NGA Meeting

Tacoma, July 25, 2023

Future Glass and Facades–

Challenges and Opportunities in a Carbon-Constrained World

Stephen Selkowitz

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Retired: Group Leader, Windows and Envelope Materials

Affiliate, Building Technology and Urban Systems

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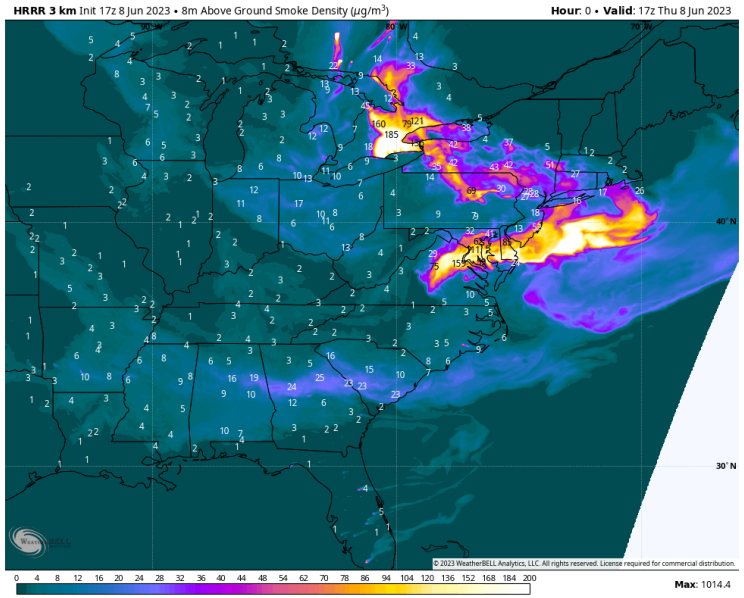


2022 NGA Claim: “Glass Can (help) Save the World”

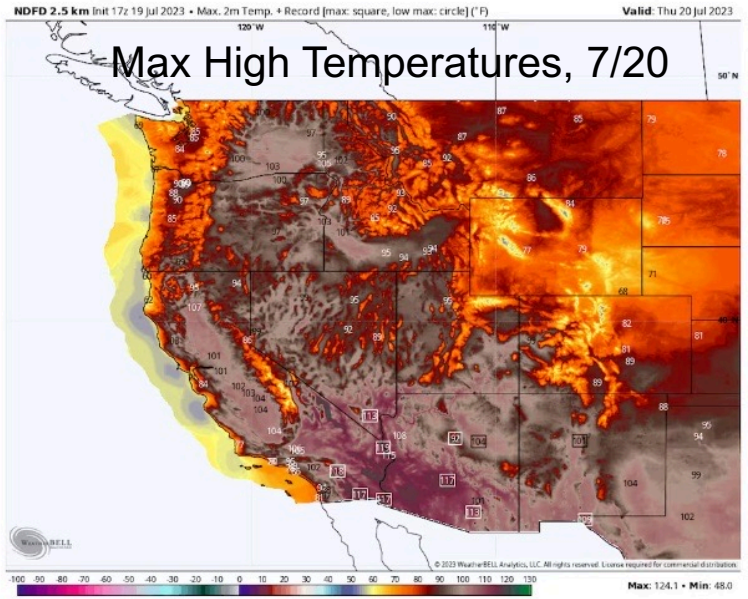
- Which Glass Solutions?
  - Glass only??.... → Integrated Façade Solutions
  - Building context
- Step 1: To Save the World → Act Quickly - Speed
  - GHG and Climate Change – the clock is ticking…
- Step 2: In Order to Have Impact → Deploy at Scale
  - Manufacturing infrastructure?
    - In place?
    - Investment needed?
  - “Affordable” to Owners
    - Low Cost
    - Higher cost but with offsets, e.g. incentives, tax credits…
    - Other financial arrangements

Climate/Carbon Indicators

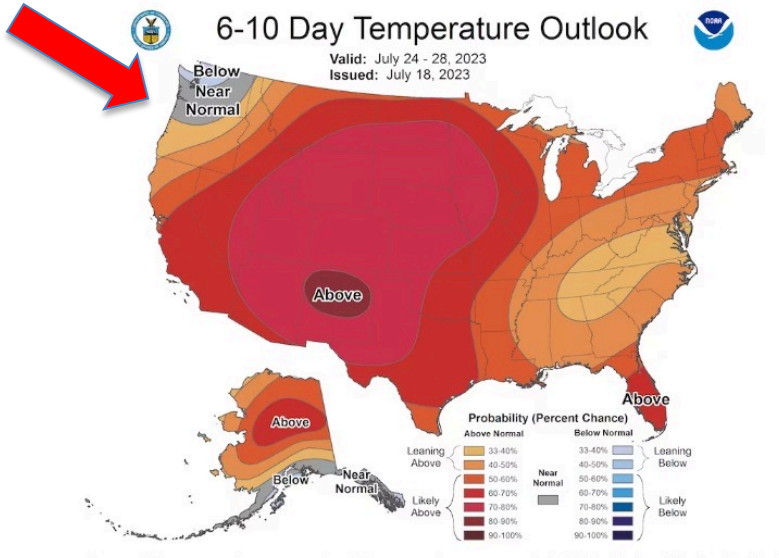




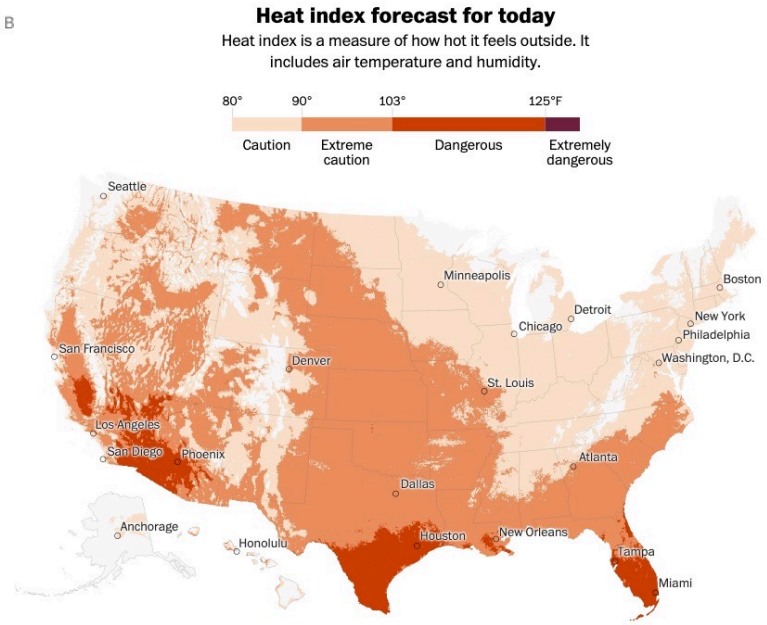
Wind driven smoke from Canada



Forecast highs on Thursday from the National Weather Service. B records. (WeatherBell)



Chance of above-normal, near-normal and below-normal temperatures July 24-28. (National Weather Service)



Goal: Create a Compelling Vision of Potential Benefits of Advanced Glazings, and Implement It

Improve Occupant Comfort, Satisfaction and Performance



Occupant

Add Value, Reduce Risk, Operating Costs



Building Owner

Reduce Greenhouse Gas Emissions



Planet

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

Energy efficient

Demand responsive

GHG/ Sustainable

Resiliency

Decarbonize

Circularity

Reduce Carbon/Energy Use?

Economics/Cost

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



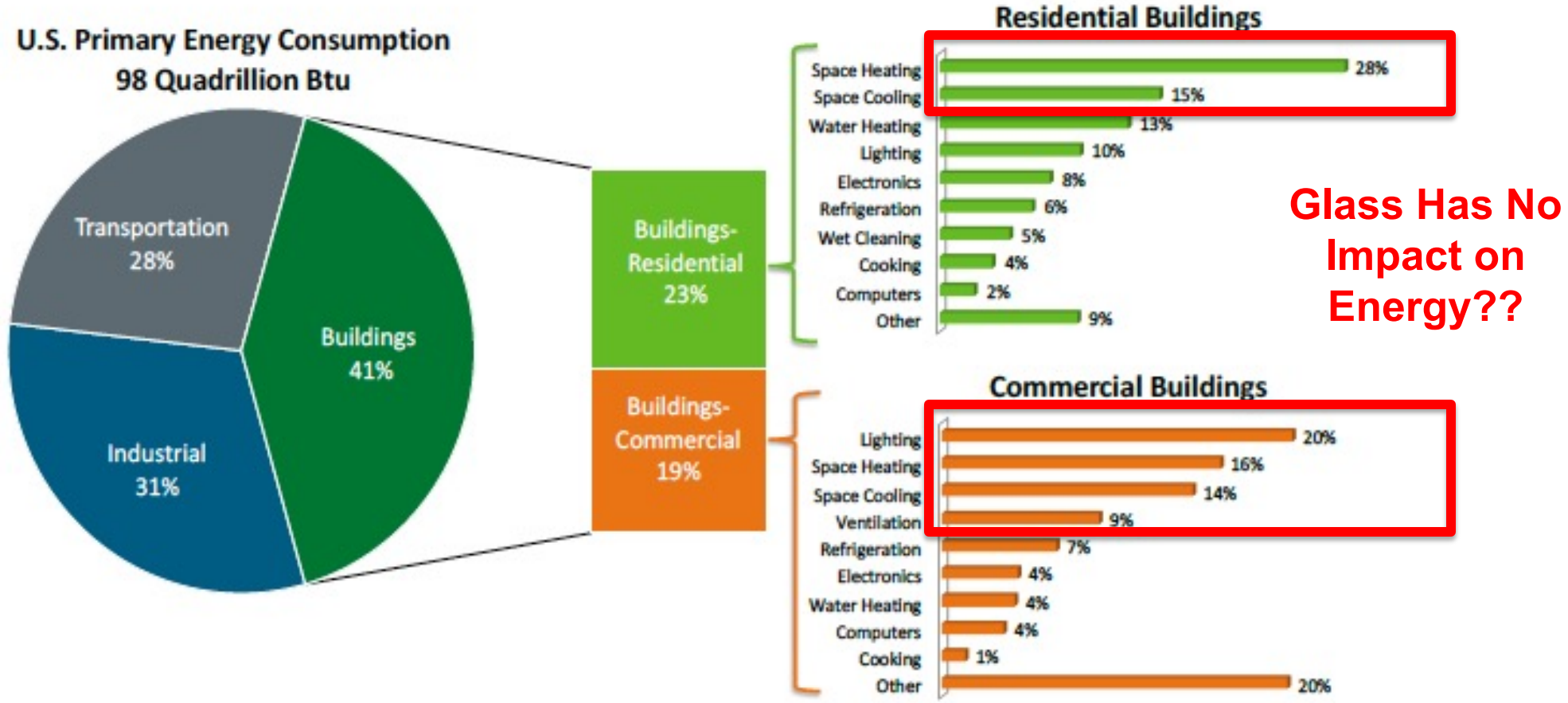
"Eight Factors Driving Glazing and Façade Design for the Next 20 Years"

1999 Paper

- ***#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."***

Role of Buildings and Energy Use in U.S.



Glass Has No Impact on Energy??

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
- Circular Economy
  - Recycled Materials
- Occupants
  - Biophilia
  - Comfort
  - View/Privacy
  - Productivity
  - Daylight spectrum
  - Health





- 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"**

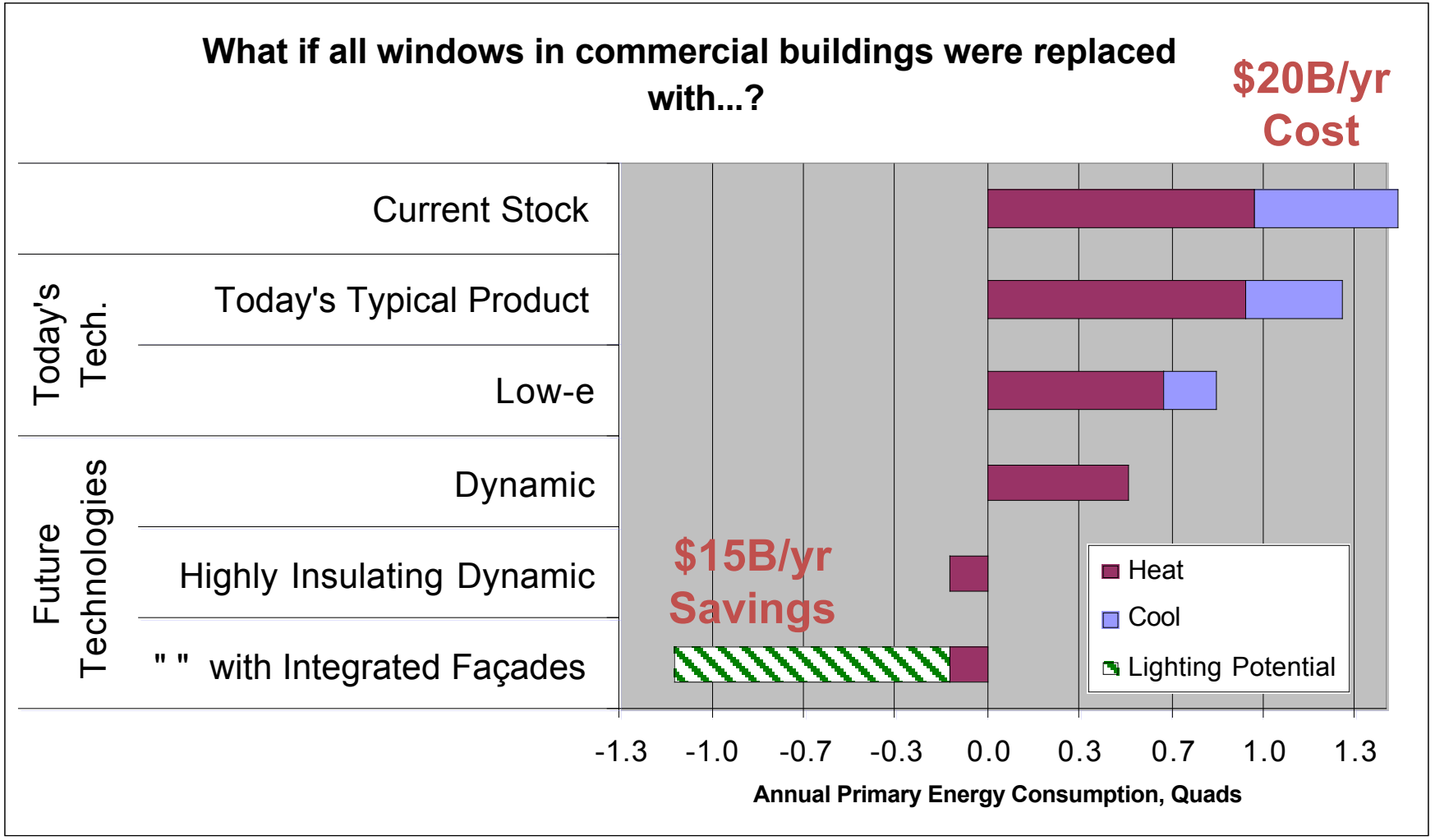
BUT today

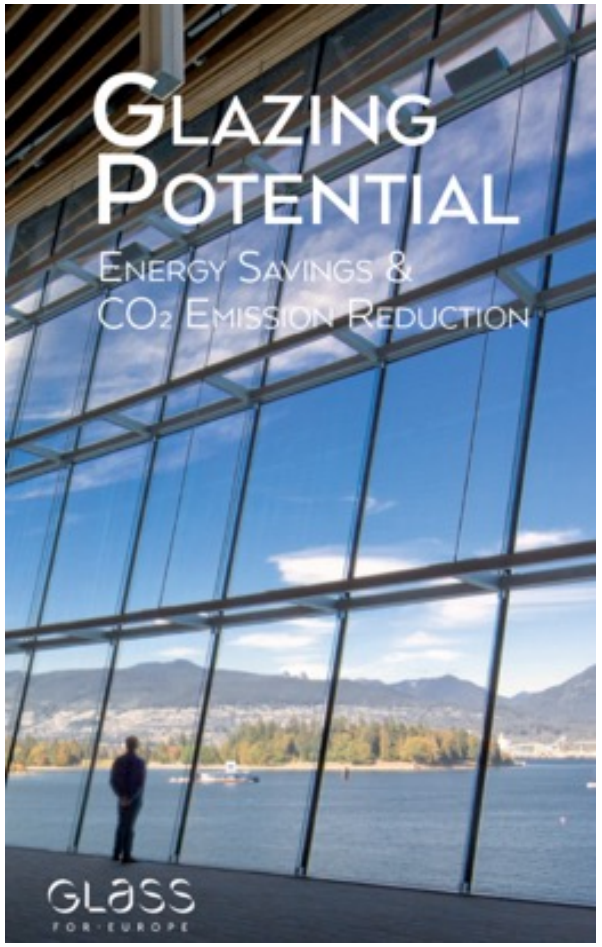
- **Not easy to design;**
- **Difficult to construct and commission**
- **A challenge to operate effectively**
- **May Cost More…**

- **One-off is "easy"**
- **Rethink everything, to do this quickly, 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"

Dynamic Façade, Smart Glass

Energy → peak demand, carbon, PV

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

"Zero Net Energy" Façade Technologies
Goal: Energy Losers --> Neutral --> Energy Supply

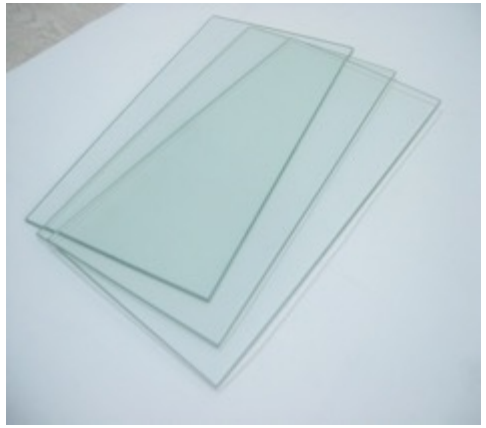
4 Technology Challenges, Vary w/ Climate

- **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**
  - Photovoltaics-building skin as power source

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

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









#1: Highly insulating, low heat loss glazing

Yesterday: U-value ~ 3.5 W/m^2-K / ~ **0.6 Btu/ft^2-hr-F**

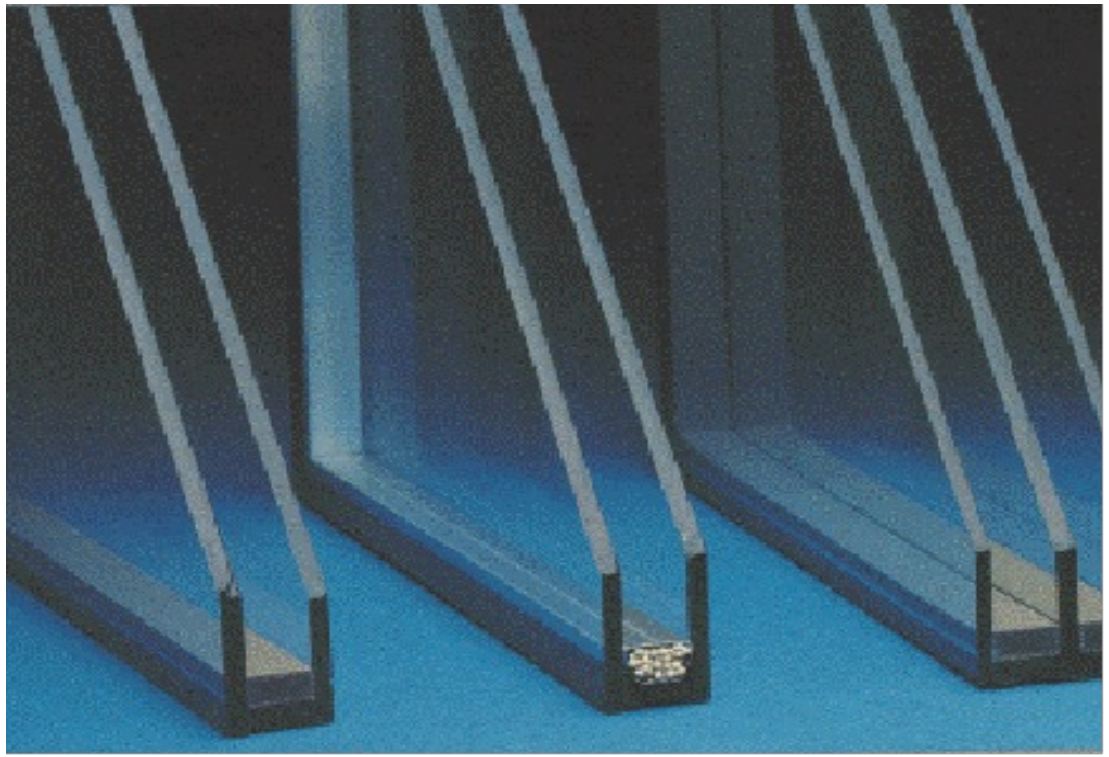
Today: U-value ~ 1.7 W/m^2-K / ~ **0.3 Btu/ft^2-hr-F**

Nearer Term Objective: U-value < 1.1 W/m^2-K; **< 0.2 Btu/ft^2-hr-F**

Longer Term Target: U-value < 0.5 W/m^2-K; **< 0.1 Btu/ft^2-hr-F**

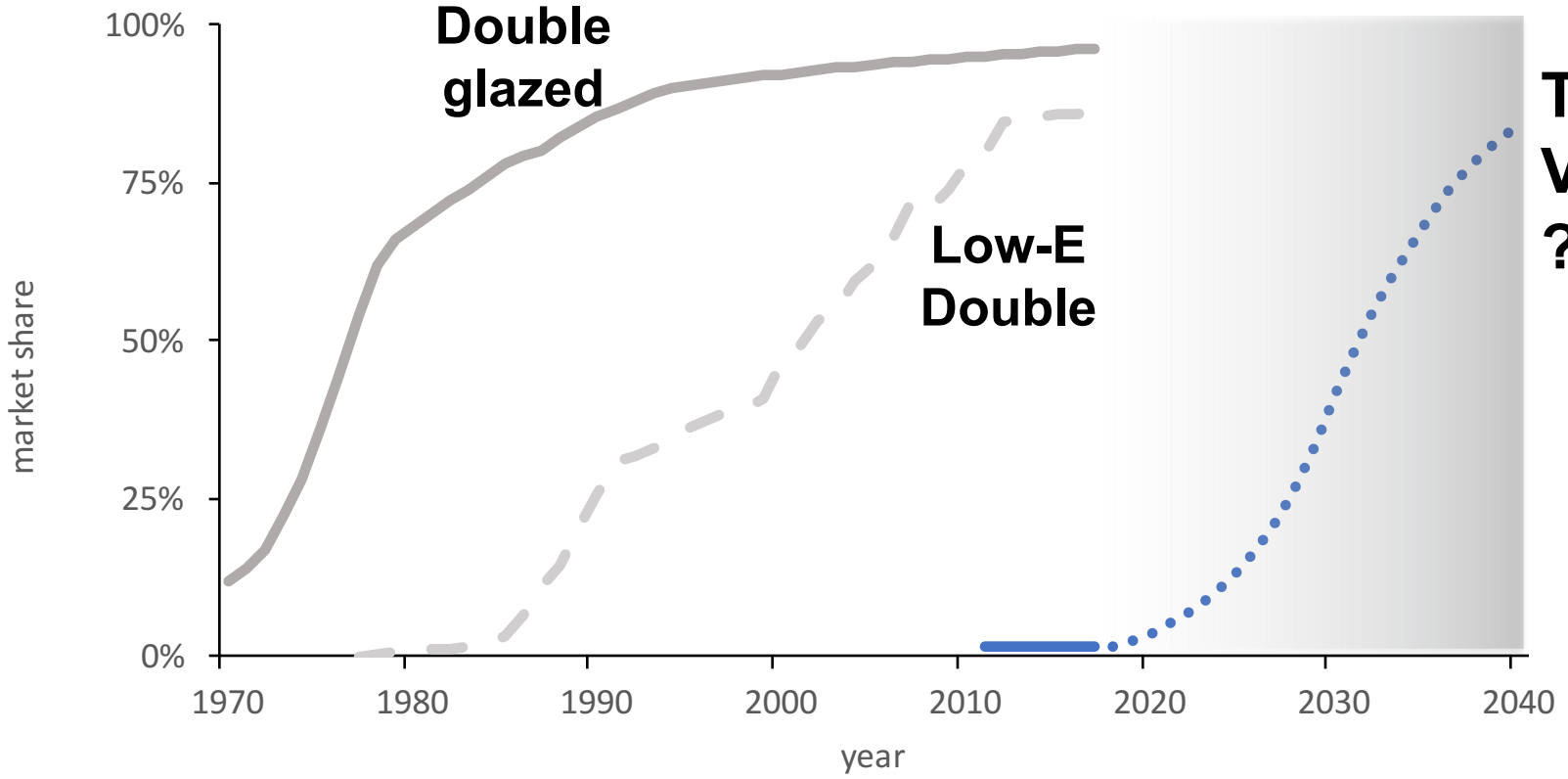
Approaches:

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



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

Resid Market Share



SPEED + SCALE

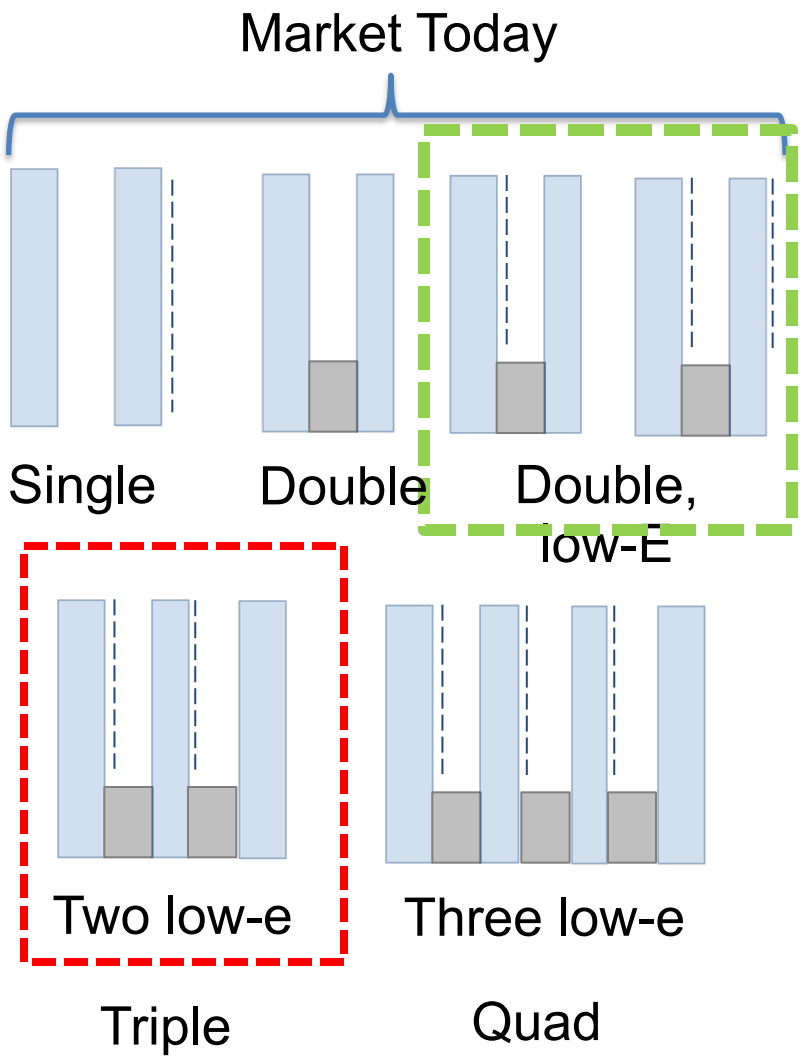
"30% by '30"
80% by 2040

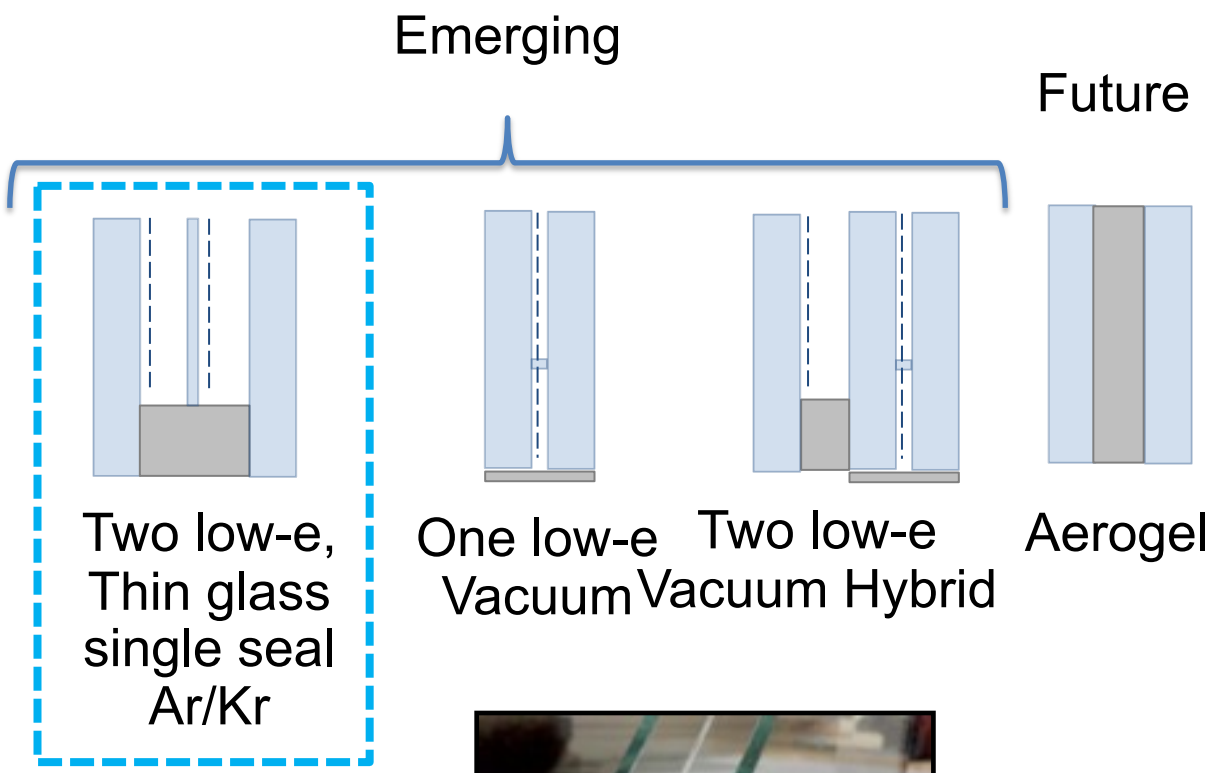
Innovation push
tech development

Market Pull
Utilities
Energy Star

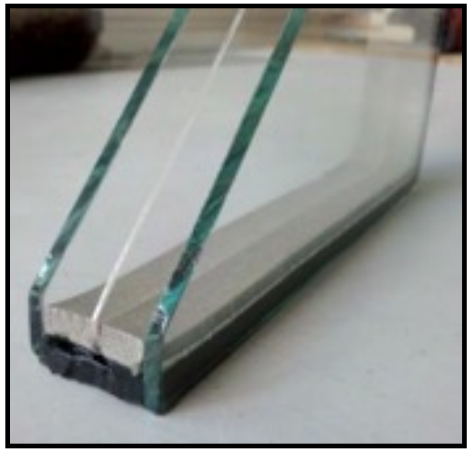
Codes and standards

HIGHLY INSULATING GLAZING SOLUTIONS:





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



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

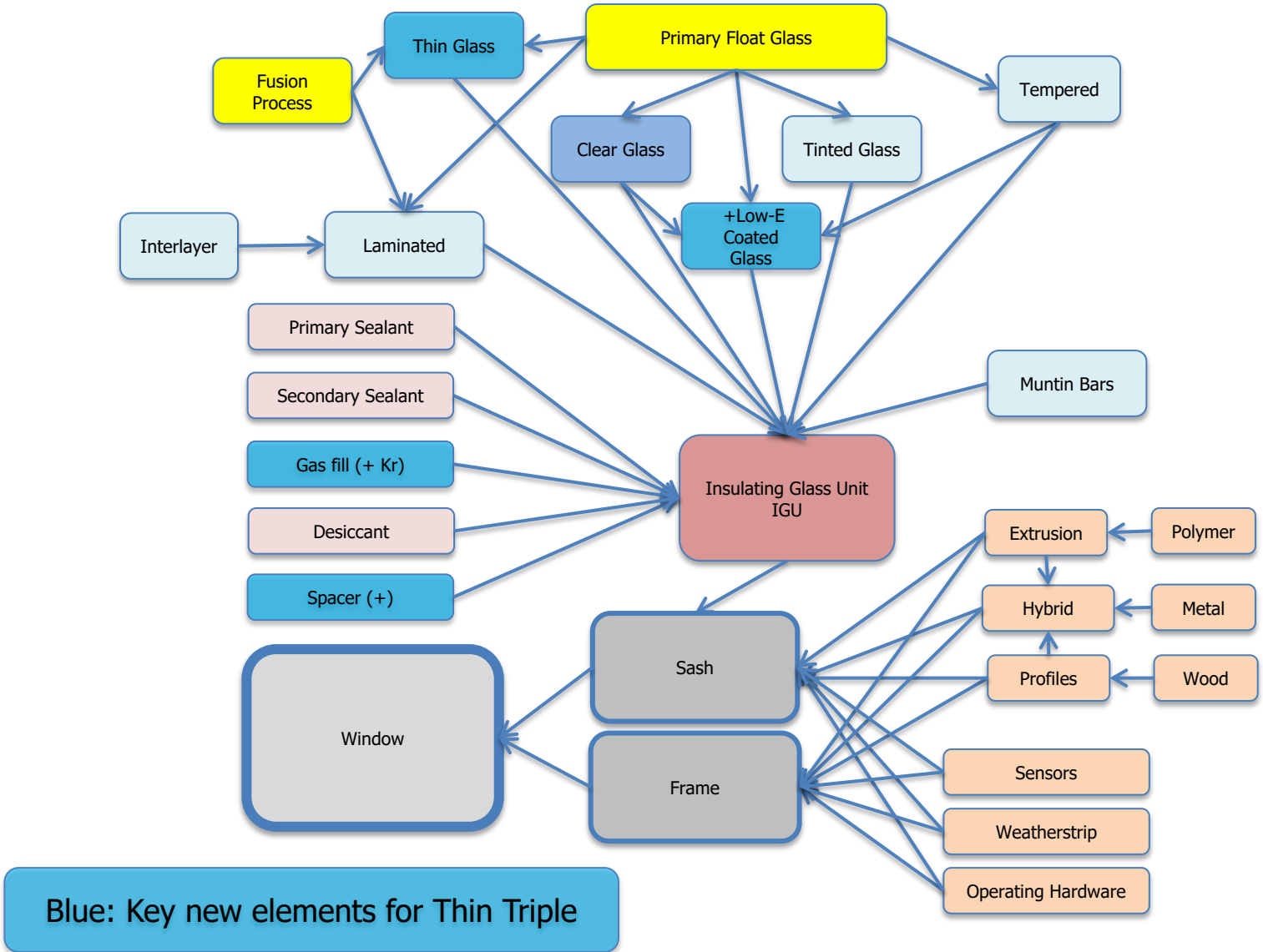
Single Spacer options

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

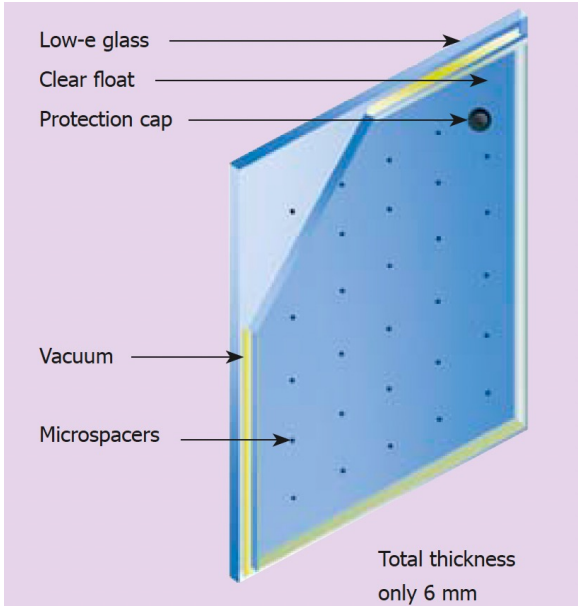
High speed (1000+ IGU/day)
Single or **double** spacer
High **gas fill** efficiency
Adjustable gap widths

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**

VIG Summit at LBNL, April 12-13
- **100 attendees**
- **Summary Report**



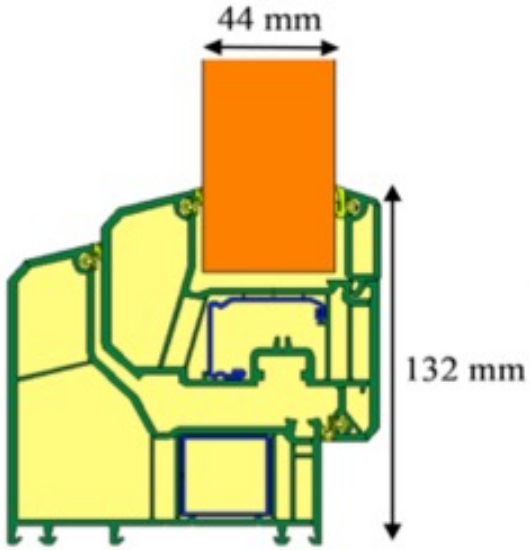


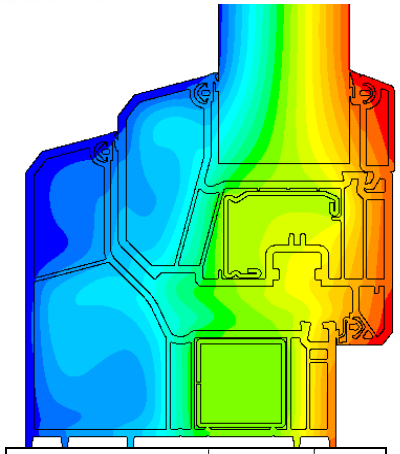


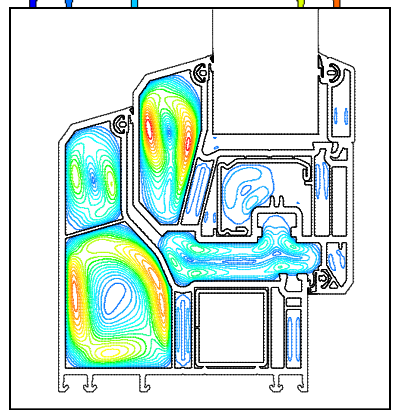
Low Conductance Window Frames

- **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



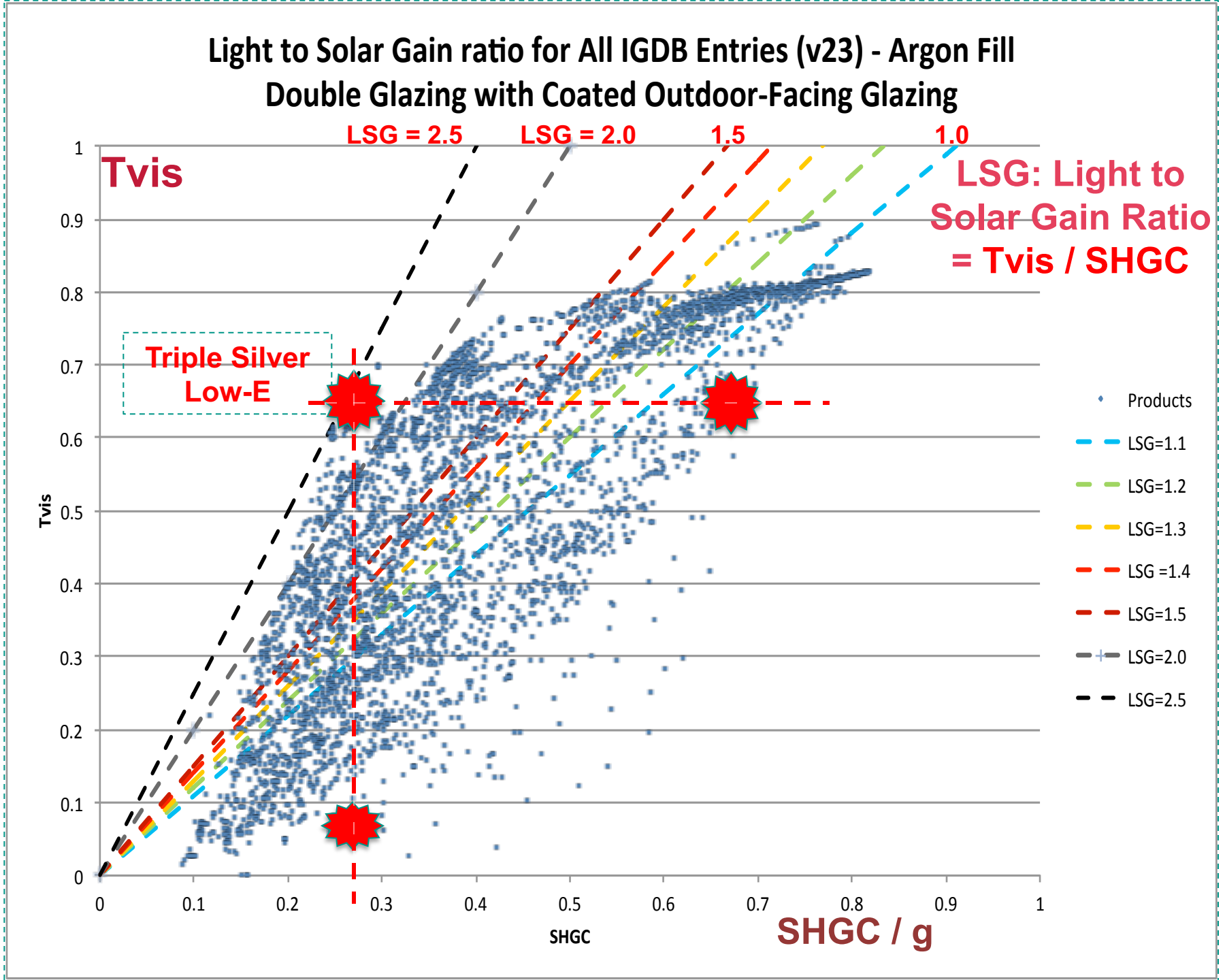
- **Control Options:**
  - Spectrum – “tuning”
  - Intensity – “dim”
  - Distribution into Room – “redirection”

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**









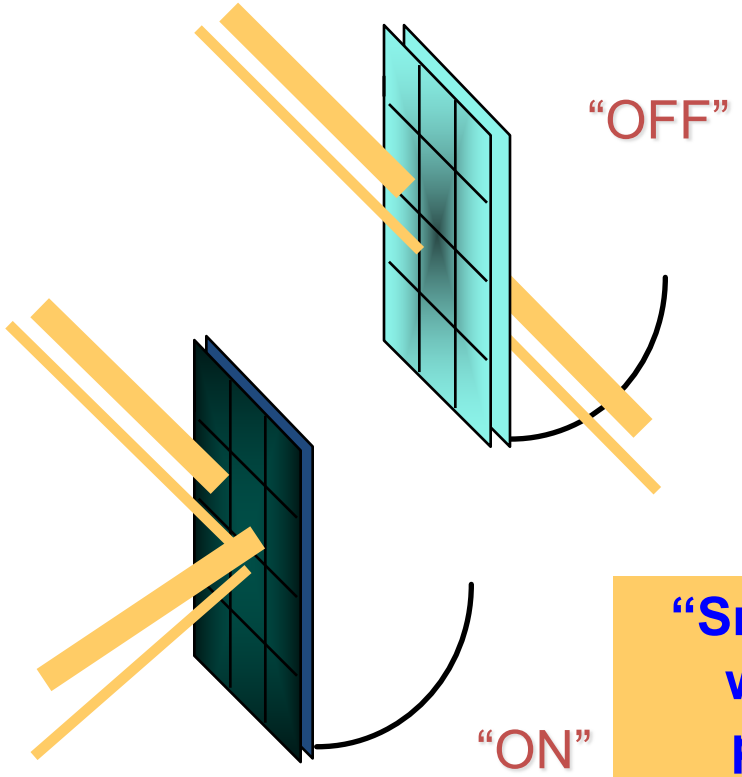




Dynamic Control of Window Solar Gain, Daylight

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+



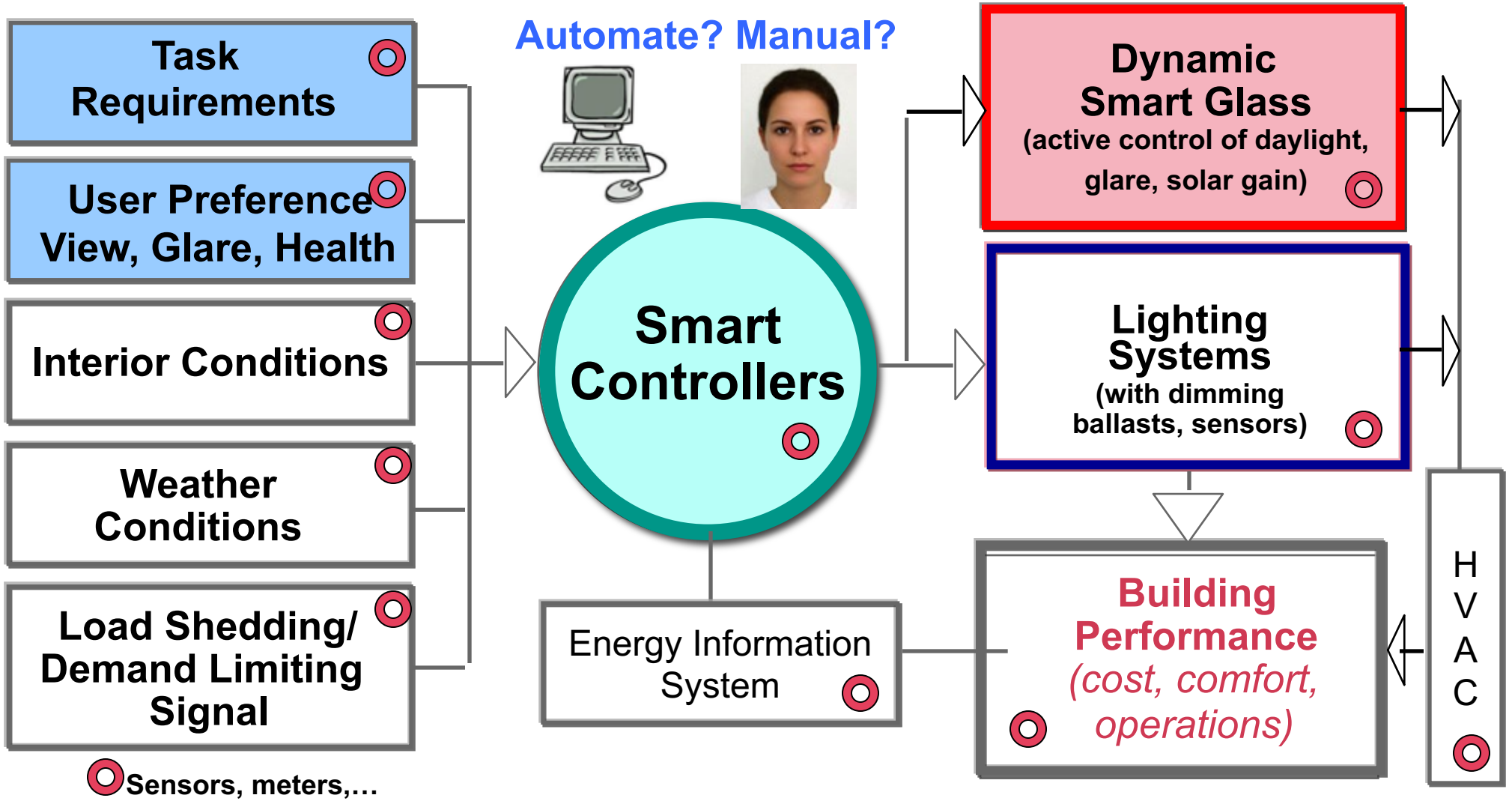
Current/Ongoing Technology Innovation

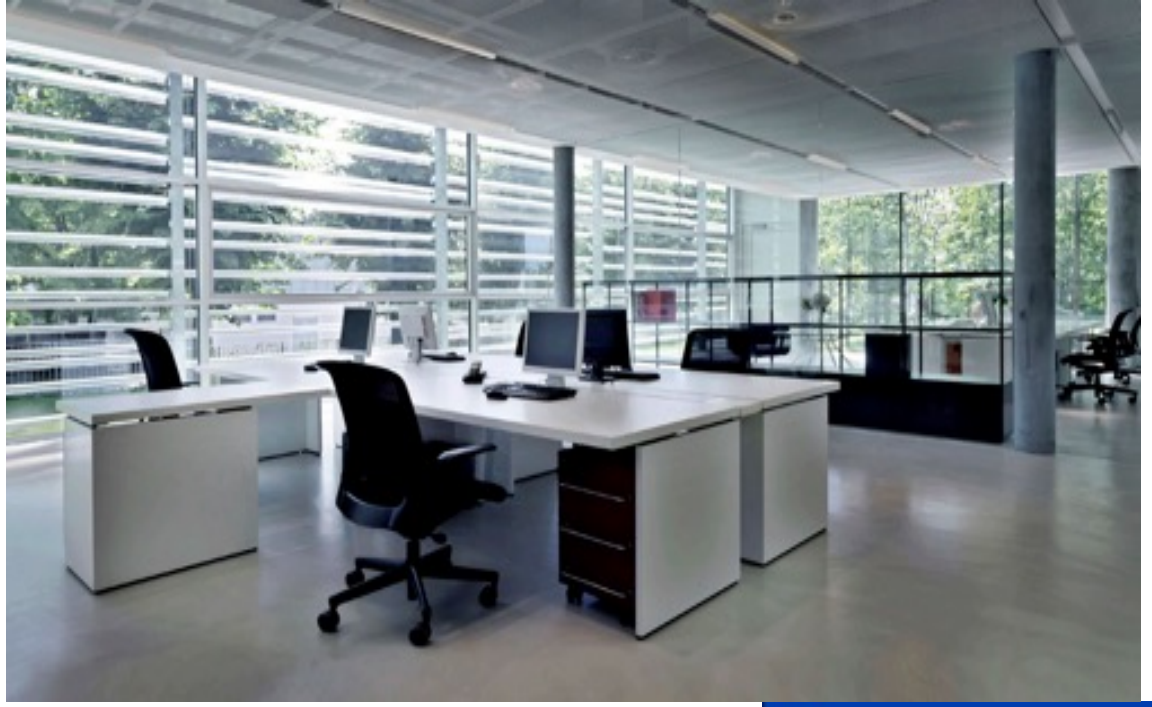
- **Speed and switching range**: "more responsive" Tv <1%: darker/reflective
  - Improved materials, new devices, e.g. Liquid Crystal
  - Anticipatory cloud sensing
- **Color: "more neutral"**
  - New EC materials
  - Different device mechanisms
  - Glazing IGU Design
- **Device Cost: "Lower..."**
  - 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 – "Open Façade Controls" Project- LBNL**
  - **Shared sensing and controls infrastructure with lighting etc**

Exploring Intelligent Control Systems:

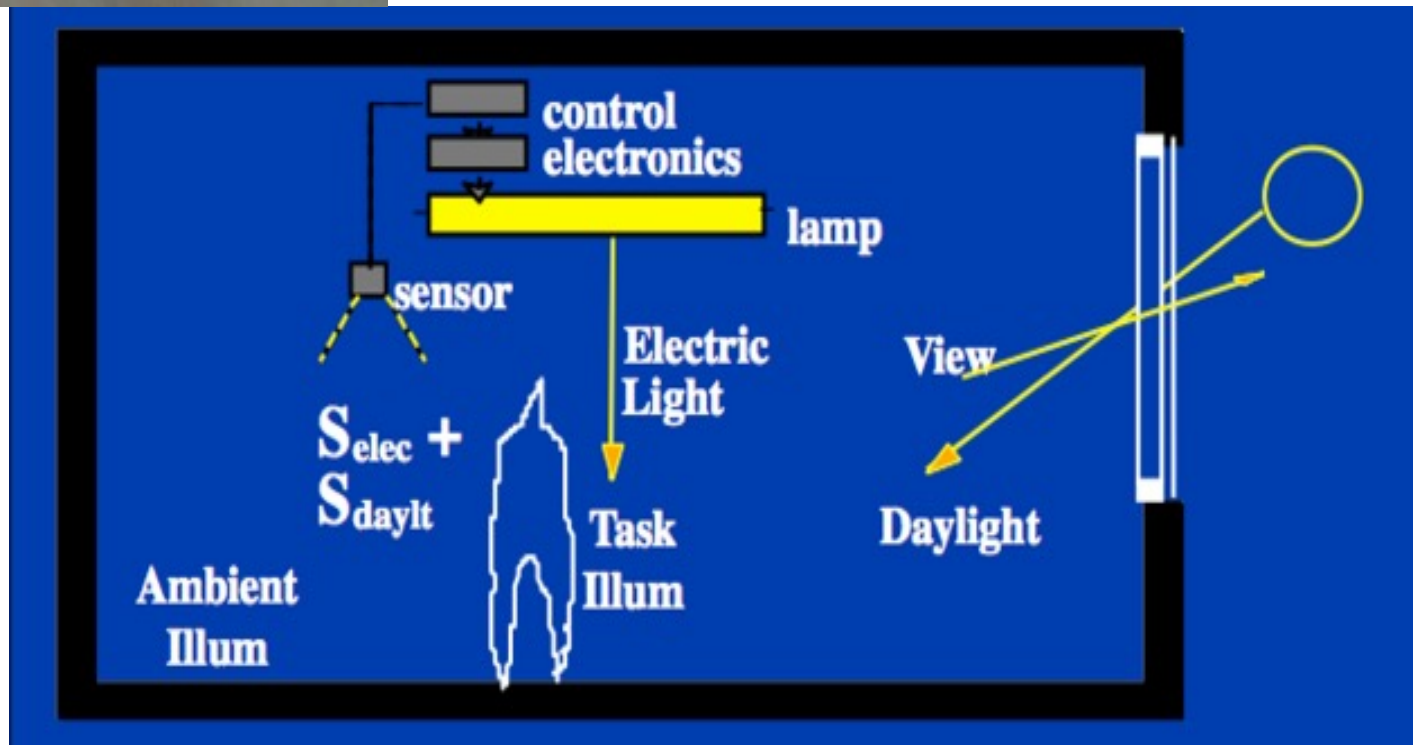
Optimal performance of dynamic windows requires full integration with building systems





#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

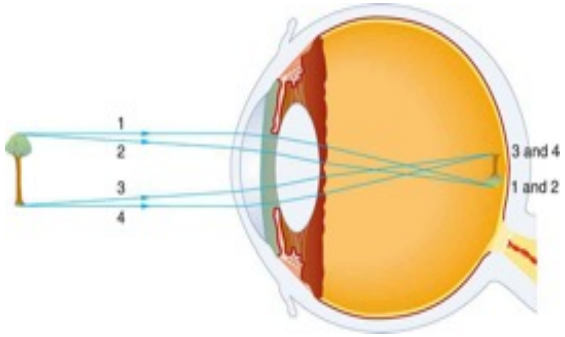
Productivity

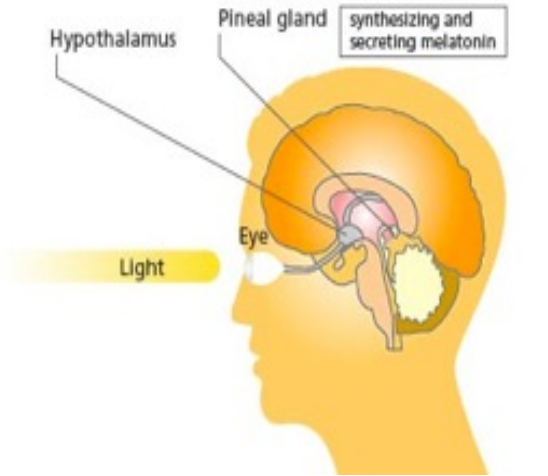
Visual Comfort

Health

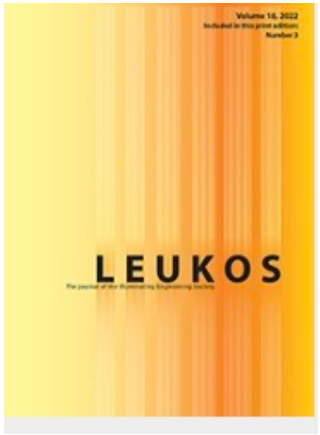
Biophilic Design







View and Daylight



LEUKOS
2022, VOL. 18, NO. 3, 259–266
https://doi.org/10.1080/15502724.2022.2055428

EDITORIAL

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

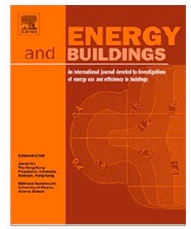
48 co-authors

Energy & Buildings 265 (2022) 112079

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb



Advocating for view and daylight in buildings: Next steps

Eleanor S. Lee [a,*], Barbara Szybinska Matusiak [b], David Geisler-Moroder [c], Stephen E. Selkowitz [a], Lisa Heschong [d]

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[b] Department of Architecture and Technology, Norwegian University of Science and Technology, Sentralbygg 1, Gløshaugen, Trondheim, Norway
[c] Bartenbach GmbH, Rinner Strasse 14, 6071 Aldrans, Austria
[d] Independent, Former Principal of the Heschong Mahone Group, USA

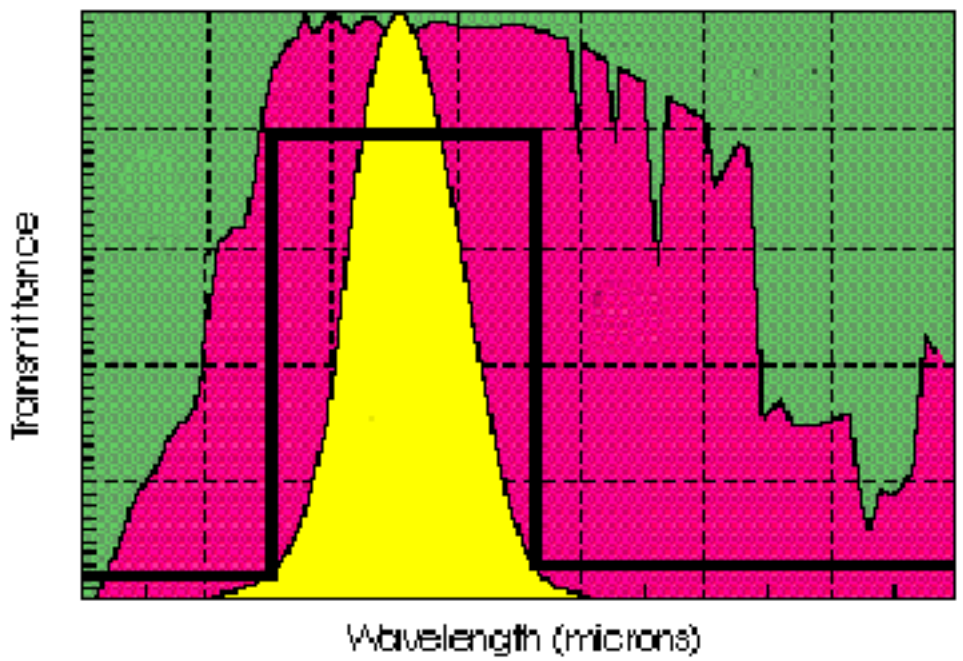
https://doi.org/10.1016/j.enbuild.2022.112079

Success: Spectrally Selective "Cool" Glazings

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

Technology:

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



Transmittance -vs- Wavelength

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

Extend Daylight Deeper into Floorplate:
Daylight Redirecting Solutions

(normal daylight depth ~ 2.5 x glass height)







Light Shelves and Louvers

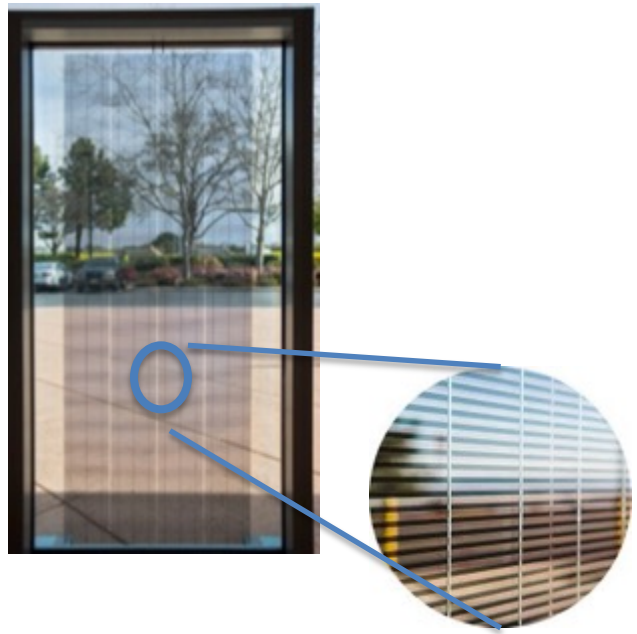
Daylight Redirecting Prismatic Film



#4: Converting Sunlight to Electricity

- **Electricity from the Sun: On-Site Power**
  - **Building Integrated Photovoltaics: BIPV**
  - **Options for view glazing**
    - Crystalline Cells
    - Expanded Cells
    - Amorphous
    - Transparent
- **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,…



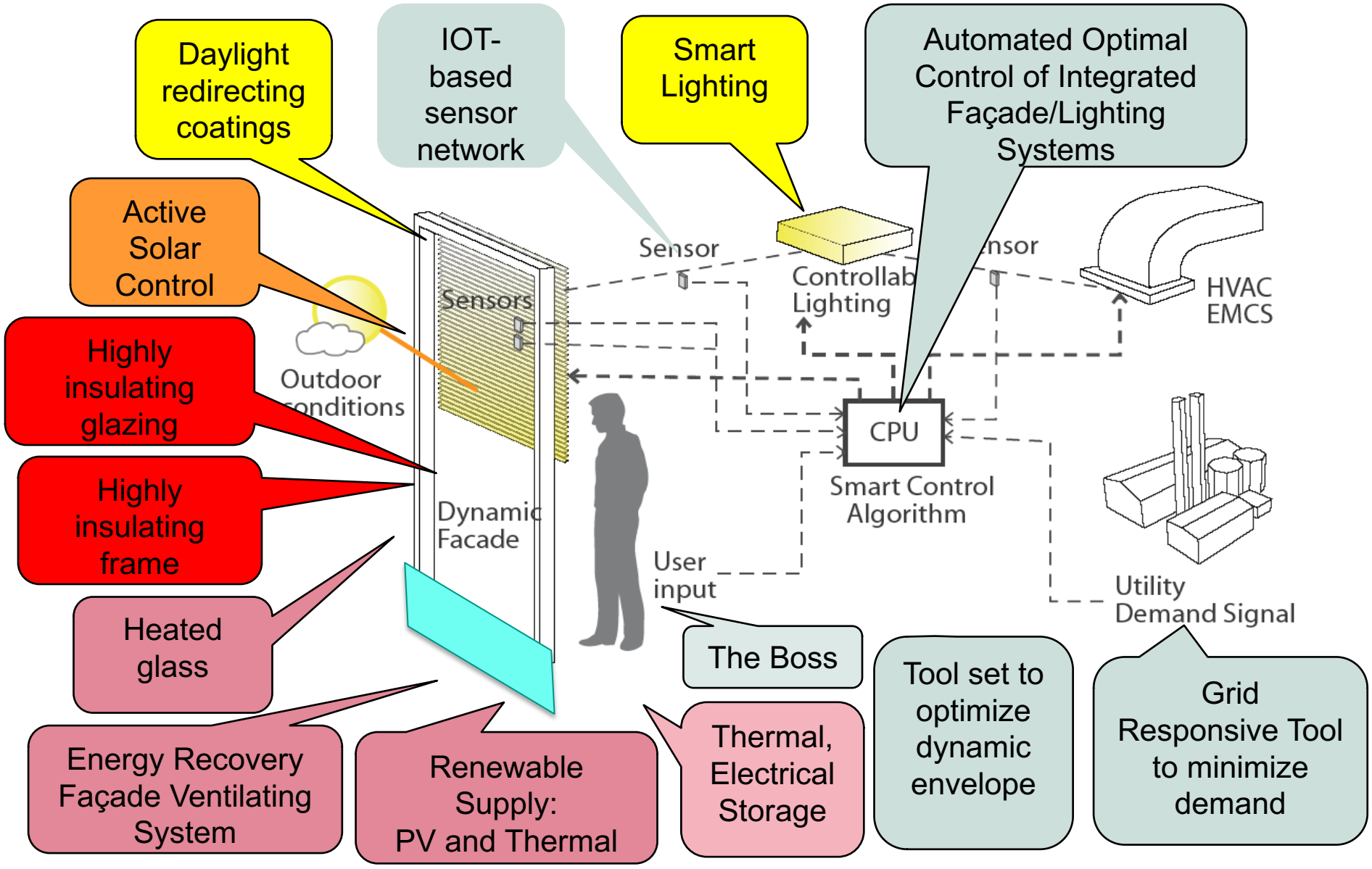


- Visible/Invisible
- Design, cost
- Electrical integration



Clear PV - but lower efficiency, power

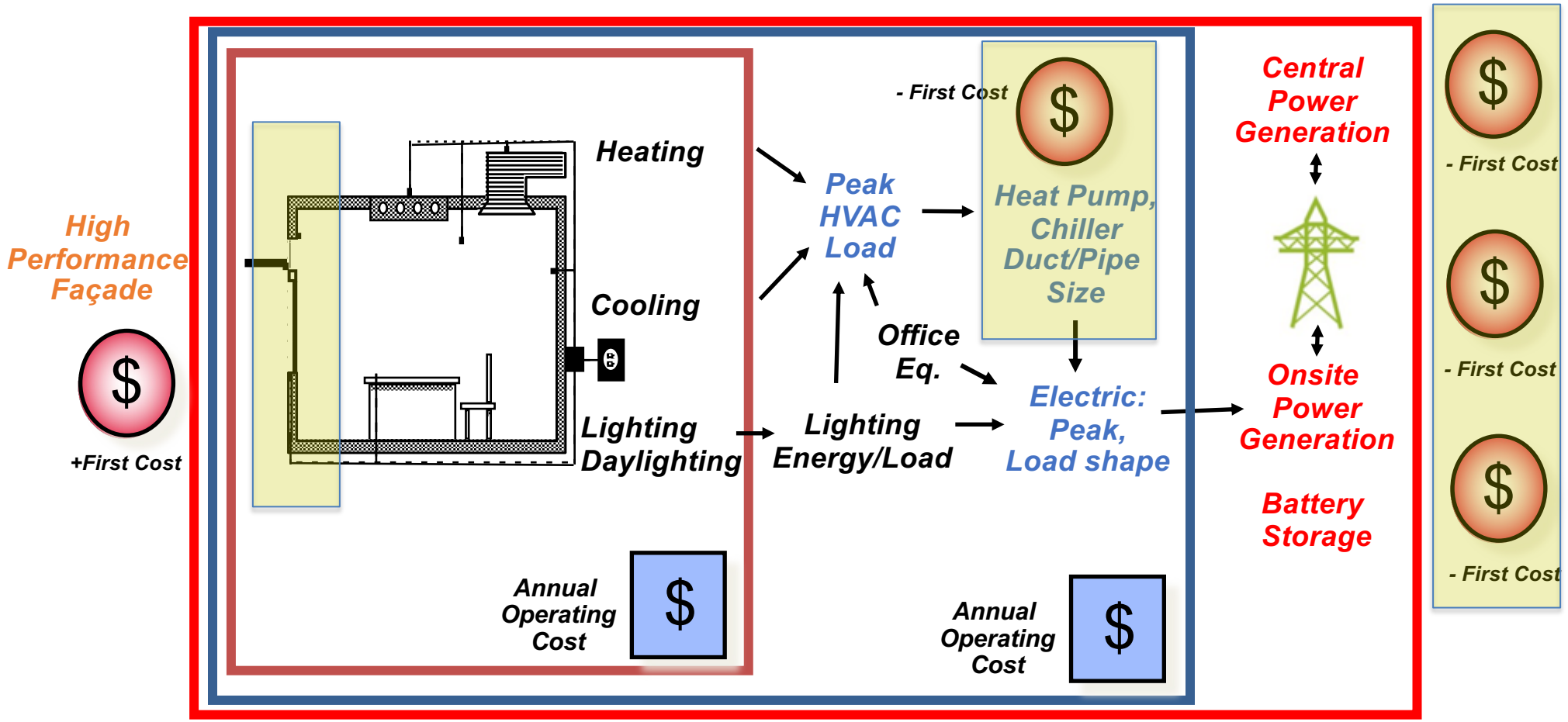
Facades are Intrinsically “Integrated systems”



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

Who Pays for Integrated Facades?

Improved Façade → Lower HVAC System Cost → Lower Grid Cost



Cost Tradeoff: Glazing vs Perimeter Heating

Triple Glazing Value Proposition:

Decrease perimeter **HVAC cost**
(pays for the glass cost?)

Reduce overall building **cost**
Condensation resistance
Comfort
Resilience
Peak heating and cooling
Stable load



	Cost/ft2 Window
Upgrade Double to Triple Pane	$5.47
Add Perimeter Heat to Double	$53.20

*image credit and cost data: Chris Mackey at Payette Architects

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

Demonstration Projects

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

“De-risk” design, cost, operations

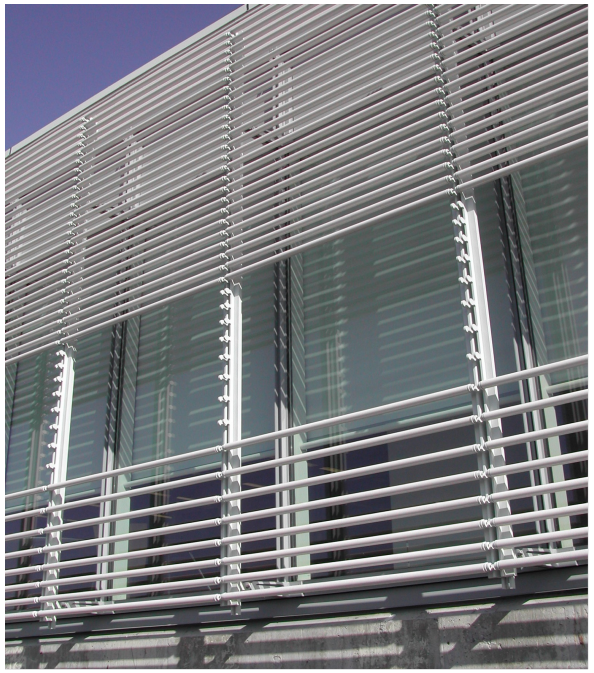
Mockups: Beyond air/water/structural

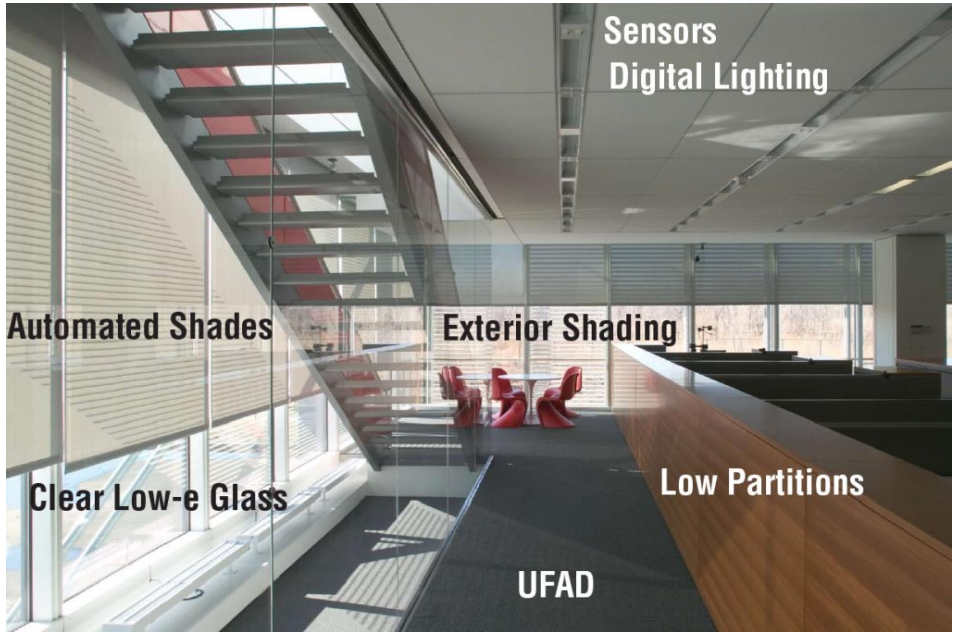
New York Times HQ, NYC 2003-2007

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

Rapid Prototyping: Mockup in FLEXLAB Rotating Testbed





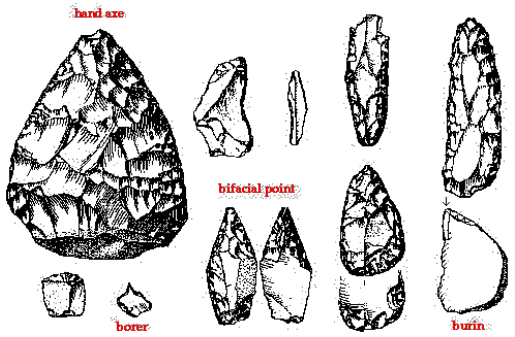


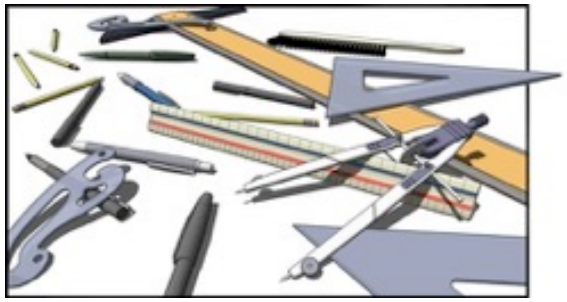


Design Tools = Virtual Building Mockup

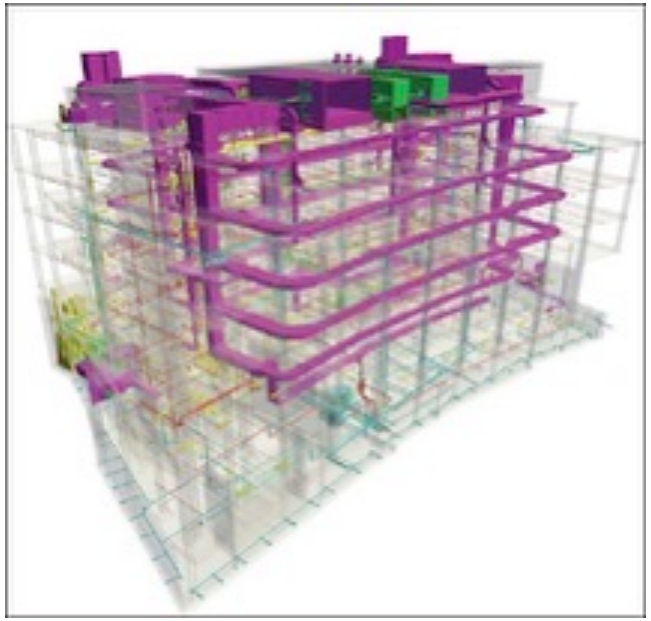
"All Simulation Models are Wrong, But Some are Useful"

How do we find the right, validated useful tools?





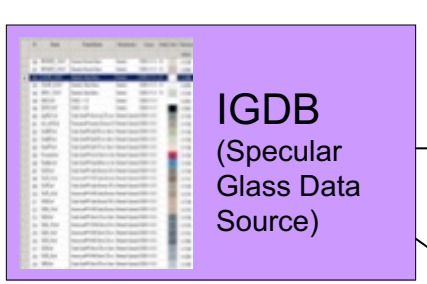




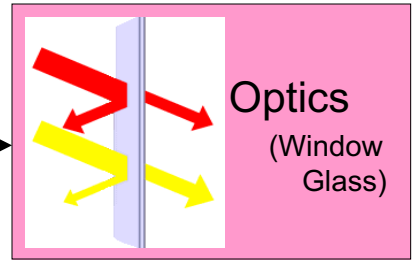
BIM, Digital Twins

Glazing and Façade Decision-Support Tools

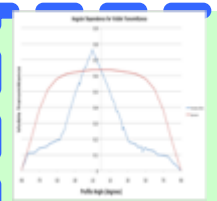
Download http://windows.lbl.gov/software/ ~ 40,000 Downloads/yr



IGDB
(Specular Glass Data Source)



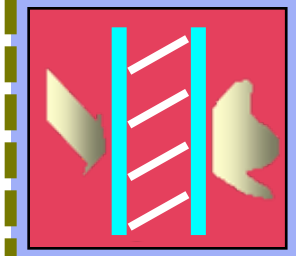
Optics
(Window Glass)



Angular SHGC/U/VT
(Rating/Lableling)



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

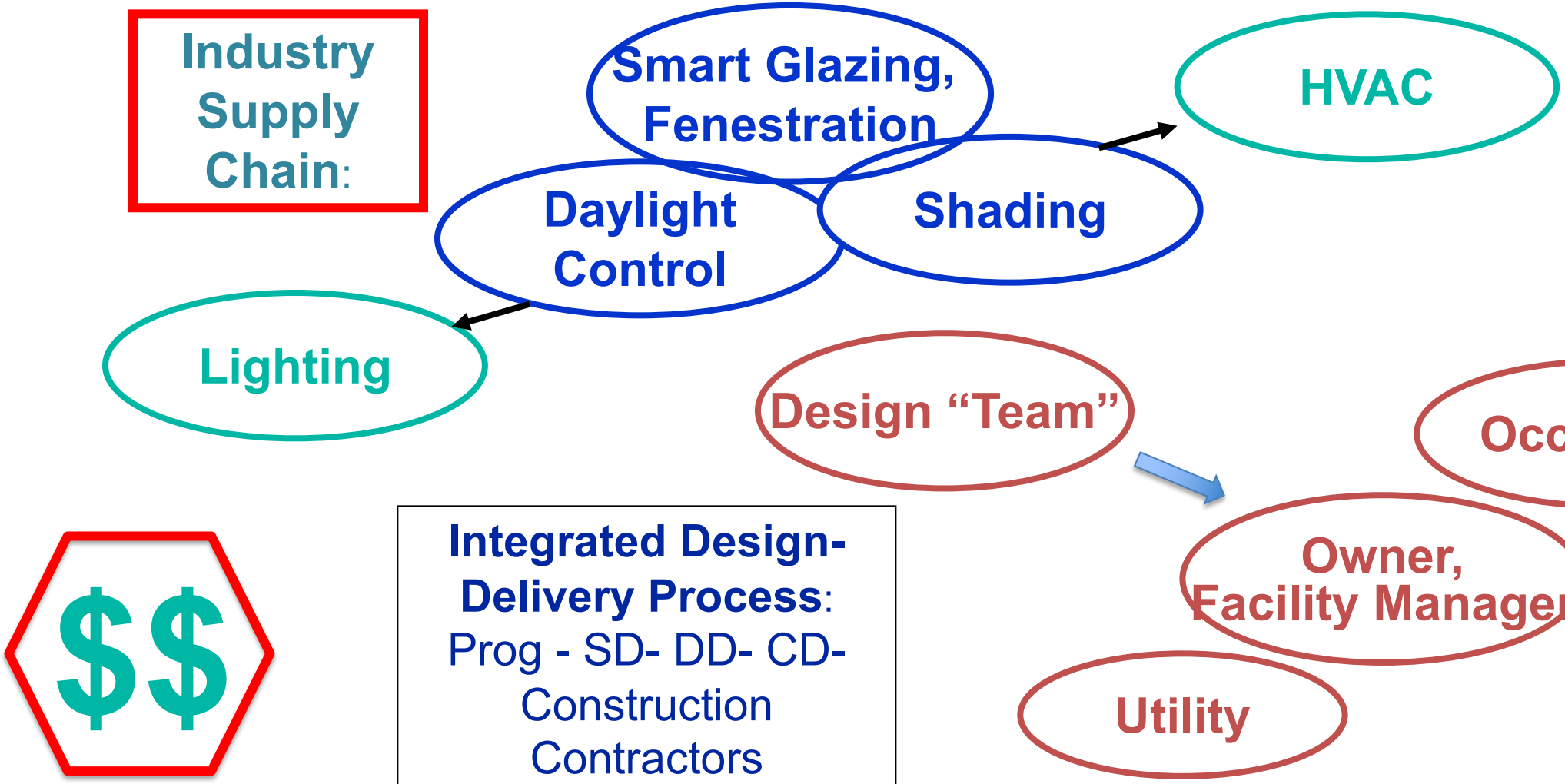
Rethinking the Façade Design/Delivery Ecosystem

To Increase speed, Scale, Impacts

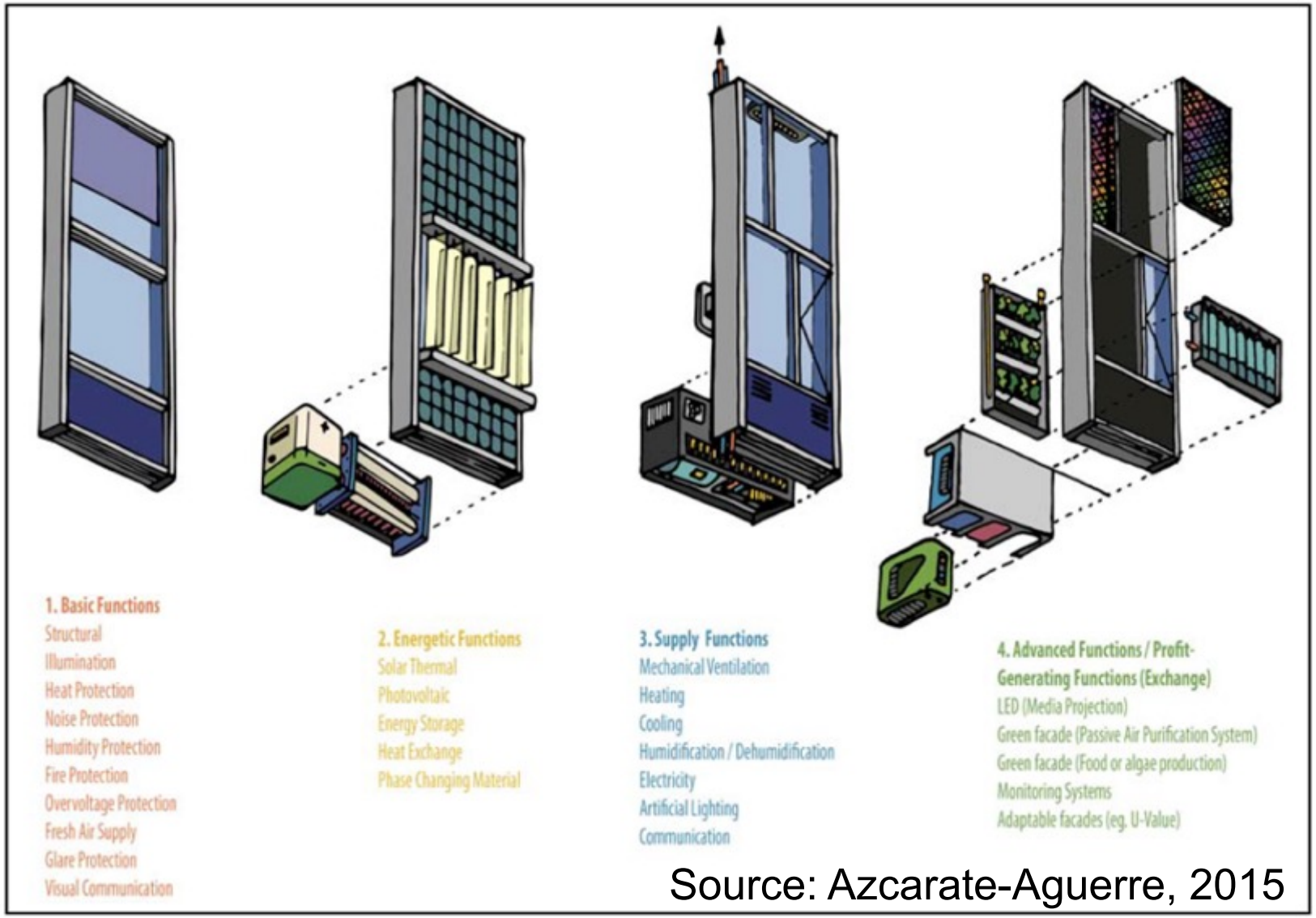
Can we predict, guarantee performance over time?

Window/Façade Design-Delivery Ecosystem

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



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

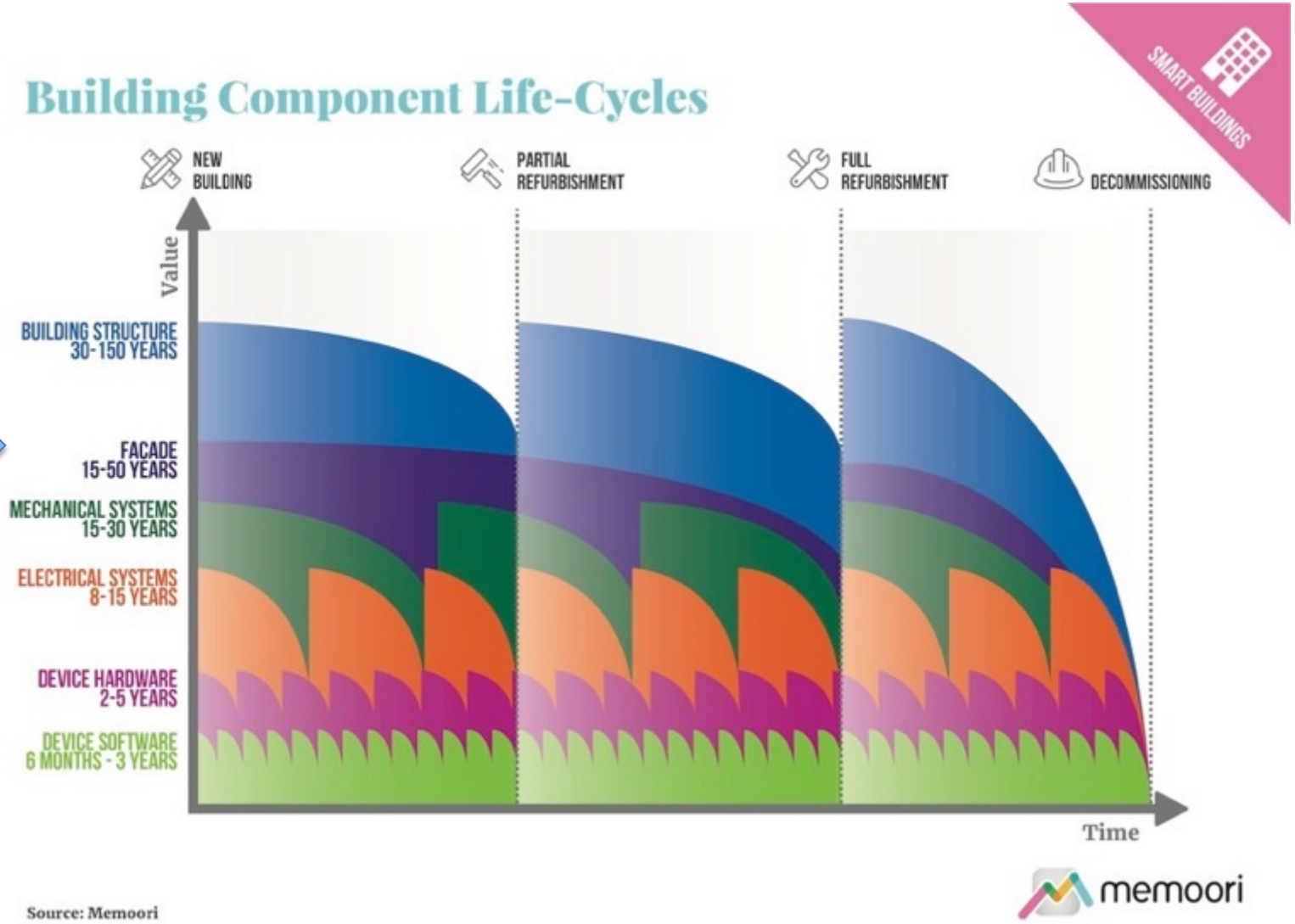


Source: Azcarate-Aguerre, 2015

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!



Façade Asset Management Tool of the Future: Preserving data across building life cycle

- “Zero guesswork in Matching Replacement Glass in the Future”
- Viracon Identification Number (VIN)



Sample code on IGU thermal spacer

- Other companies developing similar ”Durable ID” solutions

Global Investment of $Trillions in Smart Grid

MegaWatts (Powerplants) vs “Negawatts” (Buildings/Windows)



Fossil/Nuclear



Renewables and
Electric Storage





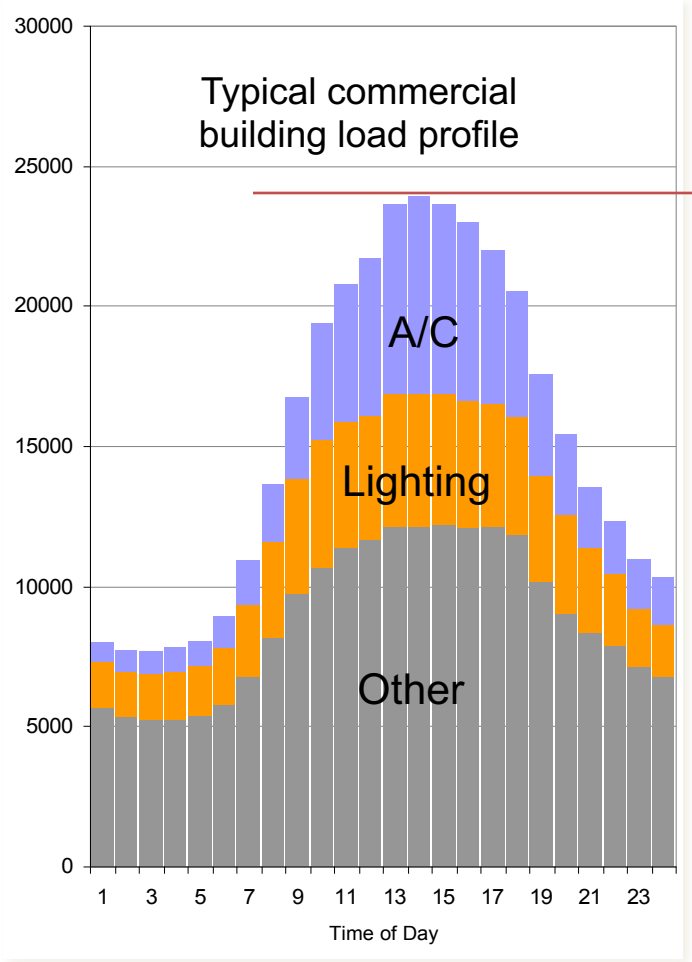
New Building Roles?

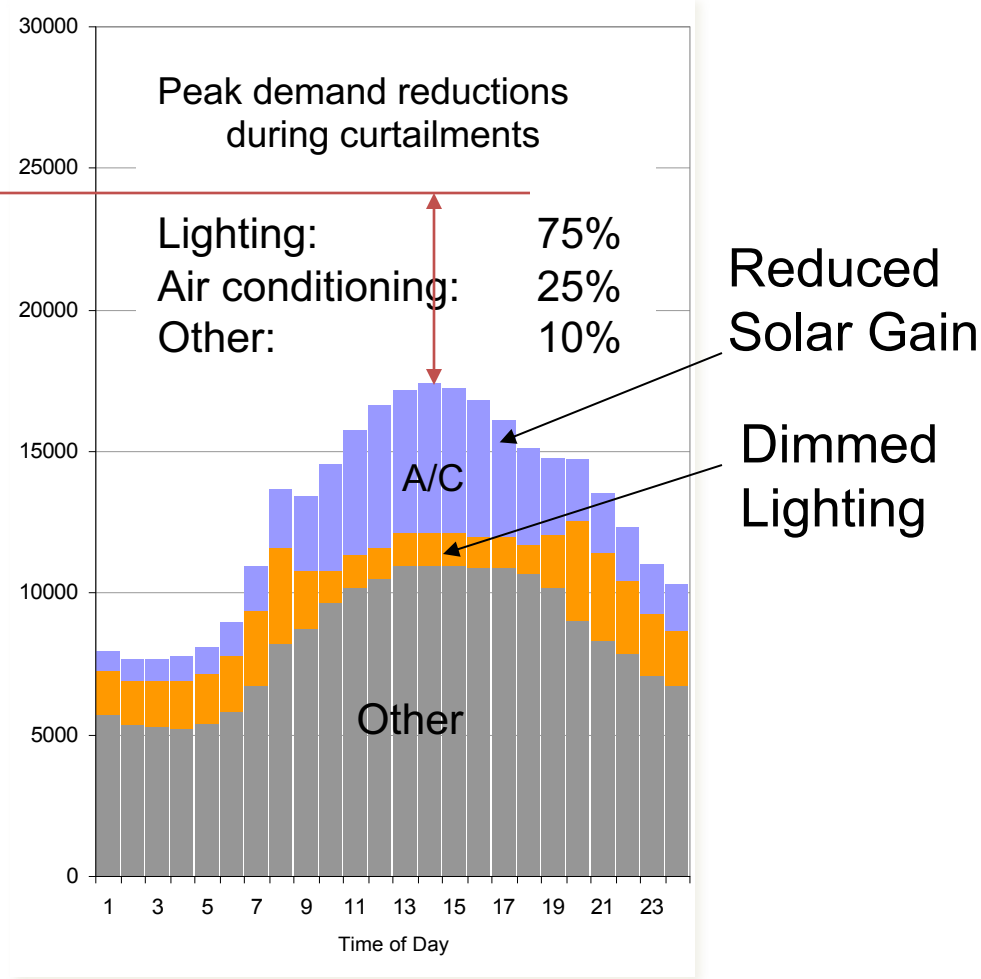
1. Manage Energy Use
2. Generate Energy
3. Store Energy

Grid-Interactive Efficient Buildings, GEB - DOE

Energy/Demand Management with Smart Windows + Daylighting Controls

Electric Demand

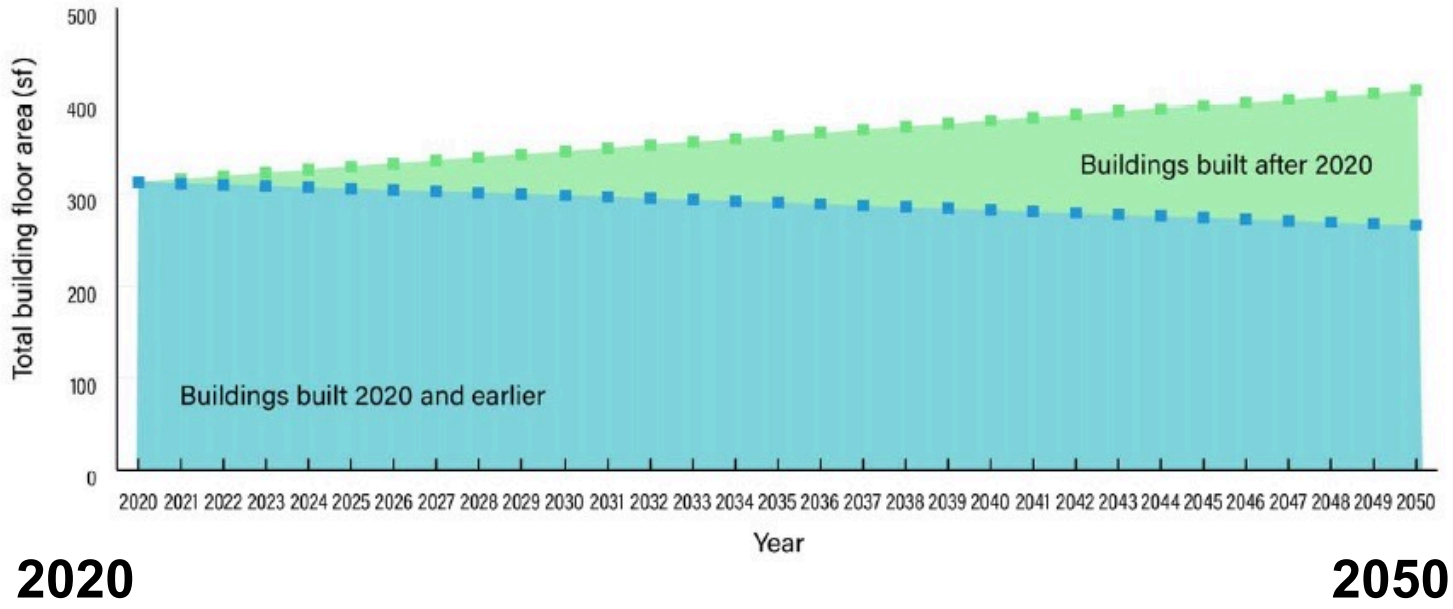




30% Peak Savings Possible from Cooling Load Control and Daylight Dimming

Existing Building Performance will Continue to Drive Overall Building Energy and Carbon Impacts

New and Existing Buildings as Share of Building Floor Area (Residential + Commercial)



2020 **2050**

Source: ACEEE calculations based on data in EIA AEO 2020.

New construction:
1-2% of stock

Renovation/Retrofit:
2-4% of stock

(wide variation by country, city, building type,…

>50% of the 2050 Building Stock Exists Today:
RETROFIT will be key to meeting 2030-2050 Goals
A New Business Opportunity for Glass?

What can the Glazing Industry do to promote "Informed Decisions" and Investment for Retrofit ?

1. Technology Innovation,
2. Promote Affordable, scalable, market-ready solutions
3. **A Voice in National/Regional Program Development (e.g. NGA Advocacy Day in DC)**

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…?**



Heat Pump advocates promoted massive investments in HP…
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)

Barriers to Better Facades



Source: Prieto
JFDEv5#1

Most Expensive Building Element?

People!

Energy: $4/sf

Productivity: $400/sf

Energy Use, Carbon

vs

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

PAWS Agrees with NGA that "Glass Can Save the World"…..

PAWS
PARTNERSHIP FOR ADVANCED WINDOW SOLUTIONS

Contact: https://www.PAWS.energy

- **Engage and Advocate for Better Glazing, Better Windows**
- Identify and promote Best Practice
- **Leverage/accelerate Public/Private Partnerships**
- Broad Scope:
  - New and Retrofit Solutions
  - Residential (ENERGY STAR) and Commercial (secondary windows)
  - Windows, Attachments
  - National - all climates

Façade Tectonics Institute, FTI

- Working with DOE/LBNL on a 9 month project:

"Accelerating the Adoption of High Performance Fenestration/Façade Solutions in Commercial Buildings"

- Broad stakeholder engagement – roundtables, forums,…e.g. meeting at BEC
- **Assess Barriers to Adoption**
  - Building type, Climate, Ownership models…
- **Recommendations for DOE**: new concepts, best practice for market facing initiatives, R&D needs, decision-support tools, public policy,… immediate and longer term

Facade Tectonics

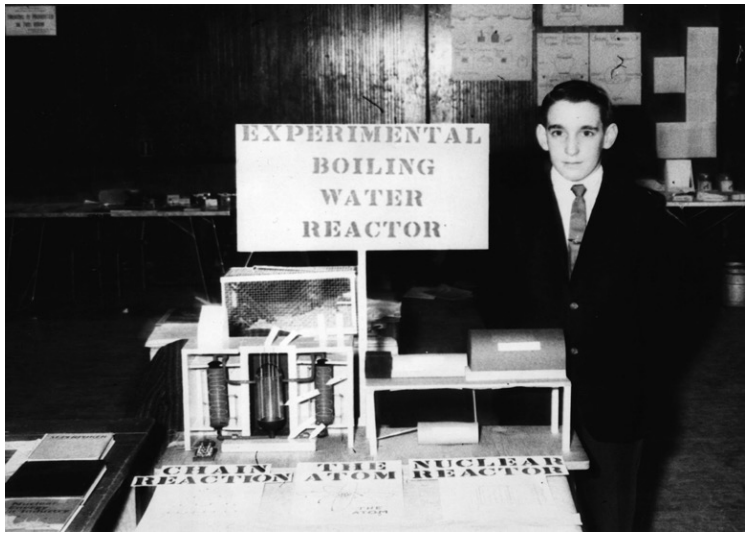
Can the Glass/Facade Industry Deliver Innovative Solutions for New and Existing Buildings, Rapidly, At Scale?

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

Glass/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/Follow-up



Stephen Selkowitz

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