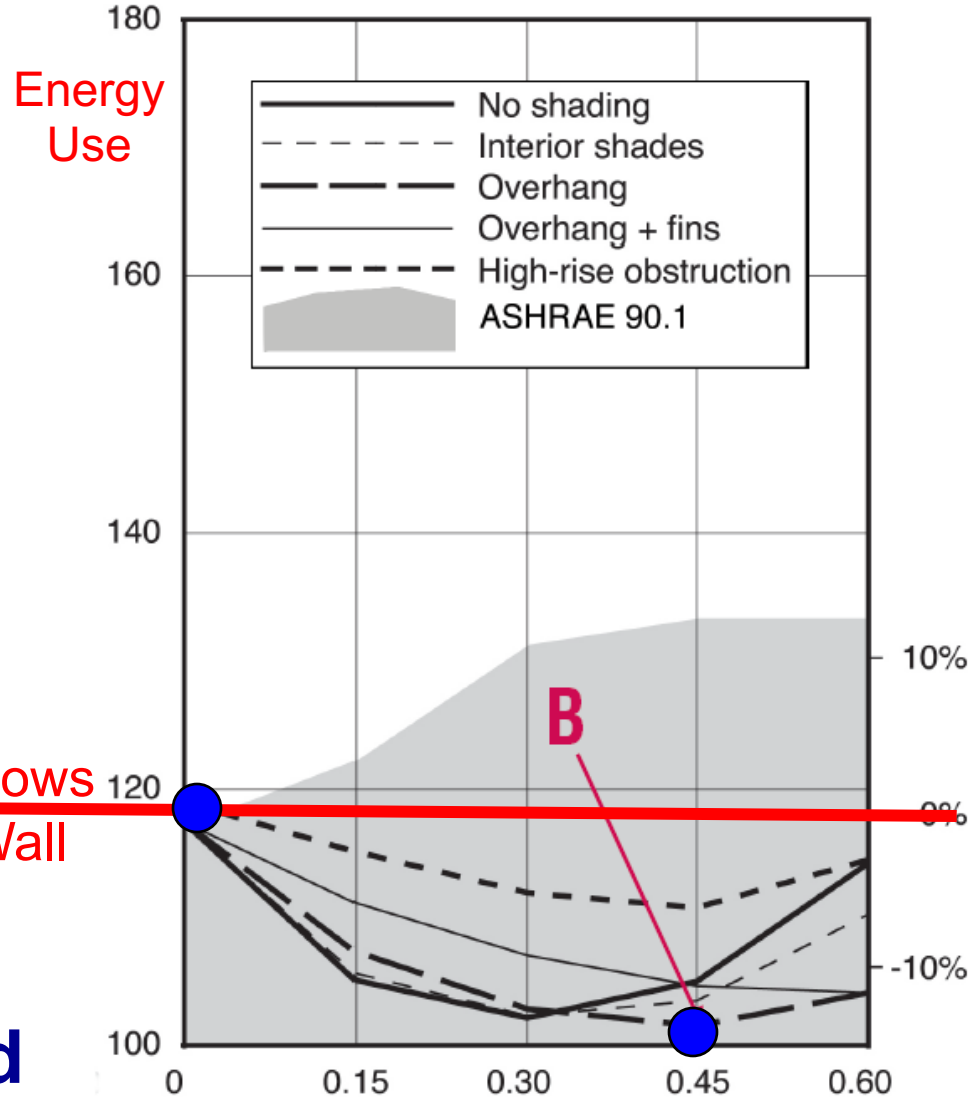
U=0.60, SHGC=0.60, VT=0.63



Window-to-wall %

High Performance, triple, low-E glazing

U=0.20, SHGC=0.22, VT=0.37



Window-to-wall %

0% Windows
100% Wall

Cold Climate

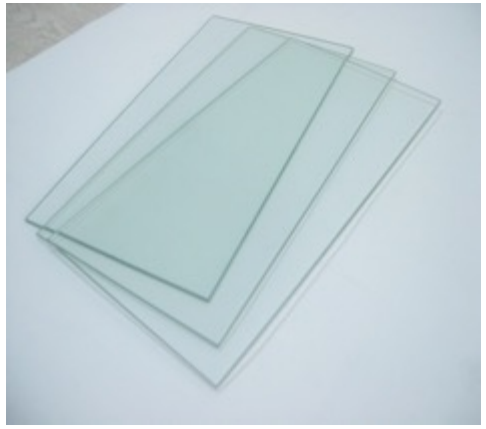
"Zero Net Energy" Facades
Goal: Energy Losers --> Neutral --> Energy Supply

4 Technology Challenges, Vary w/ Climate

- **Heating Solutions**
  - Reduce heat losses so that ambient solar energy balances and exceeds loss
  - Need lower heat loss technologies
- **Cooling Solutions**
  - Reduce solar loads, ventilate
  - Static control -> dynamic control
- **Daylight Solutions**
  - Replace electric lighting with daylight
- **Electricity supply options**

Glazing and Facade Technology Landscape:
"Scales" for Innovation
Nano ←→ Micro ←→ Macro

"1μ" coating → "1mm" glass → "1m" Window system, shading → "10-100m" Building Systems



#1: Highly insulating, low heat loss glazing

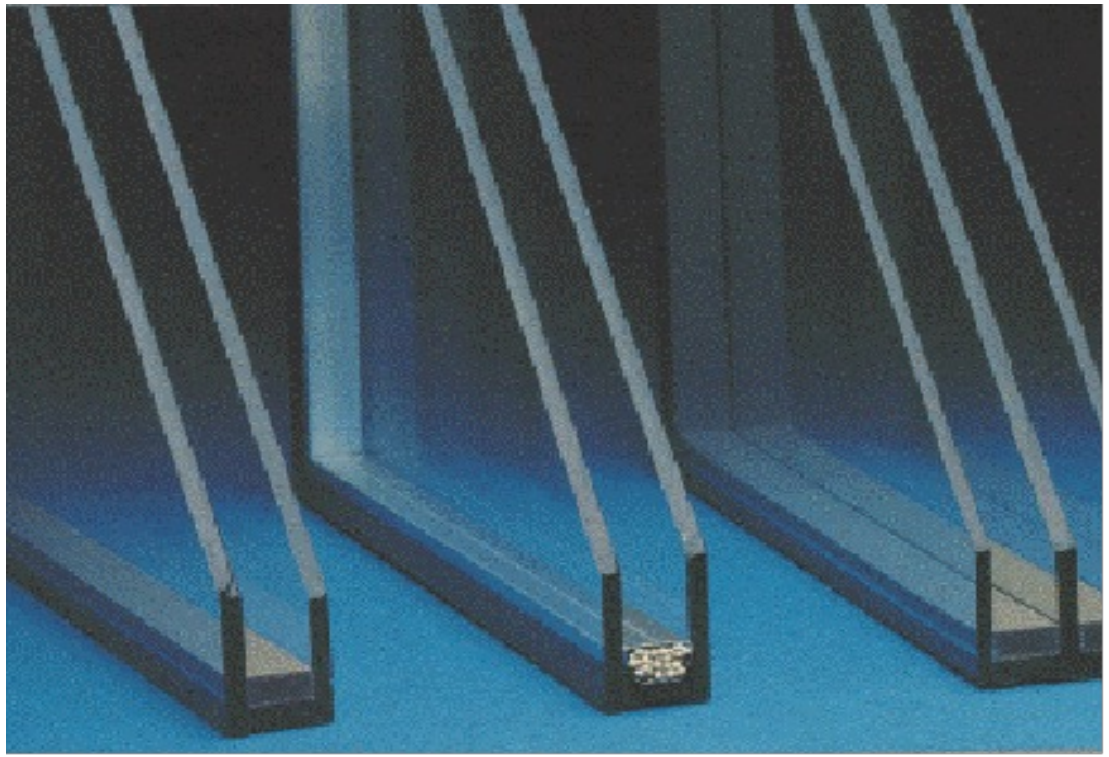
Today: U-value ~ 1.7 W/m^2-K

Nearer Term Objective: U-value < 1.1 W/m^2-K

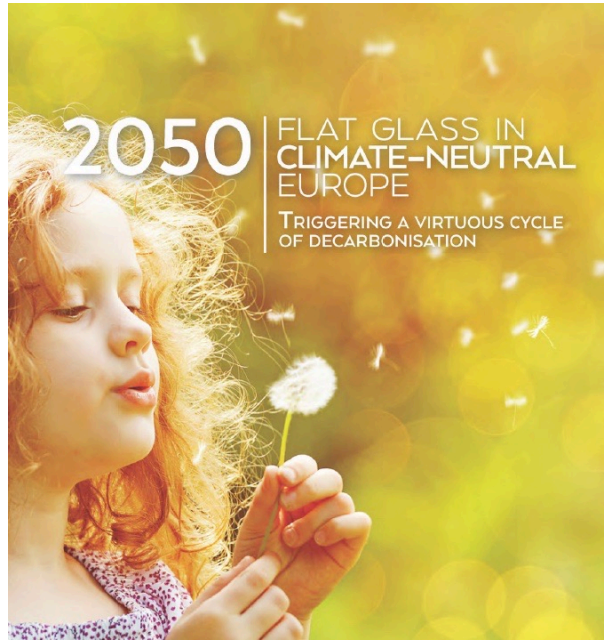
Longer Term Target: U-value < 0.5 W/m^2-K

Approaches:

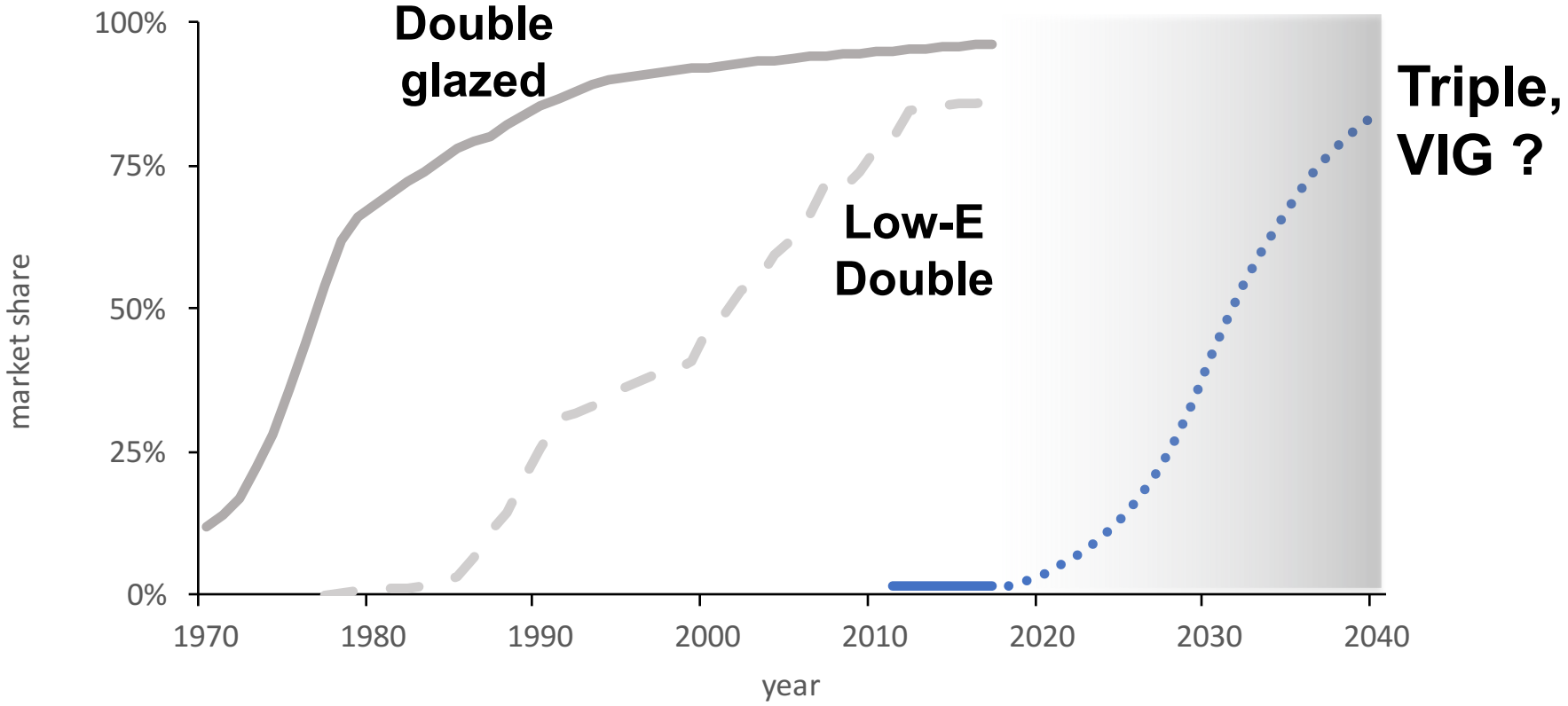
- **Low-Emissivity Coatings**
- Low Conductance Gas Fills, Vacuum
- “Warm edge” low conductance spacers
- Insulated Frame Systems



Glass for Europe



Can we **Repeat** the **Market Adoption** Success of double low-e → Triple or VIG, but Faster



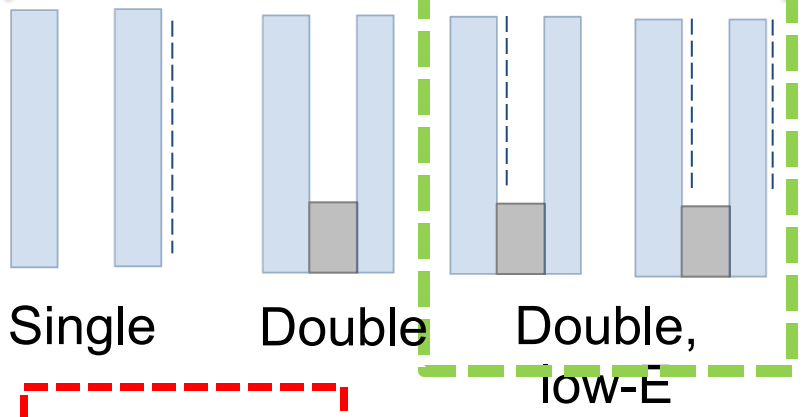
Innovation push
tech development

Market Pull
Utilities
Energy Star

Codes and standards

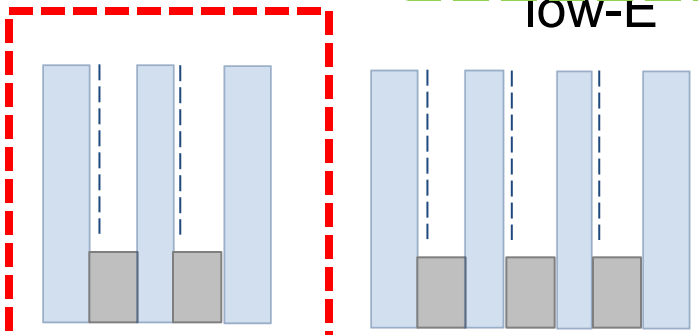
HIGHLY INSULATING GLAZING SOLUTIONS:

Market Today **U ~ 0.1.4** W/m²-K



Single Double Double, low-E

U ~ 0.6



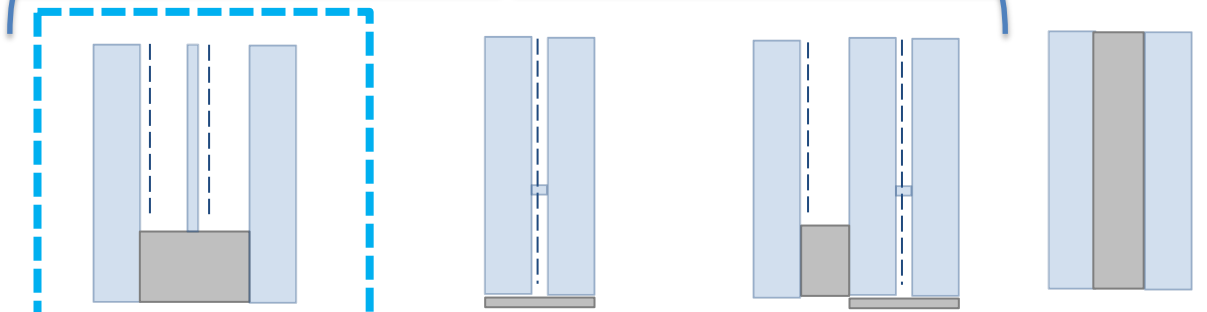
Two low-e Triple

Three low-e Quad

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

U ~ 0.6 W/m²-K

Emerging Future

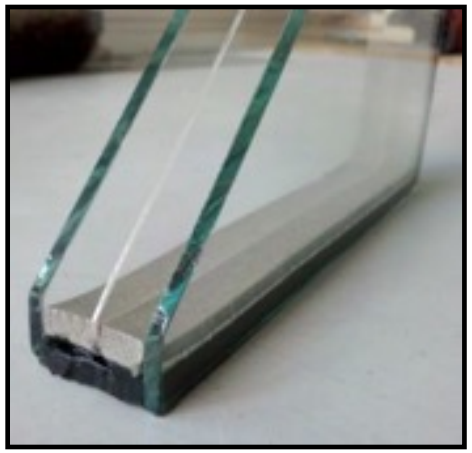


Two low-e, Thin glass single seal Ar/Kr

One low-e Vacuum

Two low-e Vacuum Hybrid

Aerogel



Triple and Quad Thin Glass IGU Options

~0.5mm – 1.2mm float/fusion glass

Safety glazing options

Large size, ~ 2m x 3m

On the Market

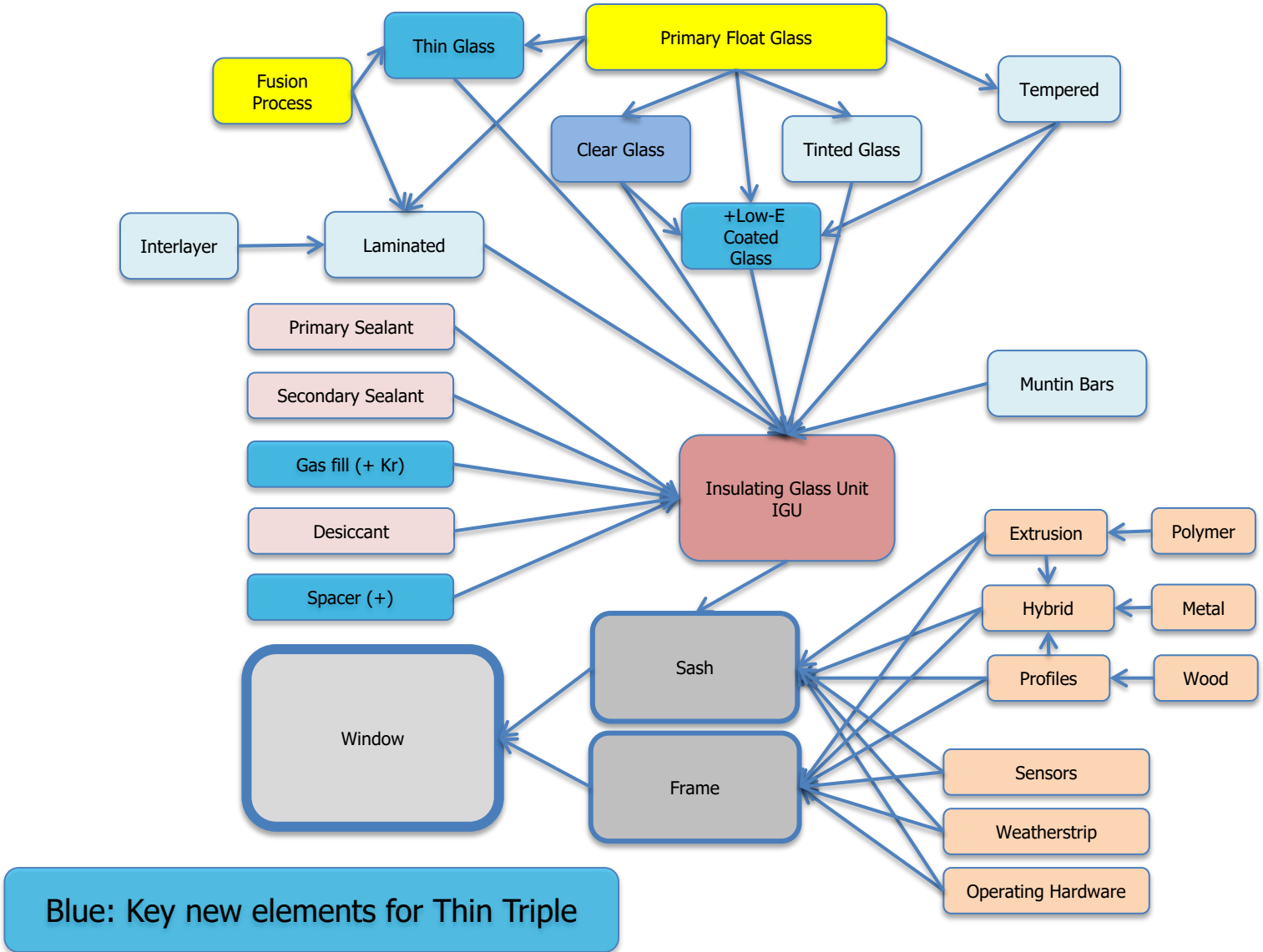
Single Spacer options

Lower Embodied Carbon

Source: Alpen HPP

Assembling Components into a Thin Triple/Quad Window:

Using the Existing Glazing/Window IGU Ecosystem



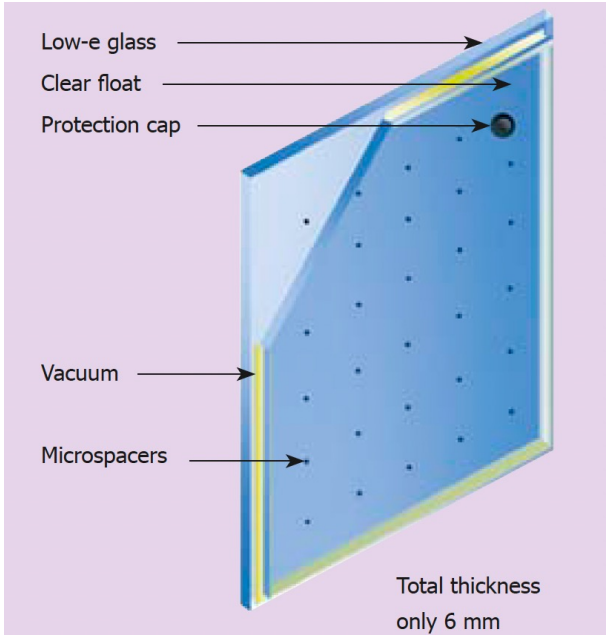
Automated Manufacturing -> Lower Cost

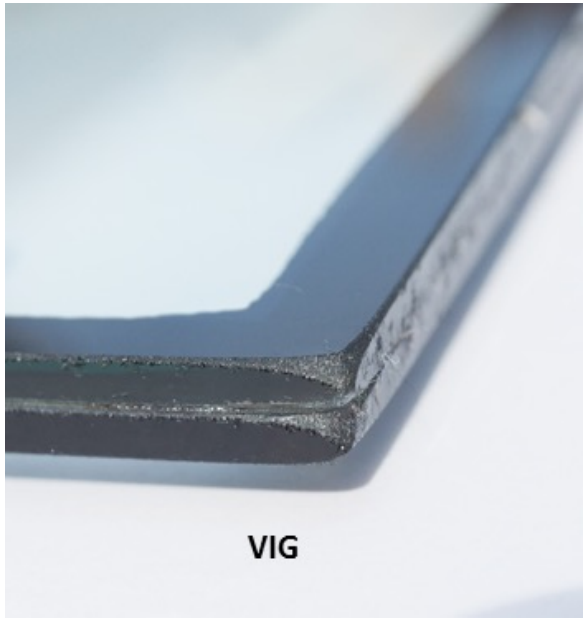
High speed (1000+ IGU/day)
Single or **double** spacer
High **gas fill** efficiency
Adjustable gap widths

Emerging Technologies: Vacuum Insulating Glass, VIG

- Limited Market availability for 20+ years
- Successful projects
- New designs: hybrids
- New R&D; New Manufacturers

- **Challenges**
  - Cost
  - Volume manufacturing
  - Durability/lifetime
  - Size/Shape constraints
  - **Integration with window frame**

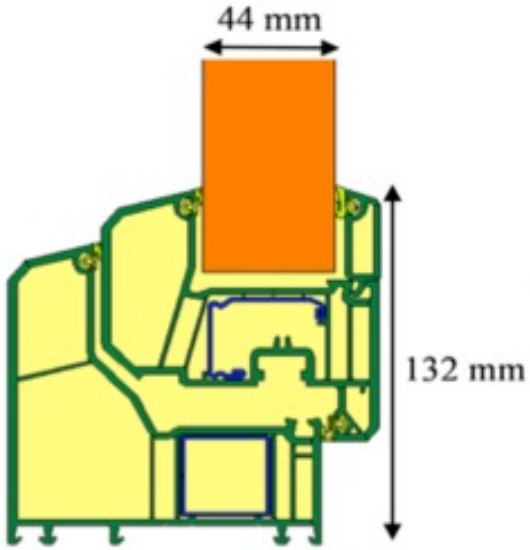


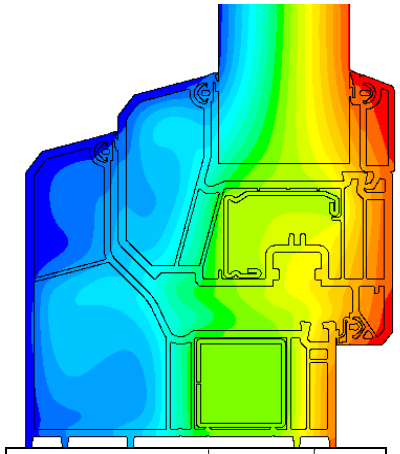


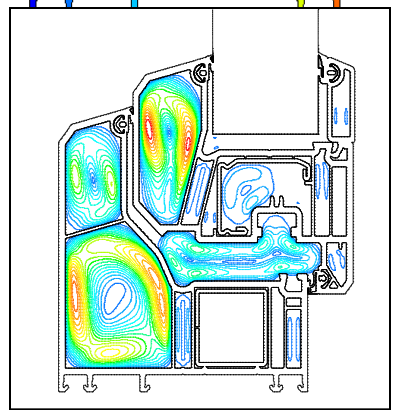
Low Conductance Window Frames

- **Key to achieve even lower window U**
  - **Frame/Window Ratio: 5% – 40%**
- **Whole window properties vs IGU**

- Condensation resistance
- Improvements with all materials
  - Aluminum w/ thermal breaks
  - Non-metallic, hybrid
- **Spandrel Panels**
- **Thermal Bridges- window/wall**
- **Double envelope w/ air flow…**







#2: Glazing Optics:

Transparency
Daylight

Solar Control? Glare?

Solar-Optical Properties of Glass

- **Highly Transparent**
  - View, Daylight
  - Passive solar gain in winter

- **Solar Protection**
  - Reduce Cooling energy
  - Minimize cooling system size and cost
  - Manage Glare

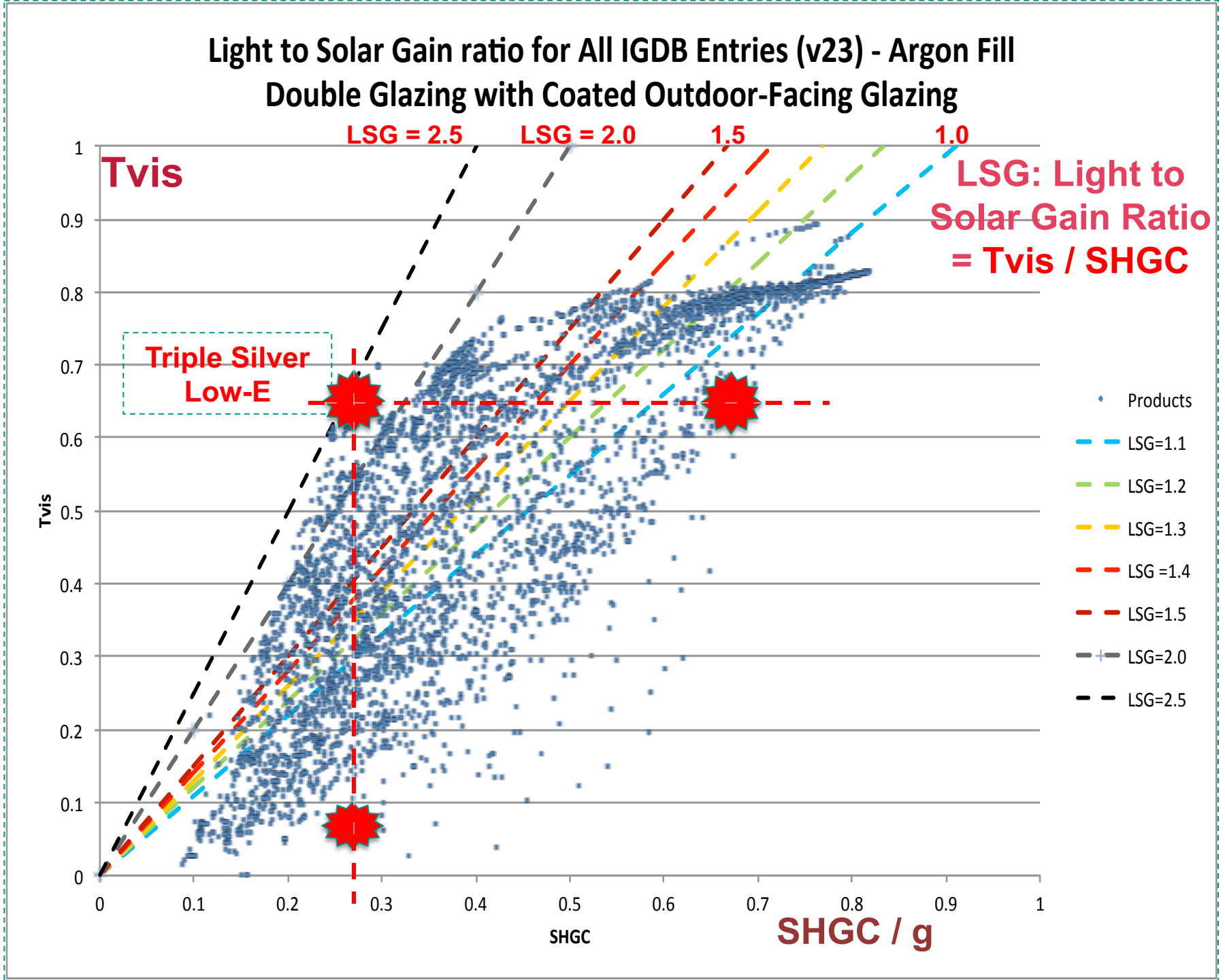
- **Control Options:**
  - Spectrum – “tuning”
  - Intensity – “dim”
  - Distribution into Room – “redirection”

Solar: 0 – 1000 W/m^2
Daylight: 0 – 100,000 lux

Glazing Ecosystem:
IGU Options

5000+ entries in LBNL Data Base

Selective Glazings:
Tv = > 2 x SHGC



Solar Shading: Active and Passive/Fixed **Options**

Shading and Facades:

Interior/ Exterior; Integral/Add-on; Manual/Auto

Interior/Exterior

Automated, Operable Shading Systems Work:

30-80% Reductions in Cooling Loads, Manage Glare

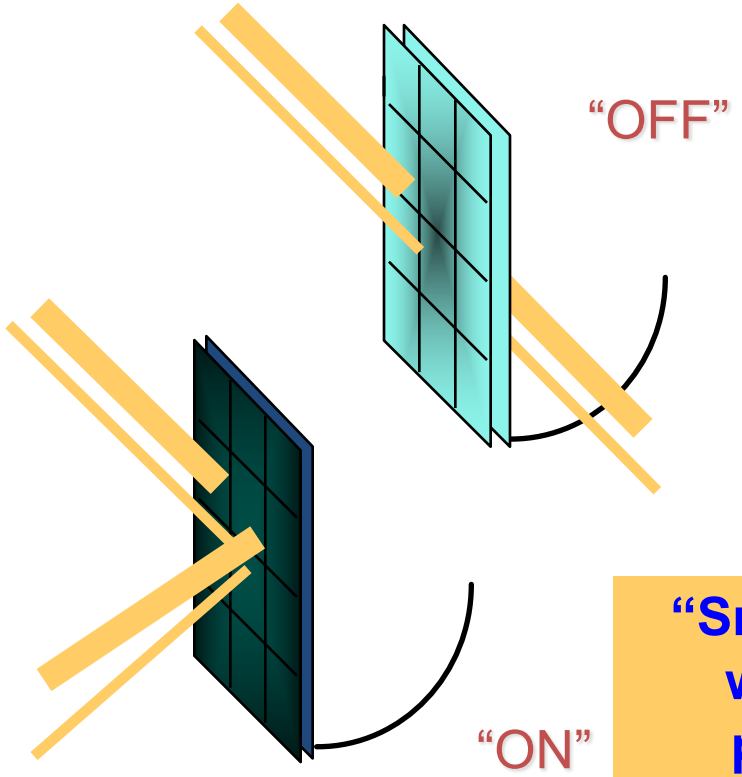
“Effective” Automation Maximizes Savings

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

Dynamic Control of Window Solar Gain, Daylight

Balancing Cooling <> Daylighting, View <> Glare
Optimized, Flexible control of solar gain, daylight

- **Mechanical Shading**
  - Interior, exterior, between-glass options
  - Range of dynamic coating options
- **Passive control - glass**
  - **Photochromic - light sensitive**
  - **Thermochromic - heat sensitive**
- **Active control - glass**
  - **Liquid Crystal**
  - **Suspended particle display (SPD)**
  - **Electrochromic**



"Smart Glass": w/ variable properties

Tvis: .01 → .60
SHGC: .09 → .5

Engineering and Occupant Response Studies with Switchable Electrochromic Windows

- LBNL Façade Field Test Facility ~2004
- First building tests: 1999 Oakland Federal Building

Large Scale EC Applications 2015+

New Options: Gradient Light Control

Source: SageGlass Harmony

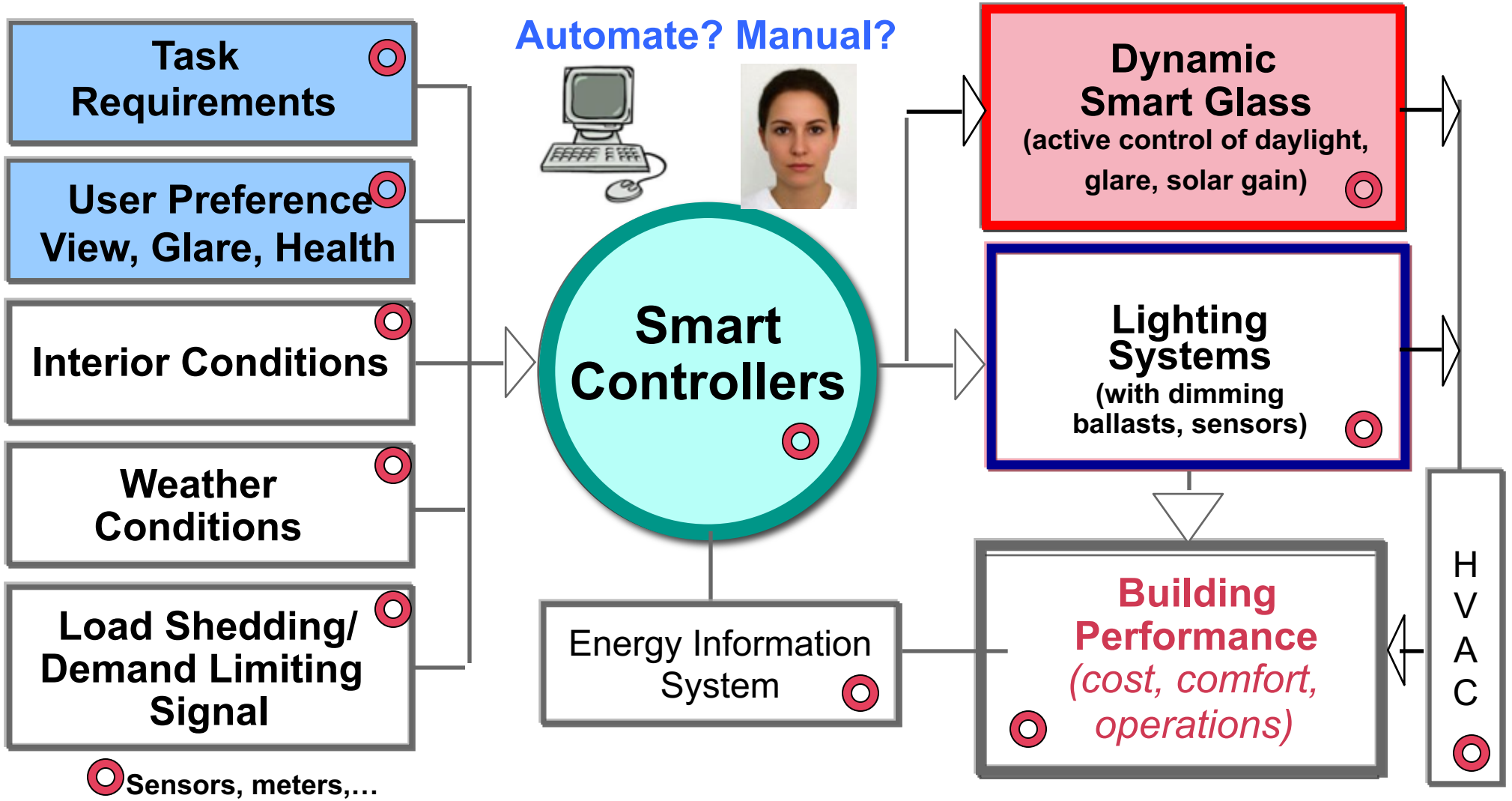
Current/Ongoing Technology Innovation

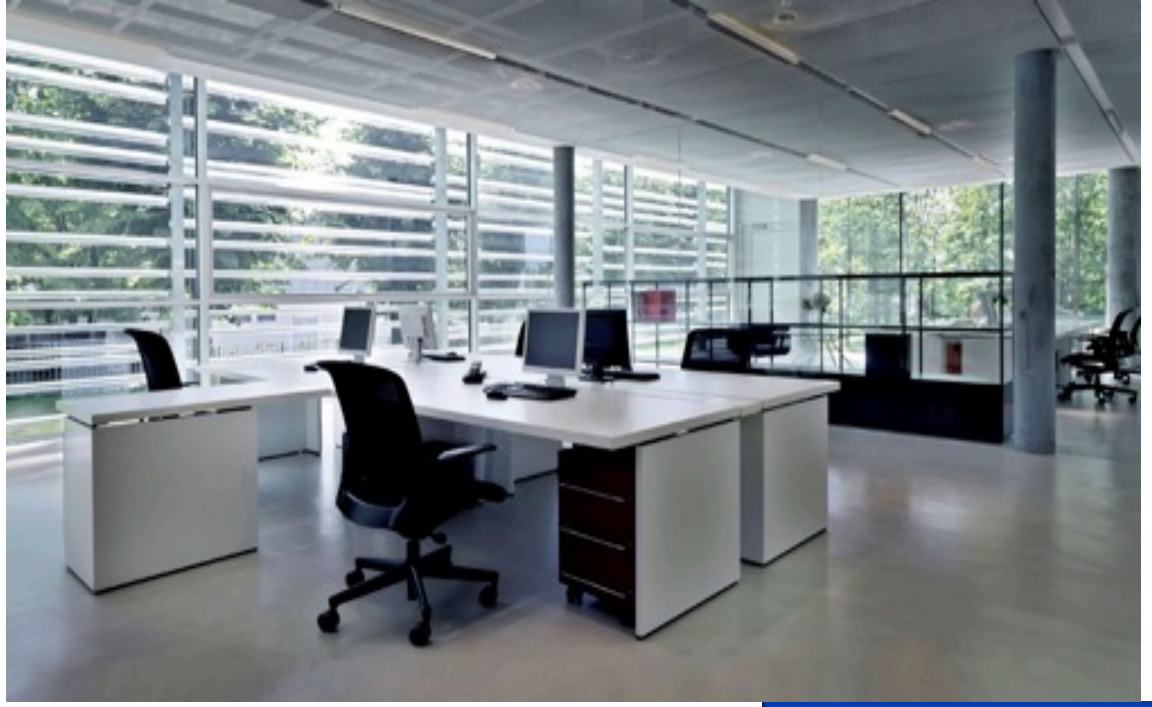
- **Speed and switching range**: "more responsive" Tv<1%:darker/reflective
  - Improved materials, new devices, e.g. Liquid Crystal
  - Anticipatory cloud sensing
- **Color: "more neutral"**
  - New EC materials
  - Different device mechanisms
  - Glazing IGU Design
- **Device Cost: "Lower..."**
  - Novel switchable materials and approaches
  - New materials/deposition process- > Manuf. process
  - New device design/fabrication- faster assembly, higher throughput
  - Supply chain structure
- **Façade System Integration/Cost + New U.S. Tax Rebates – 6-50%**

  Interoperable building controls
  - **Façade integration/standardization**
  - **Shared sensing and controls infrastructure with lighting etc**

Exploring Intelligent Control Systems:

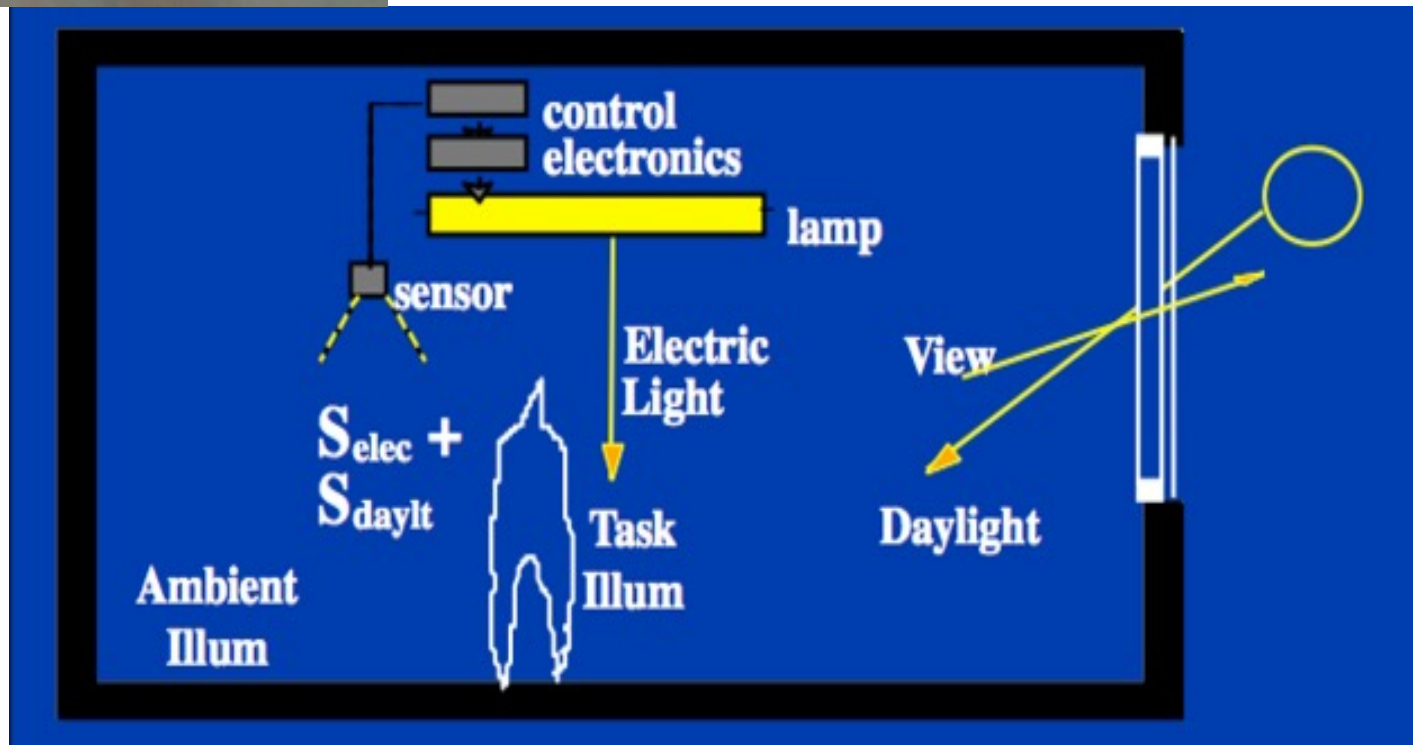
Optimal performance of dynamic windows requires full integration with building systems





#3: "Daylight" Remains a Defining Feature of Many Building Spaces

Daylighted Spaces vs (Day)Lighting Control Elements



Light/Daylight ← → People

View

Appearance/Aesthetics

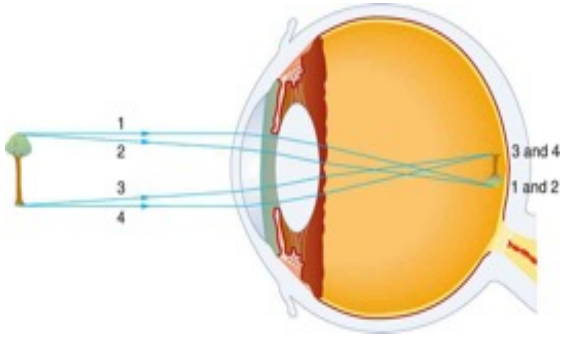
Visual Performance

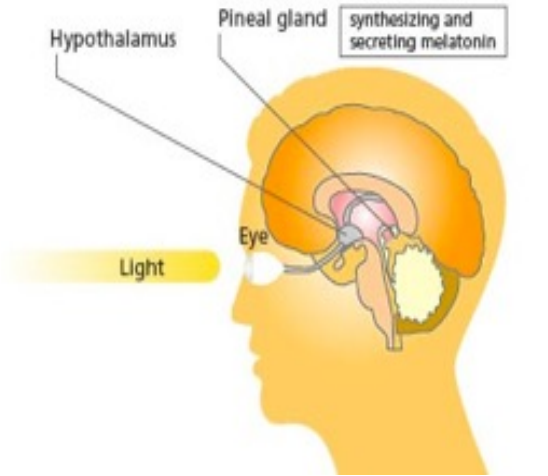
Productivity

Visual Comfort

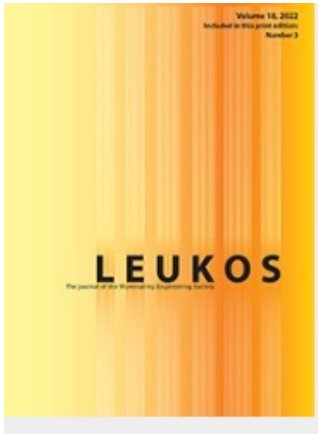
Health

Biophilic Design





View and Daylight



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EDITORIAL

Window View Quality: Why It Matters and What We Should Do

48 co-authors

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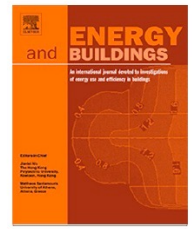

Advocating for view and daylight in buildings: Next steps

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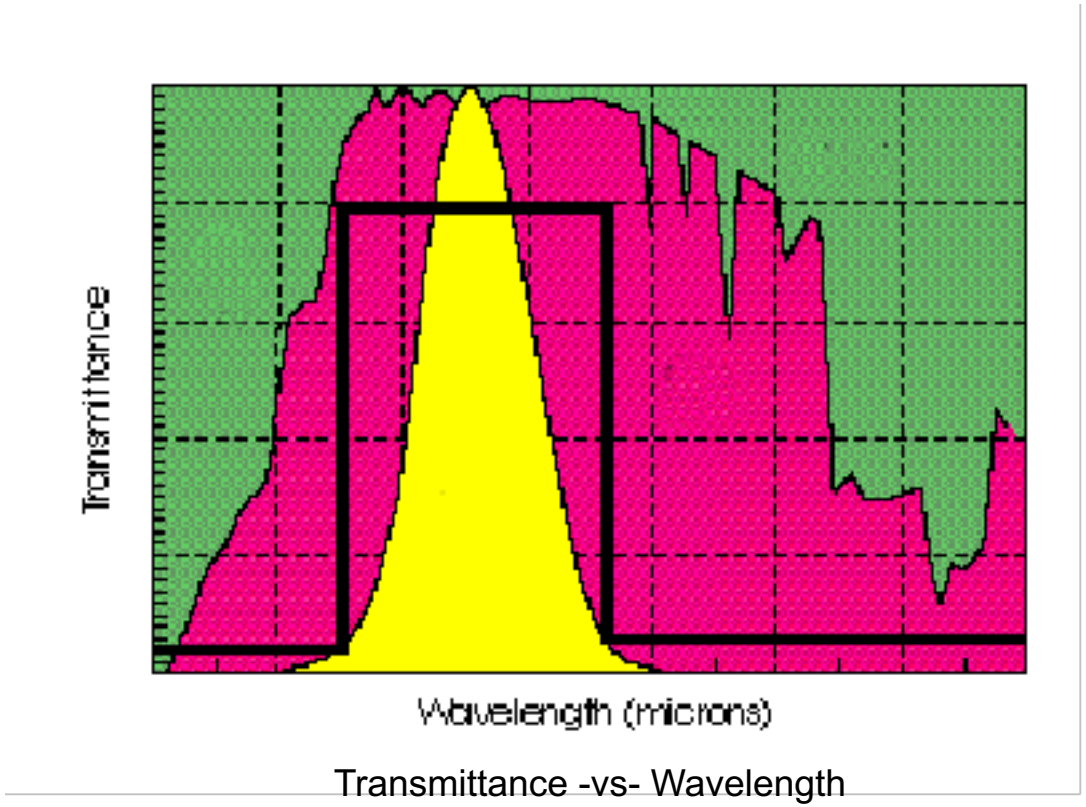
Spectrally Selective "Cool" Glazings

- Transmit light, reject near-IR heat
- **LSG = Tv/g > ~2.0**
- **Equal daylight with ~40-50% of solar gain**



Transmittance -vs- Wavelength

Technology:

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

- **Widely Available: New and Retrofit**
- **Low Cost**

Extend Daylight Deeper into Floorplate:
Daylight Redirecting Solutions

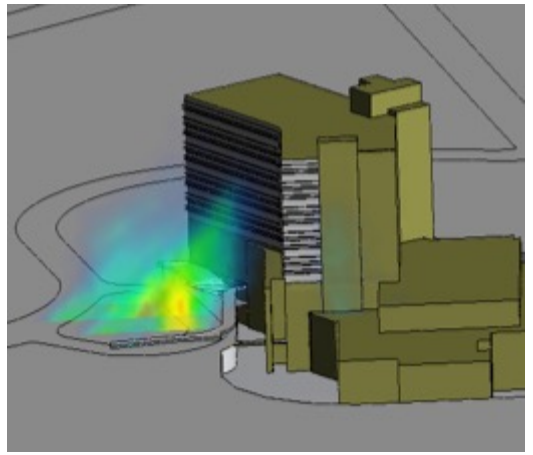
(normal daylight depth ~ 2.5 x glass height)

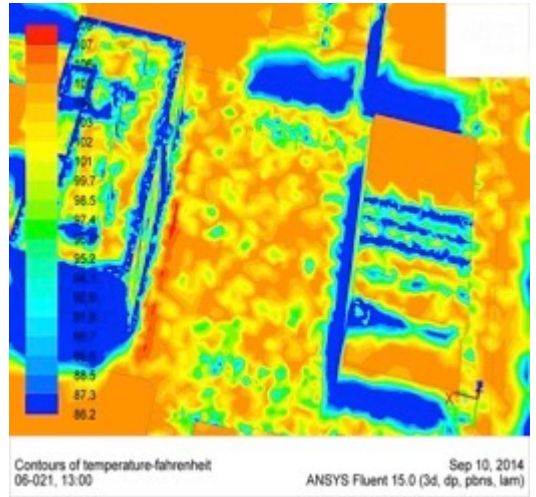
Light Shelves and Louvers

Daylight Redirecting Prismatic Film

Framework for Assessing Solar/Glare Impacts External to the Building

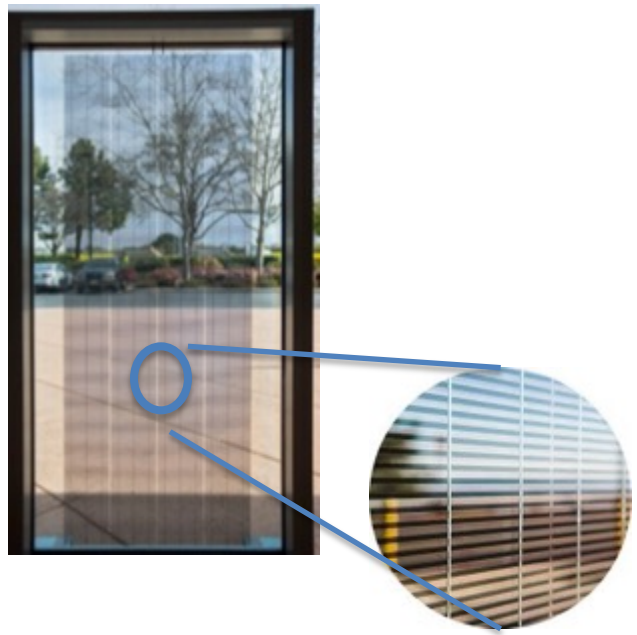
- **Internal "Perspective"**
  - Daylight illuminance <–> Visual Comfort/Glare
  - Solar Heat Gain <–> Thermal Comfort
- **External "Perspective"**
  - **Glare**
    - Pedestrian
    - Vehicles
    - Occupants of adjacent buildings
  - **Solar Heat Gain** (thermal. comfort impacts)
    - Outdoor areas- impact on people, vegetation
    - Adjacent Buildings
    - Urban heat island "microclimate"





#4: Converting Sunlight to Electricity

- **Electricity from the Sun**:
  - **Building Integrated Photovoltaics: BIPV**
  - **Options for view glazing**
    - Crystalline Cells
    - Expanded Cells
    - Amorphous
- **Solar Thermal Envelope**
  - Hot Air
  - Hot Water
- **Design Options**
  - Highlight PV
  - Hide PV



“Kit of Parts” For BIPV

Glazing element

Spandrel Panel

Wall Panel

Roof Panel

Shading Panel

Color, Patterned,…

Design, cost challenges

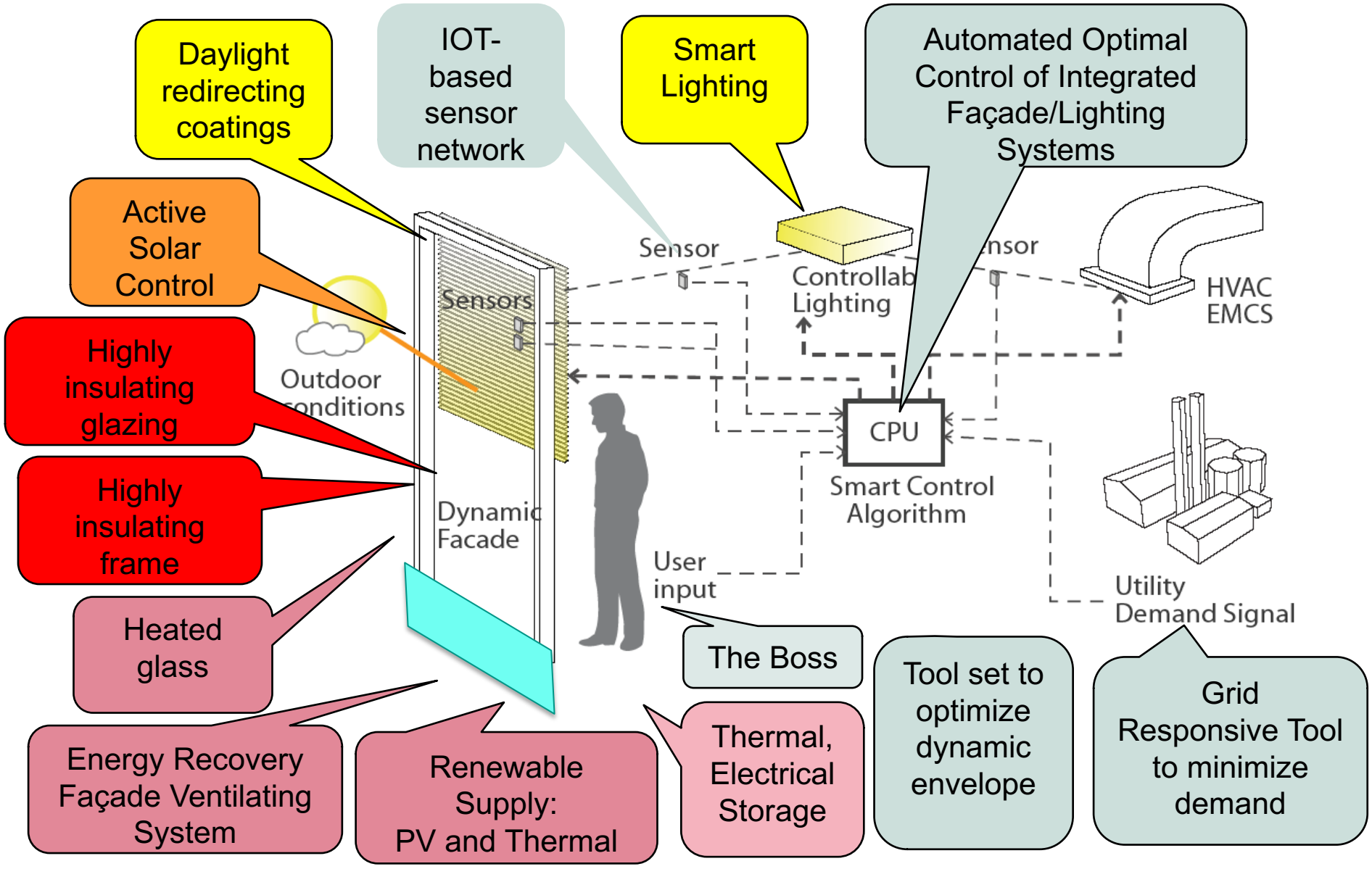
Electrical integration

Clear PV - but lower efficiency, power

Kit of Parts → Integrated Building/Facade System

- **"Optimize" – with what goals ?**
  - **Energy, carbon, comfort, view,…**
  - **Vs: Building type, climate, orientation, …**
- **Vision: "Windows outperform Insulated Walls"**
  - "Active" and "Smart" Elements
  - Climate Control, serve as Powerplant?
- Façade Controls ←→ Building Control
- Design – Build – Operate – Renovate …
- Finance…

Facades are Intrinsically “Integrated systems”



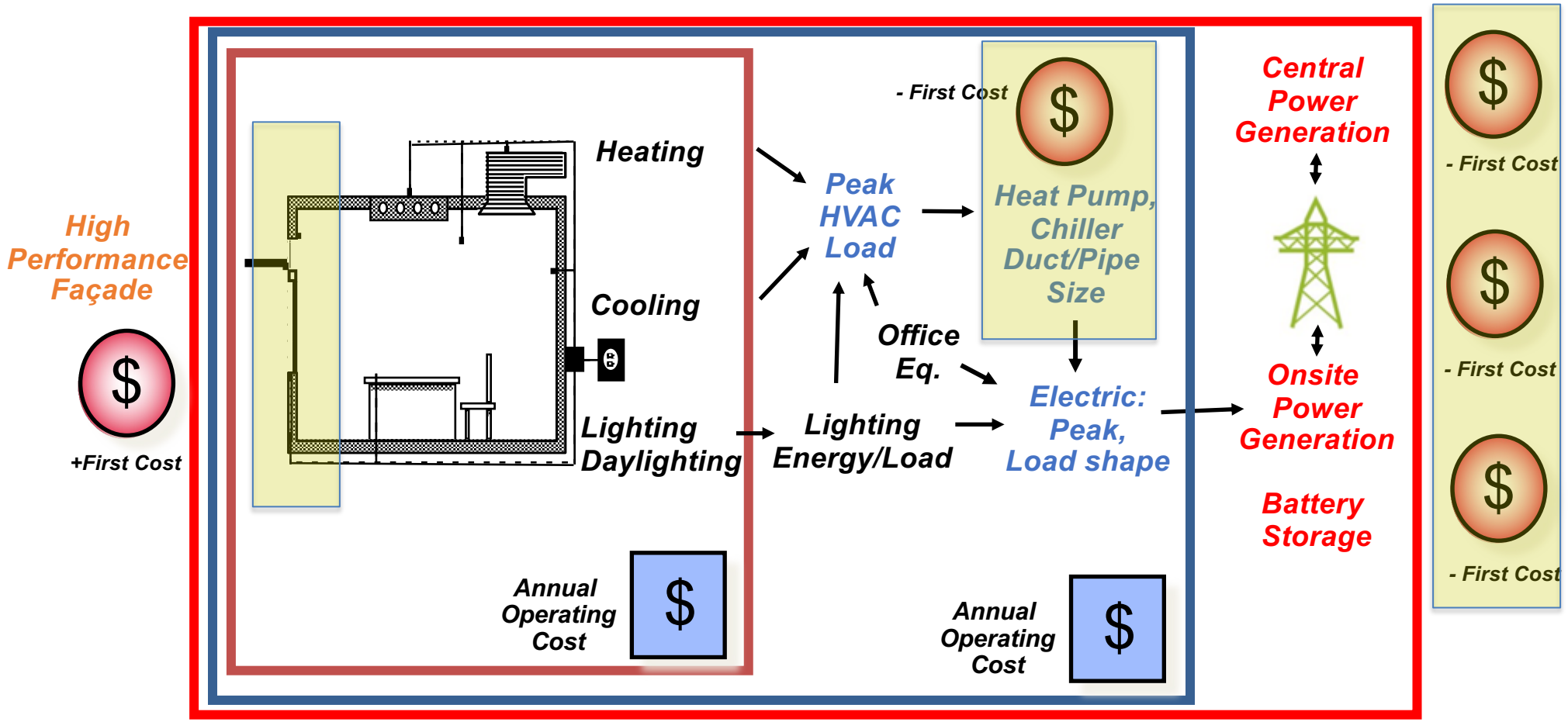
- ✓ Light
- ✓ Glare
- ✓ Solar Heat Transfer
- ✓ Thermal
- ✓ Ventilation
- ✓ Power Generation
- ✓ …

Components → Integrated Façade System

Oldcastle

Who Pays for Integrated Facades?

Improved Façade → Lower HVAC System Cost → Lower Grid Cost



How Do We Build Owner Confidence in these Systems Integration Challenges?

Demonstration Projects

“Field test” at comprehensive, but practical scale before major buildings

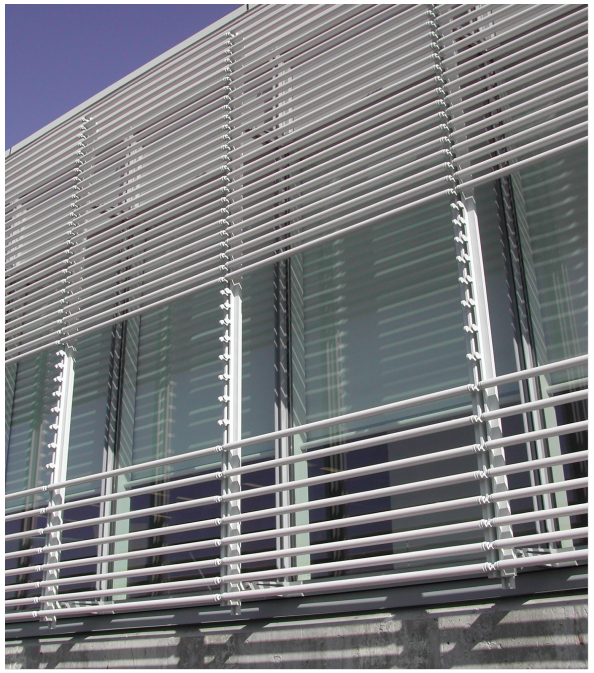
“De-risk” design, cost, operations

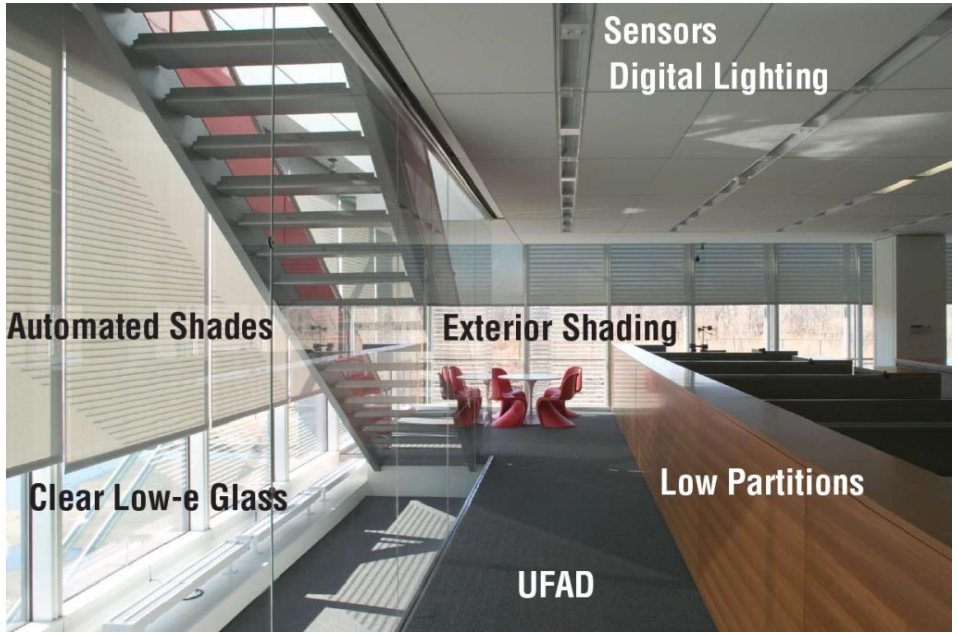
Mockups: Beyond air/water/structural

New York Times HQ, NYC 2003-2007

Largest Installation of Automated Shading + Daylight Dimming in U.S.

Renzo Piano, Gensler, F&K





2 years of LBNL testing in a 500 m^2 mockup was used to refine and spec the final design

Outcome: Measured Energy < 40% WWR Code Compliant Design; Comfort and Occupant Satisfaction were high

LBNL Advanced Façade Testbed Facility

2003-2006
Electrochromic windows

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

2007-2023
Automated Shading, Thermochromic, Electrochromic BIPV/battery storage

Newest Generation of LBNL Testbeds:

Facility for Low Energy eXperiments in Buildings

FLEXLAB:

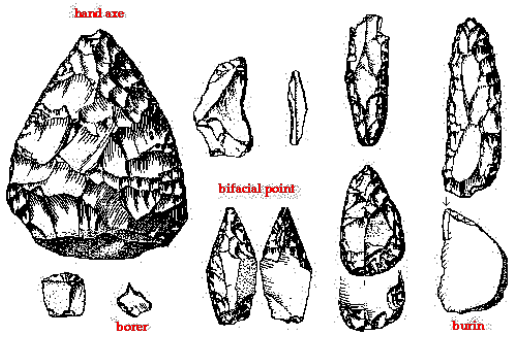
Rapid Prototyping: Mockup in FLEXLAB Rotating Testbed

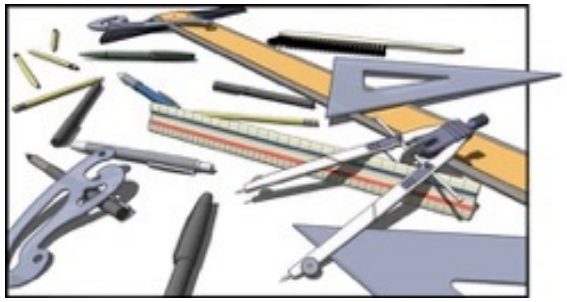
Thermal Comfort in FLEXLAB: Thermal Manikins, Computers and Ceiling Fans

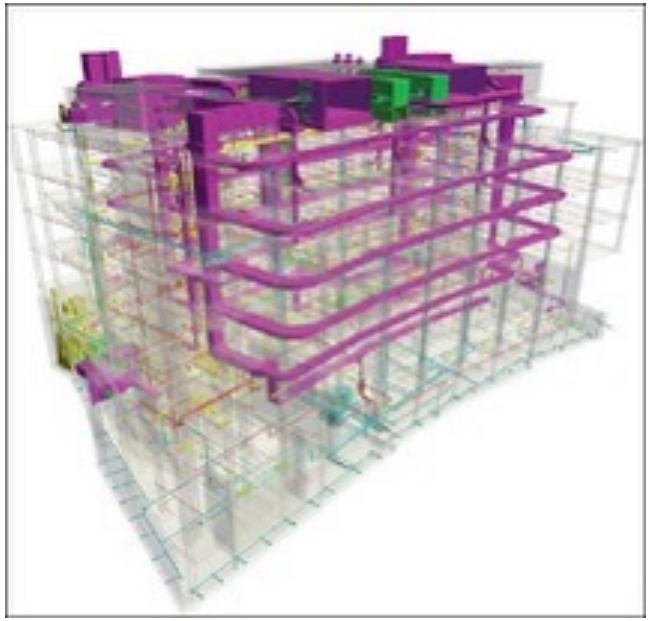
Design Tools = Virtual Building Mockup

"All Simulation Models are Wrong, But Some are Useful"

How do we find the right, validated useful tools?



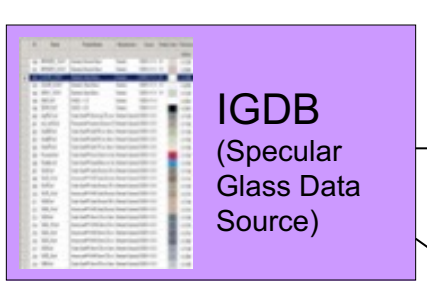




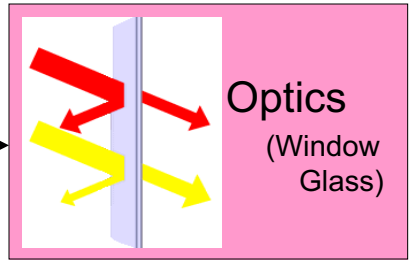
BIM, Digital Twins

Glazing and Façade Decision-Support Tools

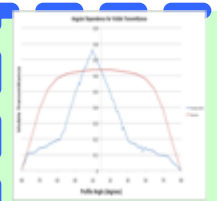
Download http://windows.lbl.gov/software/ ~ 40,000 Downloads/yr



IGDB
(Specular Glass Data Source)

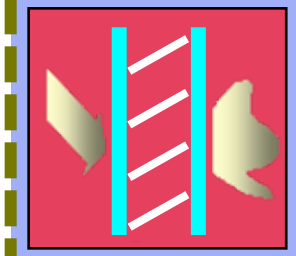


Optics
(Window Glass)



Angular SHGC/U/VT
(Rating/Lableing)

THERM
(Window Frame)



CGDB
(Complex Glazing Data Base)

WINDOW
+
Shading Systems
(Whole Window)

NFRC Ratings and Labels

EnergyStar Ratings

Radiance
Lighting /Daylighting

COMFEN
(Whole Building Commercial)

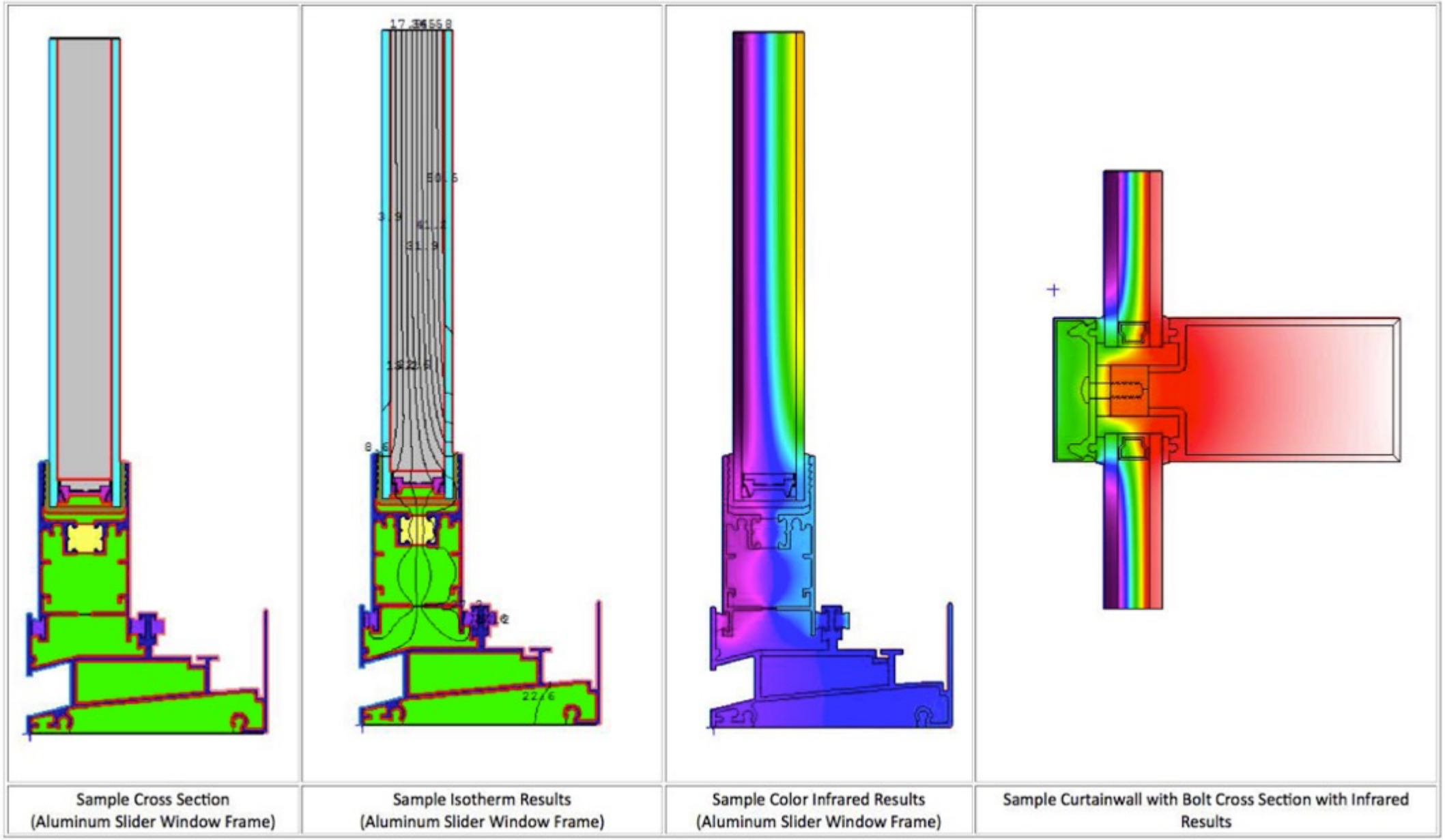
RESFEN
(Whole Building Residential)

Commercial Windows Website Efficient Windows Website

Design /Simulation Tools

Making Performance Visible: Fast and Cheap vs Testing

THERM: 2-D Heat Transfer Effects



Sample Cross Section (Aluminum Slider Window Frame)	Sample Isotherm Results (Aluminum Slider Window Frame)	Sample Color Infrared Results (Aluminum Slider Window Frame)	Sample Curtainwall with Bolt Cross Section with Infrared Results

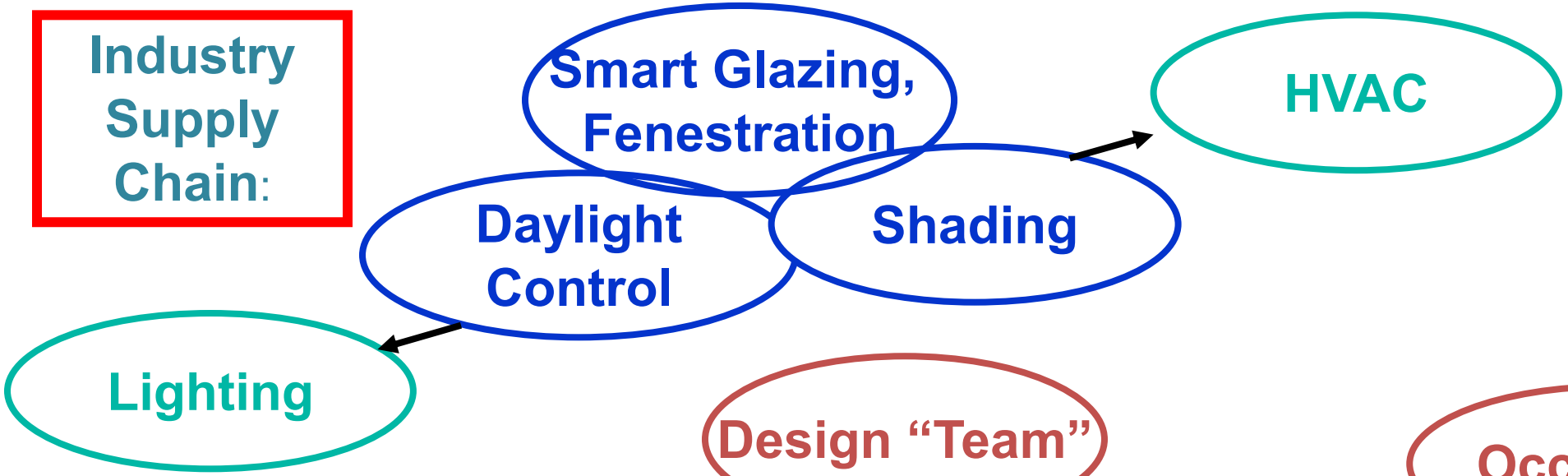
Rethinking the Façade Design/Delivery Ecosystem

Increase speed, scale, impacts

Can we predict, guarantee performance over time?

Window/Façade Design-Delivery Ecosystem

Who's In Charge? Who Delivers Complete Solutions? Performance over Time??



Design "Team"

Occupants

Owner, Facility Manager

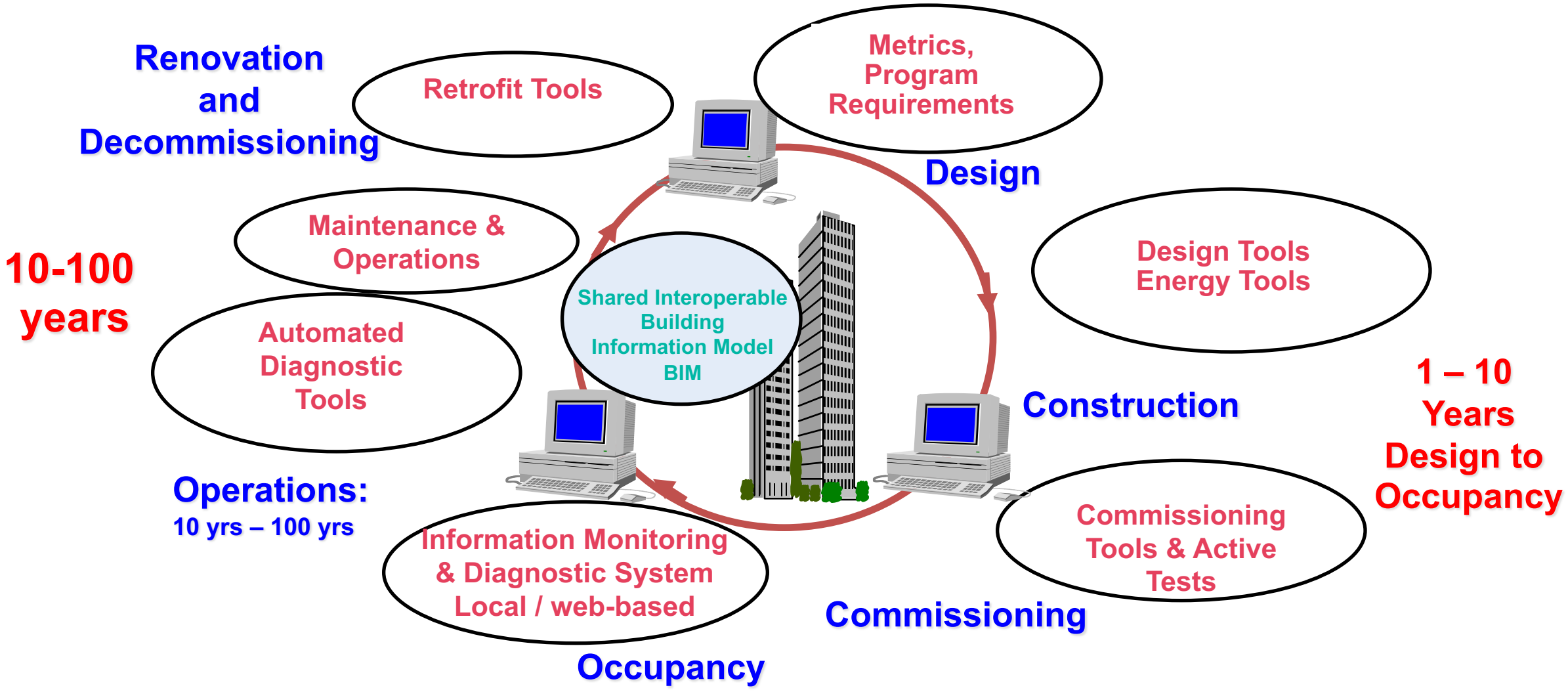
Utility

Integrated Design-Delivery Process:
Prog - SD- DD- CD- Construction

Operations
. Maintenance
Renovation

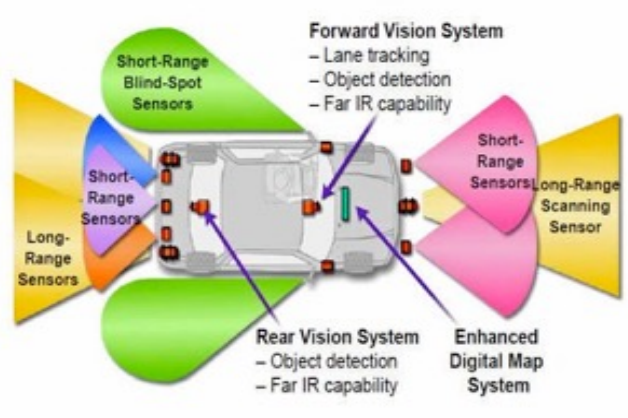
Performance Over Time?
1 yr? 10 yrs? 100 yrs?

IT-based Building Life-Cycle Integration View: Digital Twins to Manage Operations → Renovation



Relative Cost, Complexity, Reliability?
A Tale of Two Industries

INDUSTRY "A"

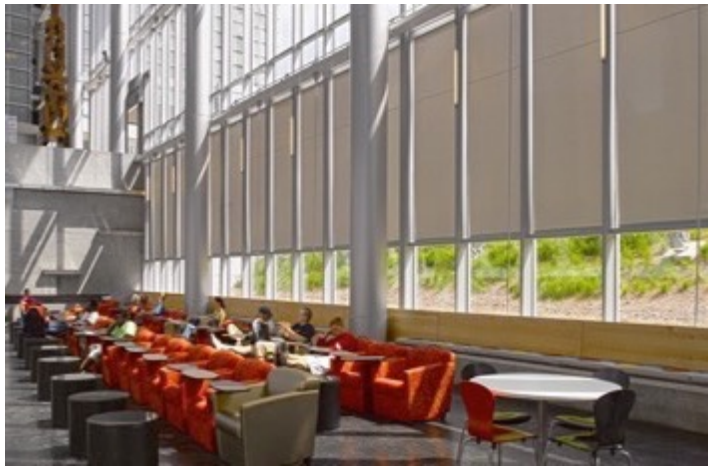


Integrated System:
Autonomous Car w/ Smart Sensors

Coming soon...??

VS

INDUSTRY "B"

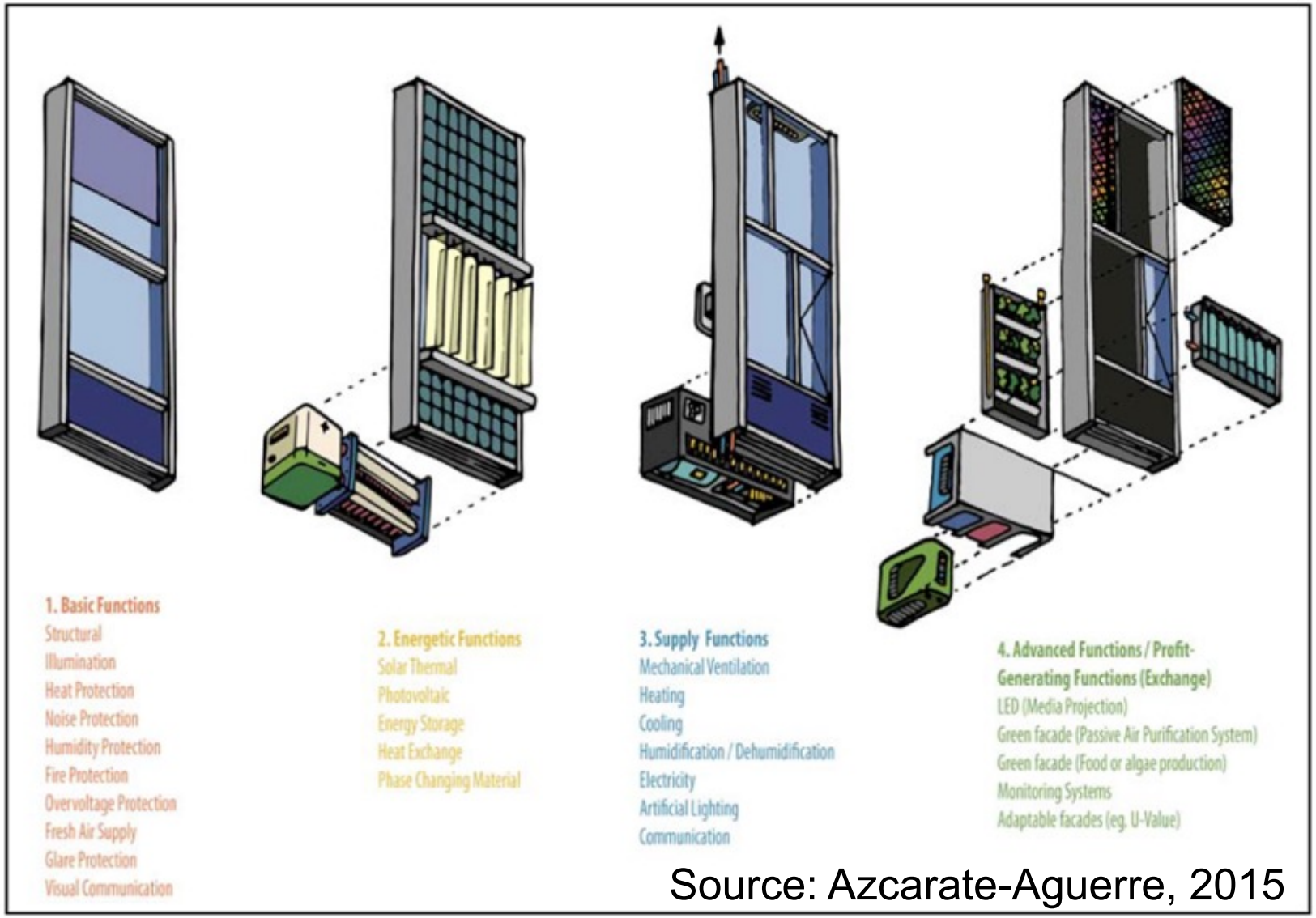


Integrated System:
Sensor-Driven
Automated Shade or Smart glass
w/ Daylight Dimming

Wishful thinking...??

Can Buildings Be More Like Cars?? (should they be?)

New Models: Lease your Integrated Façade System: FaaS: "Façade as a Service"



Source: Azcarate-Aguerre, 2015

Mismatch: Building Elements Do Not "Age" at the Same Rate Rethink Durability, Design for Disassembly, and Repair …

Facades:
15-50 yrs

HVAC: 15-30 yrs
Gas → Heat Pumps;
Decarbonize!

Decarbonize Existing Building Stock, with Heat Pumps

- If a leaky boat is sinking ….
- Do we…
  - -- Bail faster,
  - -- add an electric powered pump?

……or……

  - **—First find and fix the thermal leaks…?**

Better Glazing/Windows for Thermally Leaky Buildings

Façade Retrofit Options

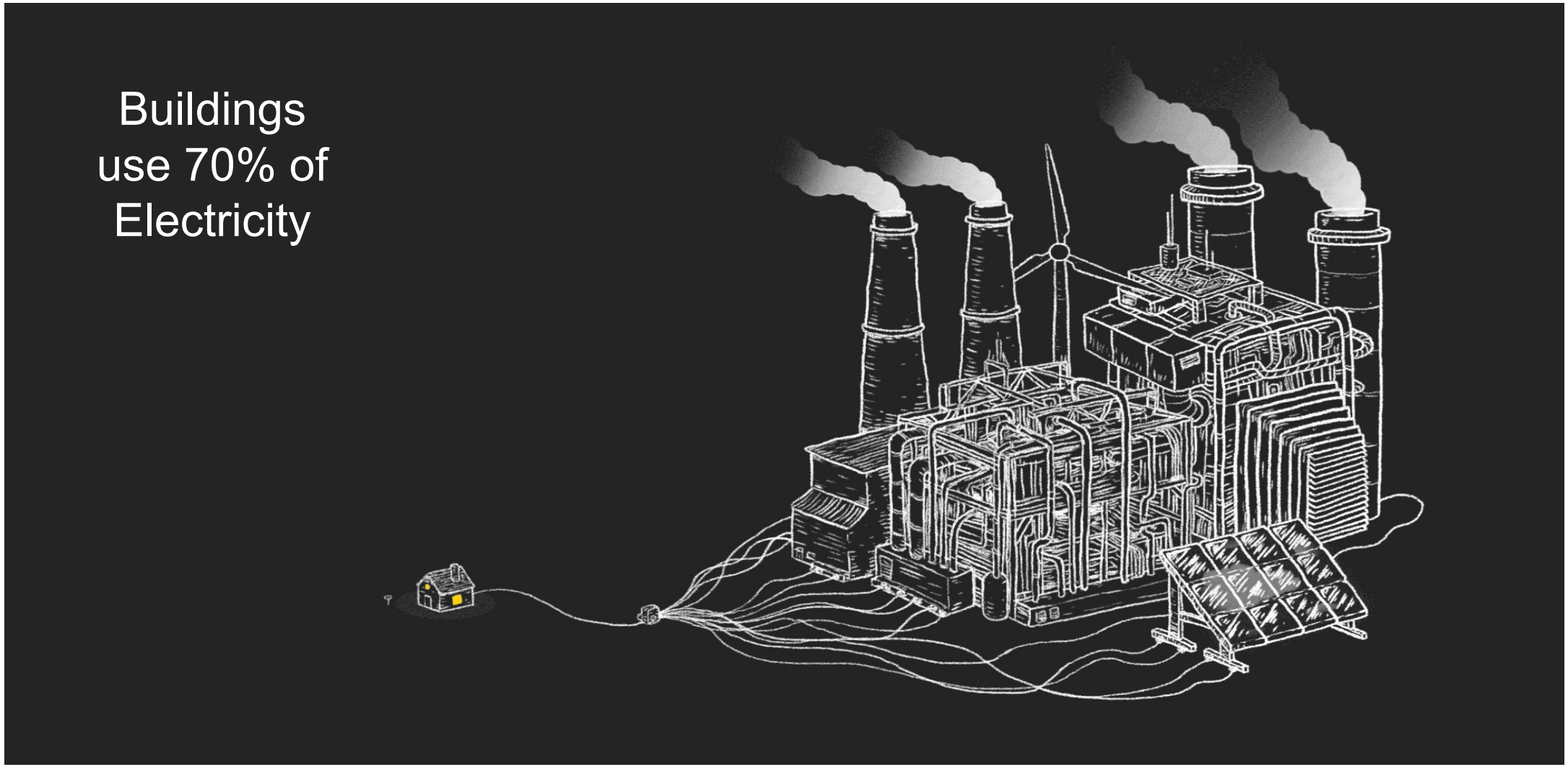
- **Façade Replacement**

- **Glazing Replacement**
- **Façade refurbishment**
  - **Interior glazing add-on**
  - **Interior film add-on**
  - Exterior glazing add-on

- Shading Replacement/Add-on
  - Interior/Exterior
  - Automation
- Daylighting Add-on/refurbishment

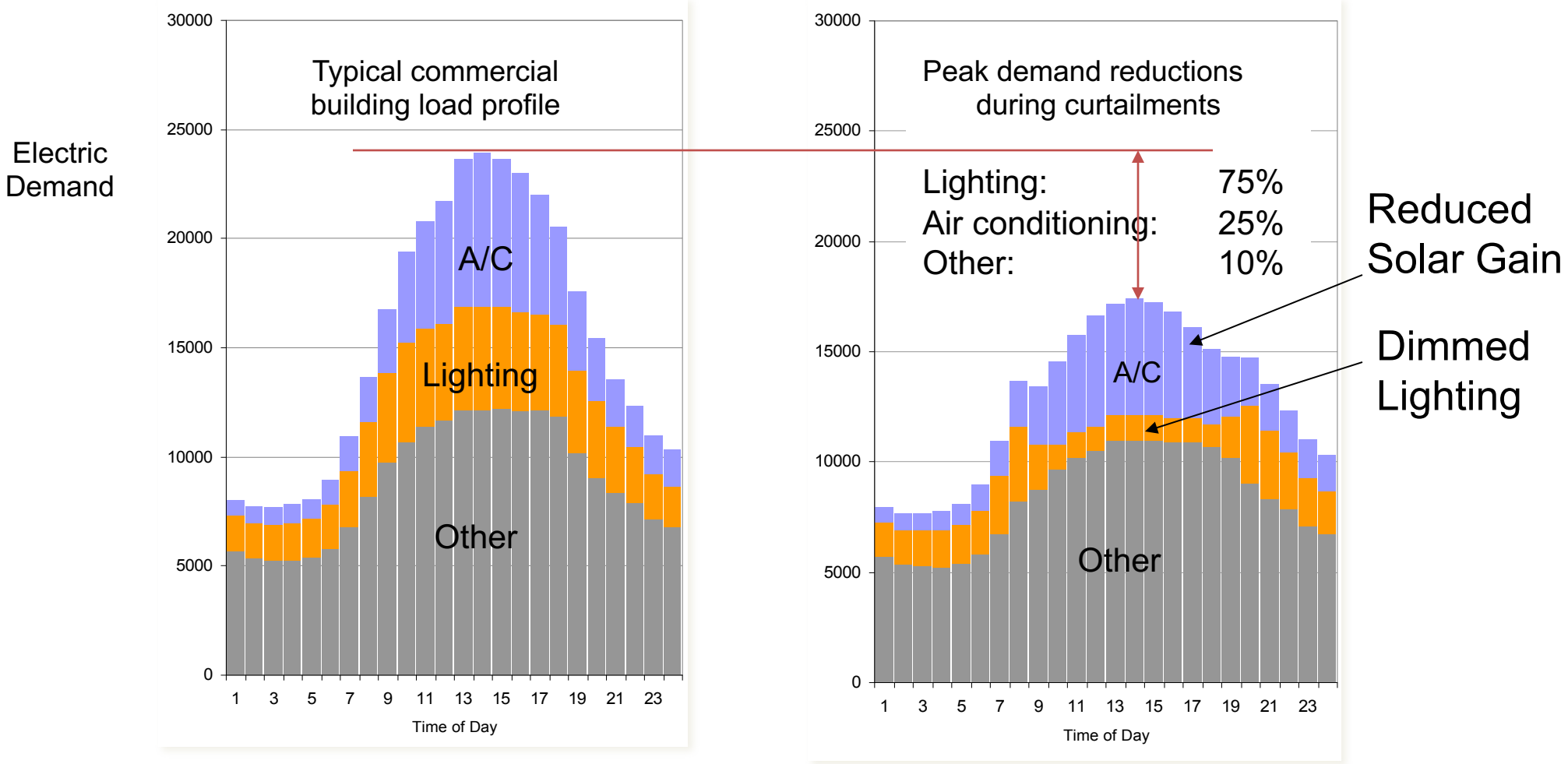
U.S.: 2.4 million Commercial Buildings w/ Single Pane (40% of Buildings)

Grid: How Should We Power Our Buildings?
Decarbonizing the Grid and our Buildings



Grid-Interactive Efficient Buildings, GEB

Energy/Demand Management with Smart Windows + Daylighting Controls



30% Peak Savings Possible from Cooling Load Control and Daylight Dimming

Global Investment of $Trillions in Smart Grid

Relative Cost and Complexity?

MegaWatts (Powerplants) vs “Negawatts” (Windows)

Fossil/Nuclear

Renewables

New Building Roles:

1. Generate Energy

2. Manage Energy Use

3. Store Energy

Barriers to Better Facades

Source: Prieto
JFDEv5#1

Most Expensive Building Element?

People!

Energy Use, Carbon

vs

Occupant performance, salary, comfort, health, satisfaction, …

The Most Costly “Building Component”?

People: Occupancy Costs = 100 x Energy Cost

Well-Designed Building Façade Can Improve Satisfaction, Comfort and Productivity

Cost / Sq. M. Floor -Year

- **Energy Cost:** **$40**
- **Rent:** **$400**
- **“Productivity”** **$4000+**

Can the Facade Industry Deliver Innovative Solutions for New and Existing Buildings, At Scale?

Make High Performance Facades a Market Advantage, Minimize Added Cost or Risk

Façade Technology, Building Integration, Smarter Design offers:

- Manufacturers → New Business Opportunities
- Architects → Design freedom and flexibility
- Occupants → Better comfort, view, acoustics…
- Owners → Higher Value Properties
- Society → Lower impact on global environment

Contact/Followup

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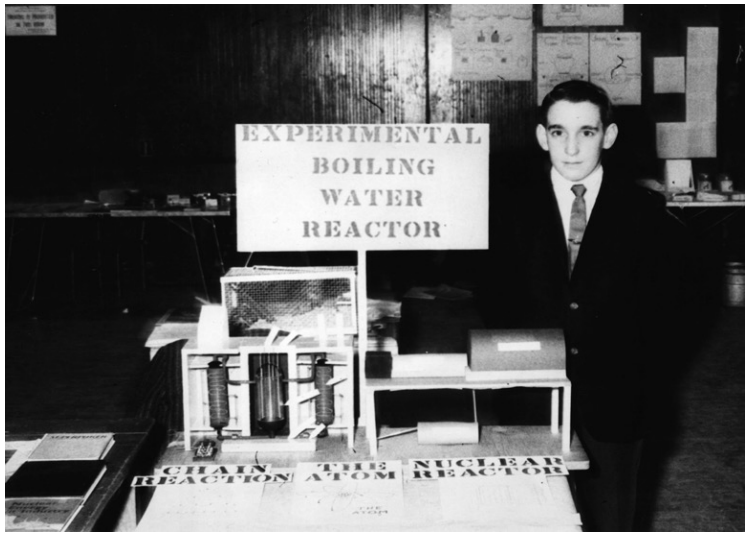
seselkowitz@lbl.gov

Affiliate, Lawrence Berkeley National Laboratory

Principal, Stephen Selkowitz Consultants



Explore Current Windows-related R&D, projects, tools, etc at https://windows.lbl.gov/

Search on-line, free downloads of Technical Papers, Case Studies and Software Tools:

https://eta.lbl.gov/publications - key word searches to access ~ 400+ “glass/facade” reports