Pathways to Net Zero Energy Buildings

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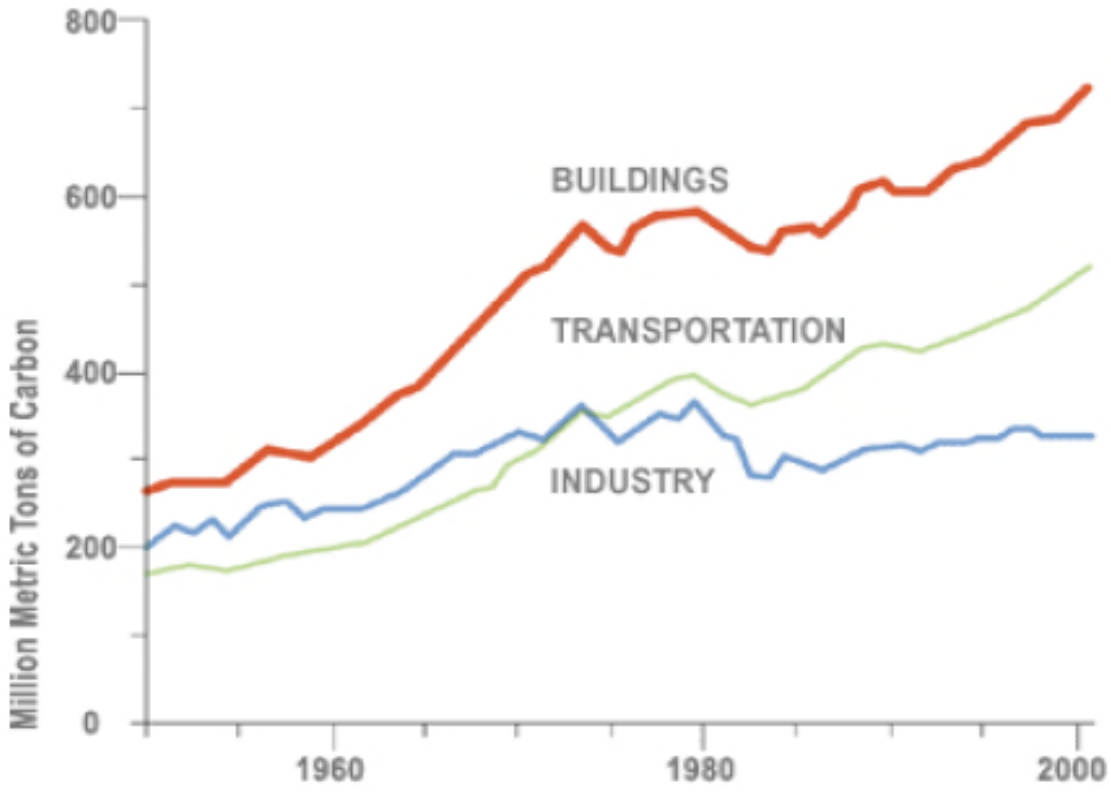
Outline

1. Energy Efficiency and Buildings - the big picture
2. Net Zero Energy Buildings - goals, challenges
3. Windows and Integrated Façade Systems
4. NY Times building: Automated shading and daylighting
5. Intelligent Lighting Systems
6. Smart Grid and Demand Response
7. Integrated Building Systems
8. Performance Benchmarking and Labeling
9. Simulation Tools
10. Summary

U.S. End-Use Energy/Carbon Split

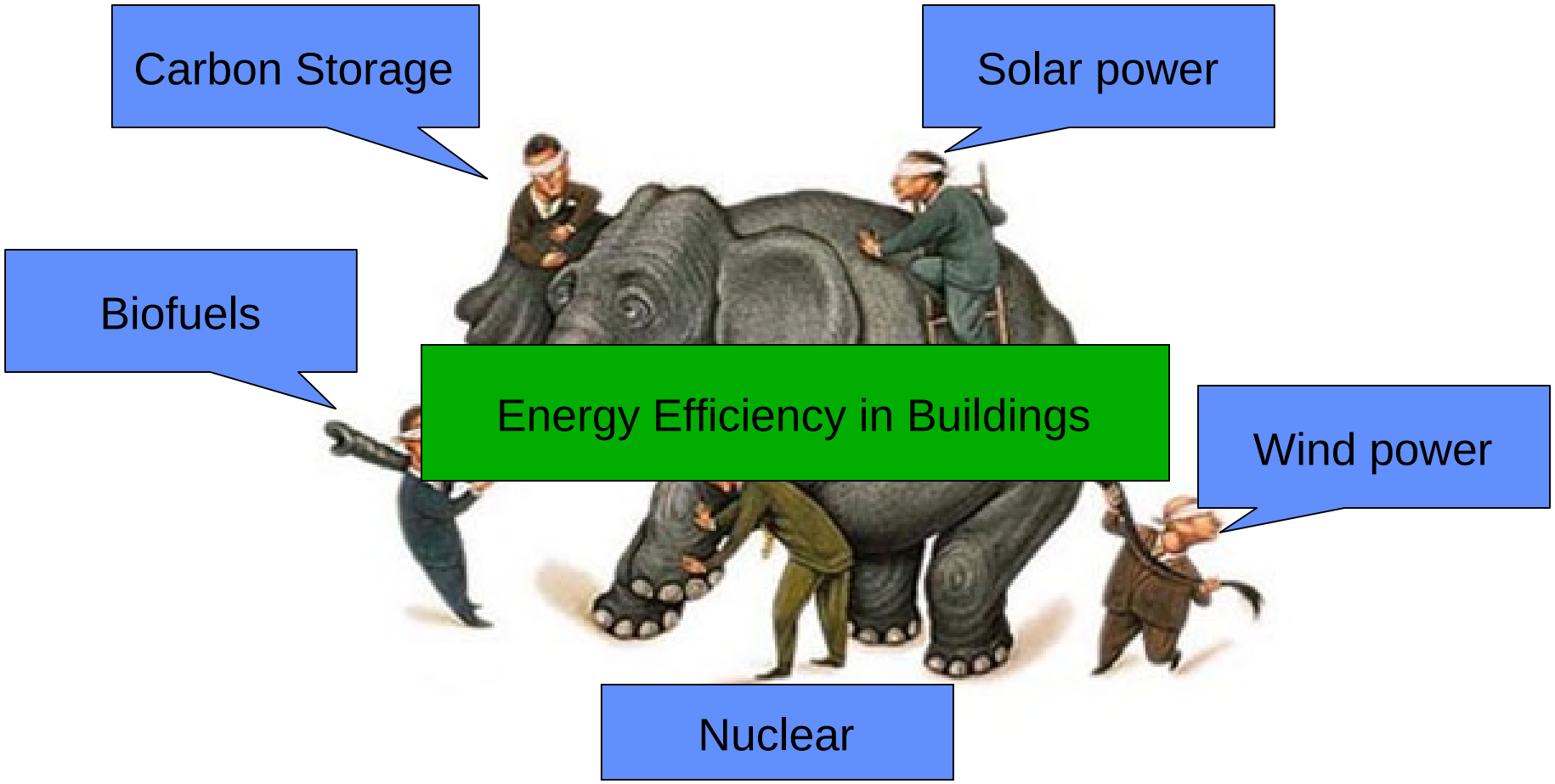


Building Energy Use:

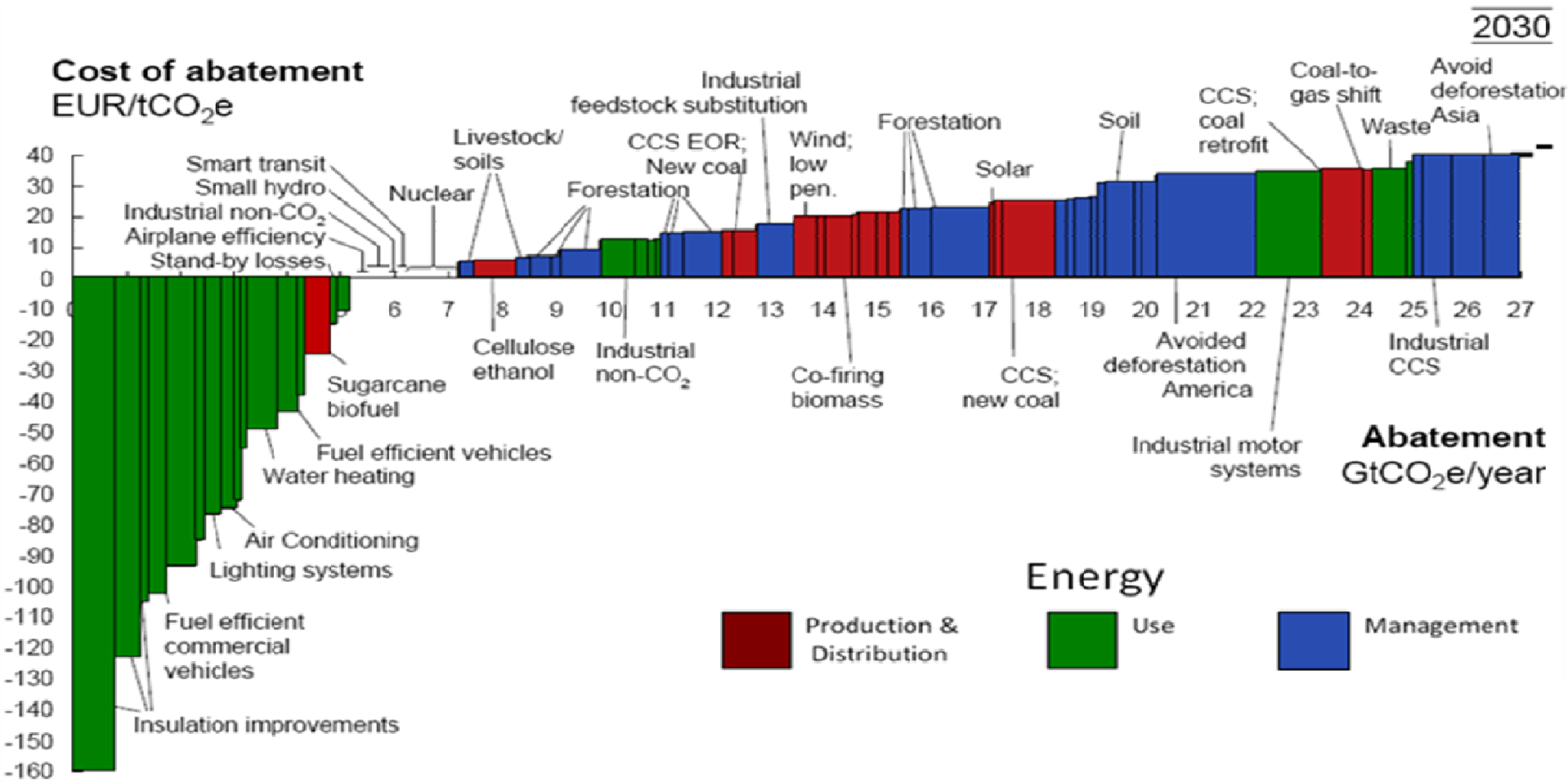
39% total U.S. energy
40% of carbon emissions
71% electricity
54% of natural gas

Fastest growth rate!

Defining the Energy/Climate Change Problem:

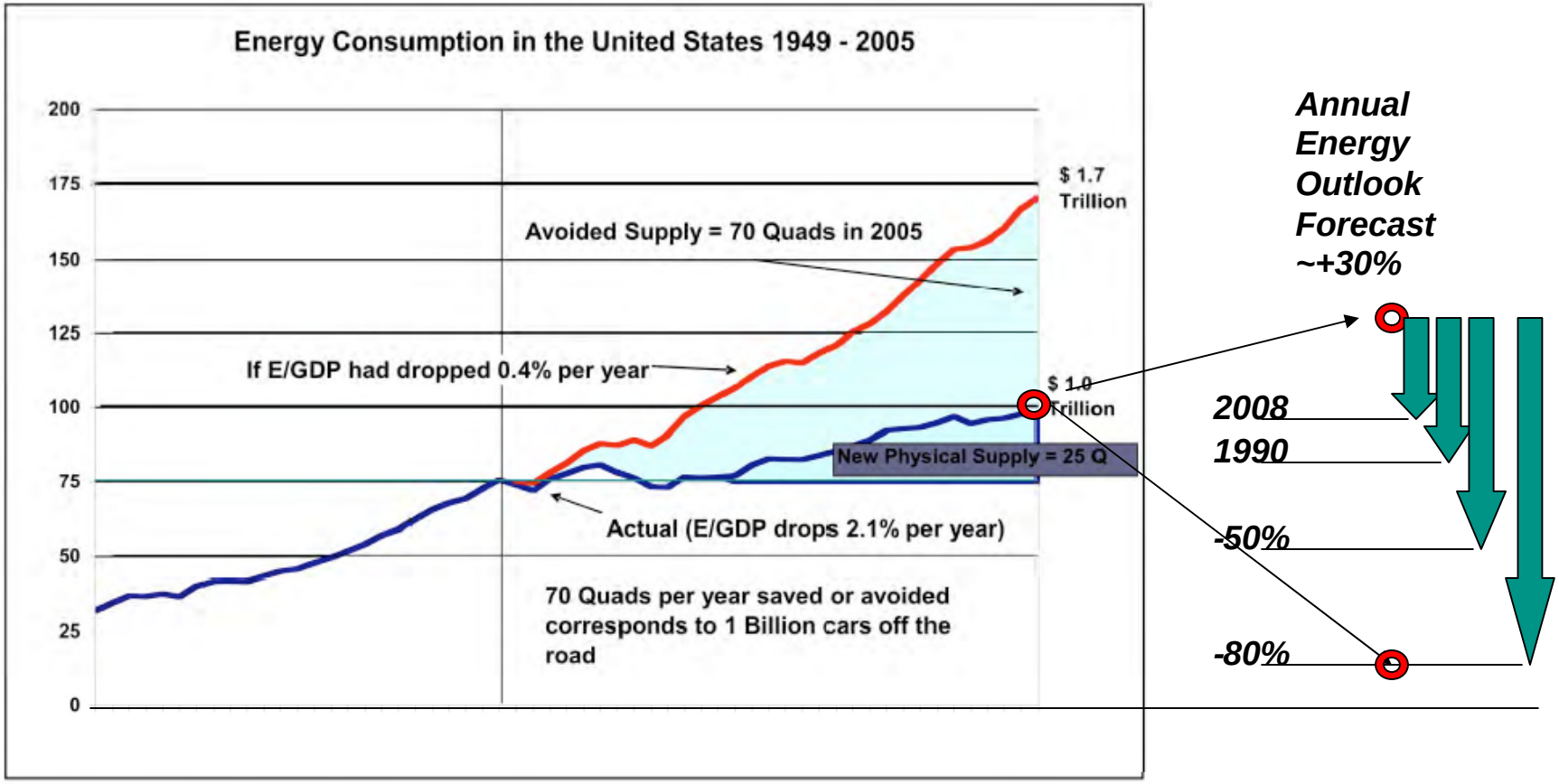


Saving Carbon vs. Energy Sectors
Production, Distribution, Use



Source: McKinsey Global Institute, 2007
Replotted: John Zysman, UCB

Good News/Bad News



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Net Zero Energy Buildings

The Vision

- "Net Zero Energy Buildings" is the right long term goal

The Dream

- **Just Do It**
  - Set a goal - march toward it
  - Its easy, if we commit and apply ourselves
  - We have the technology and know-how

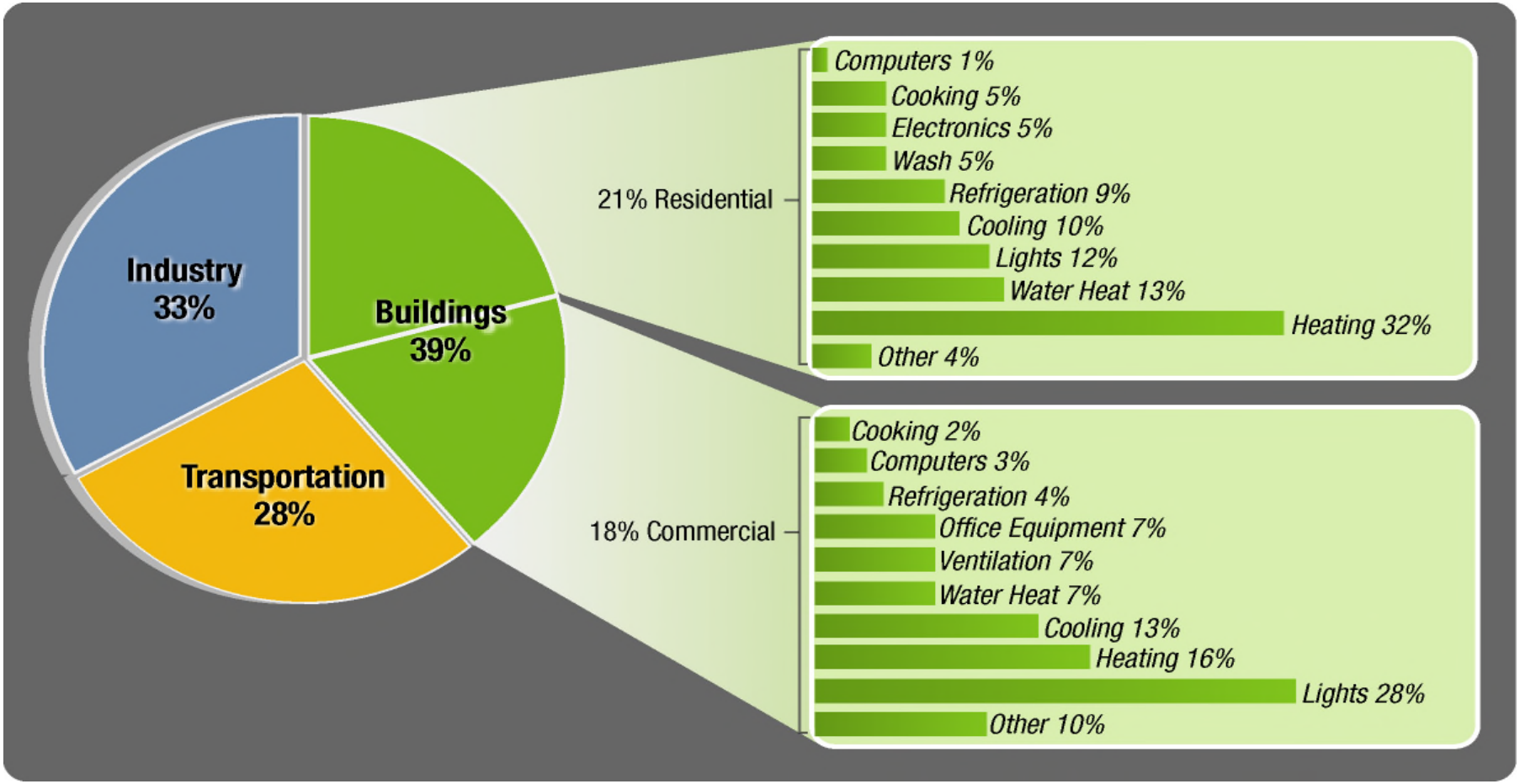
The Reality

- **Major National Challenge**
  - Technically attainable - Difficult to achieve in scale
  - Shortcomings: Owners? Users? Tools? Construction? Operations?
  - Integrated Standards -Deployment-Demonstration-Research
  - Issues- Policy, Finance, Design Process, Technology

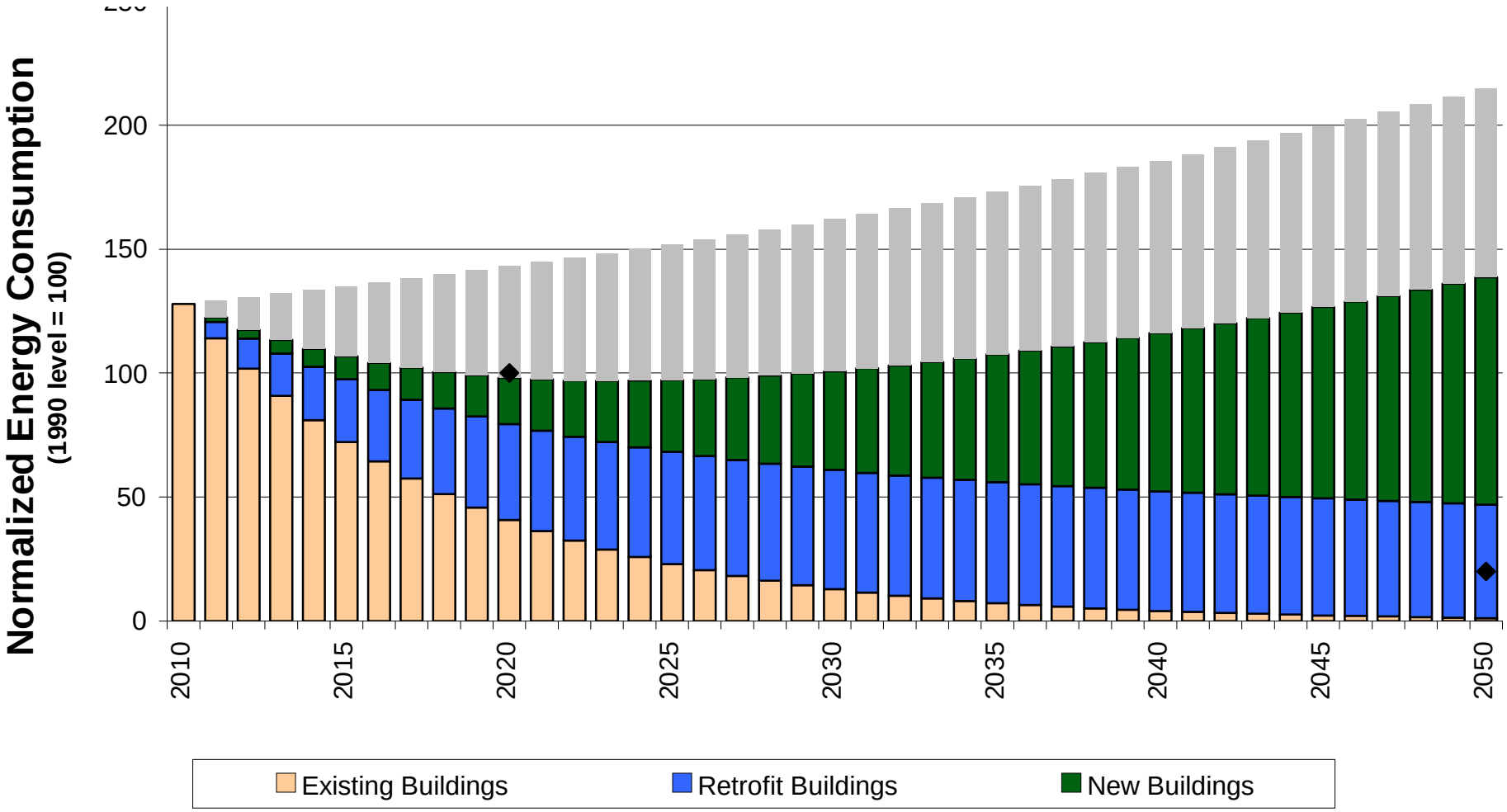
Building Energy Demand Challenge: End Use Energy Consumption

Buildings consume 39% of total U.S. energy

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



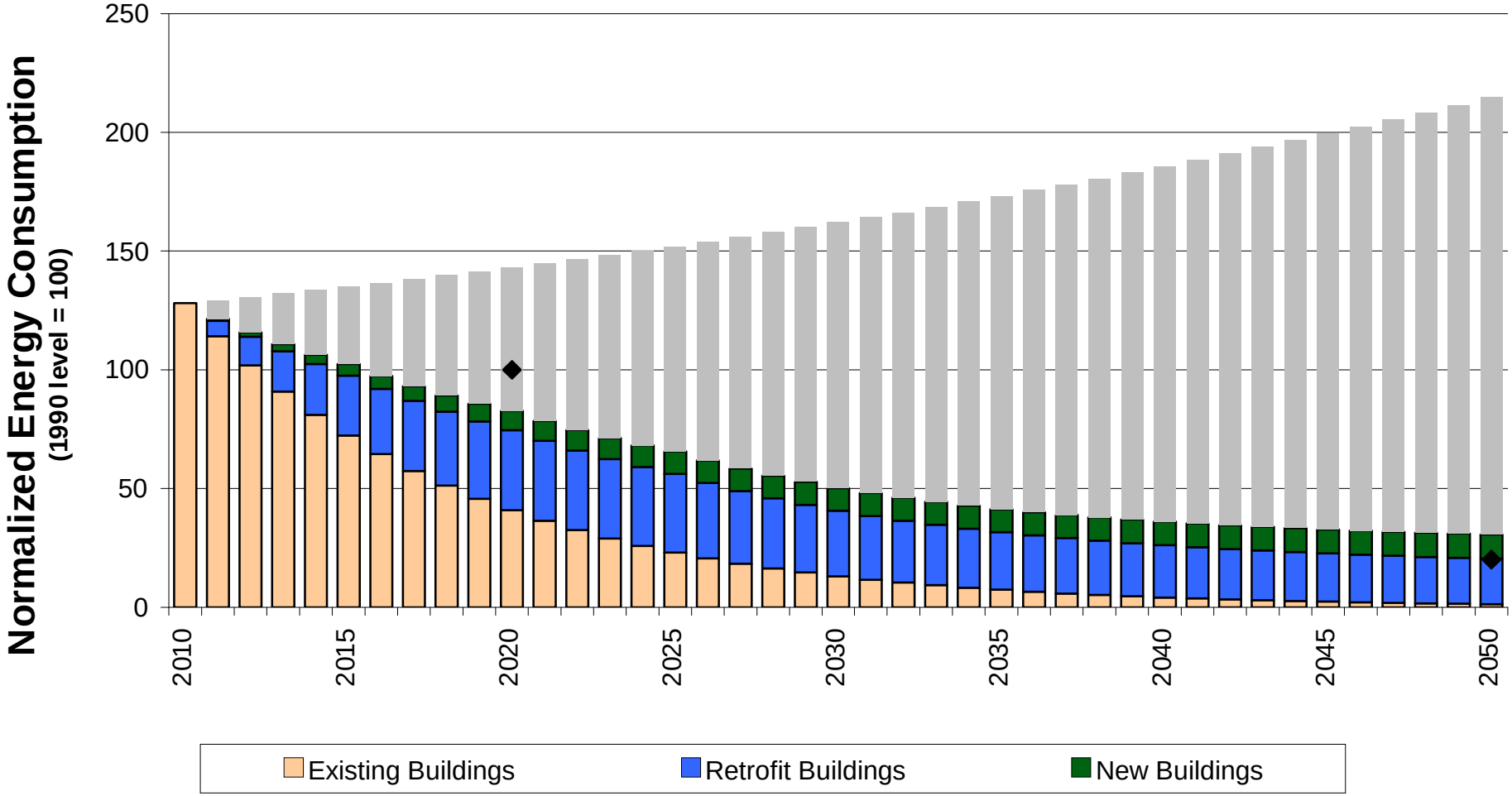
Inventing the Future:
New construction: 50% saves 50%; Retrofit: 10%/yr w/ 50% savings



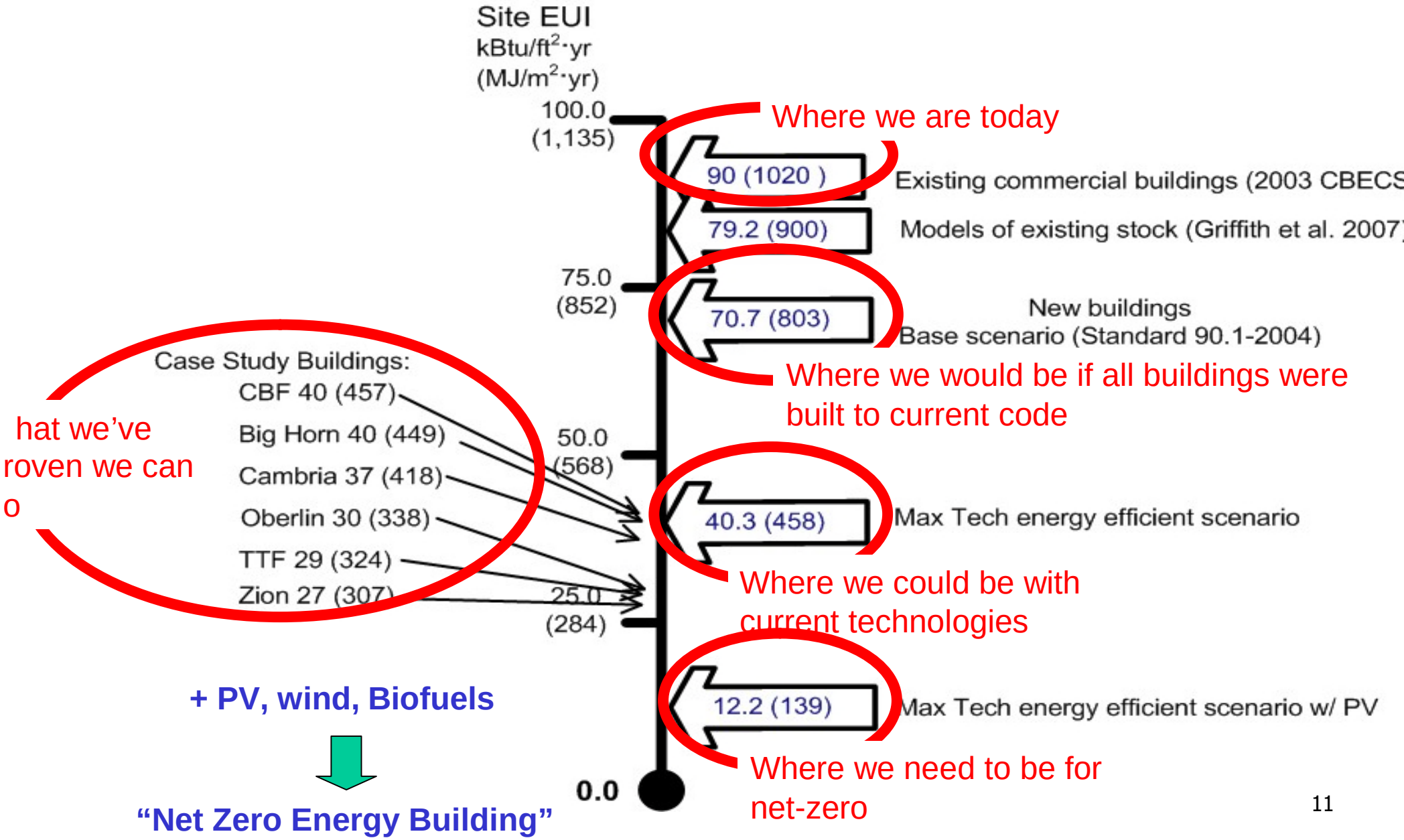
Inventing the Future: "Ultra Aggressive"

New construction: 60% --> 90% in 2030

Retrofit: 10%/yr; 50%--> 80% in 2030

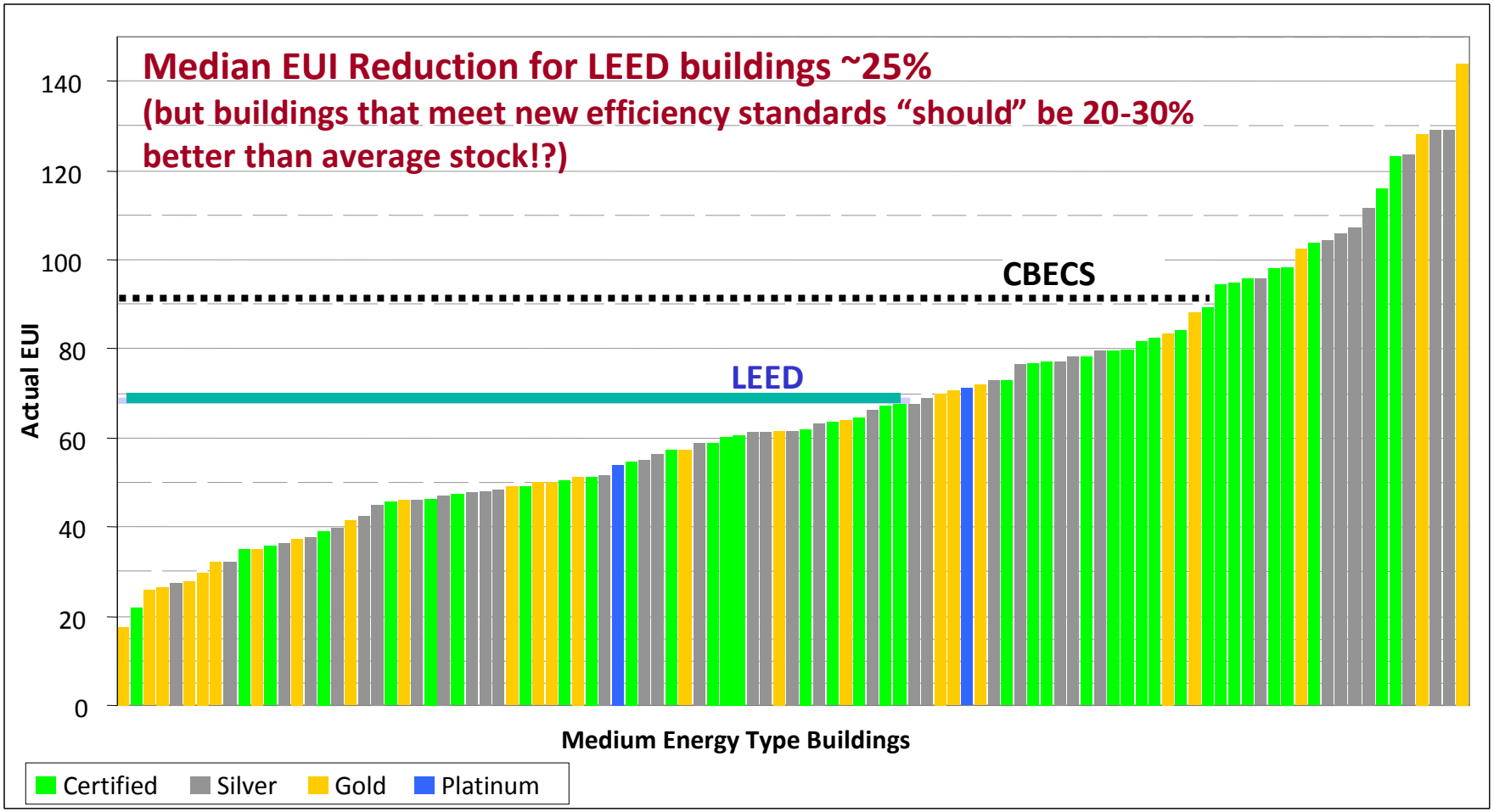


Driving Building Energy Use to "Zero"



Progress(?) with New Buildings

LEED Buildings (medium types) vs. CBECS Stock Data



EUI = Energy Use Index, kBTU/sf

Source: www.newbuildings.org

Conclusions

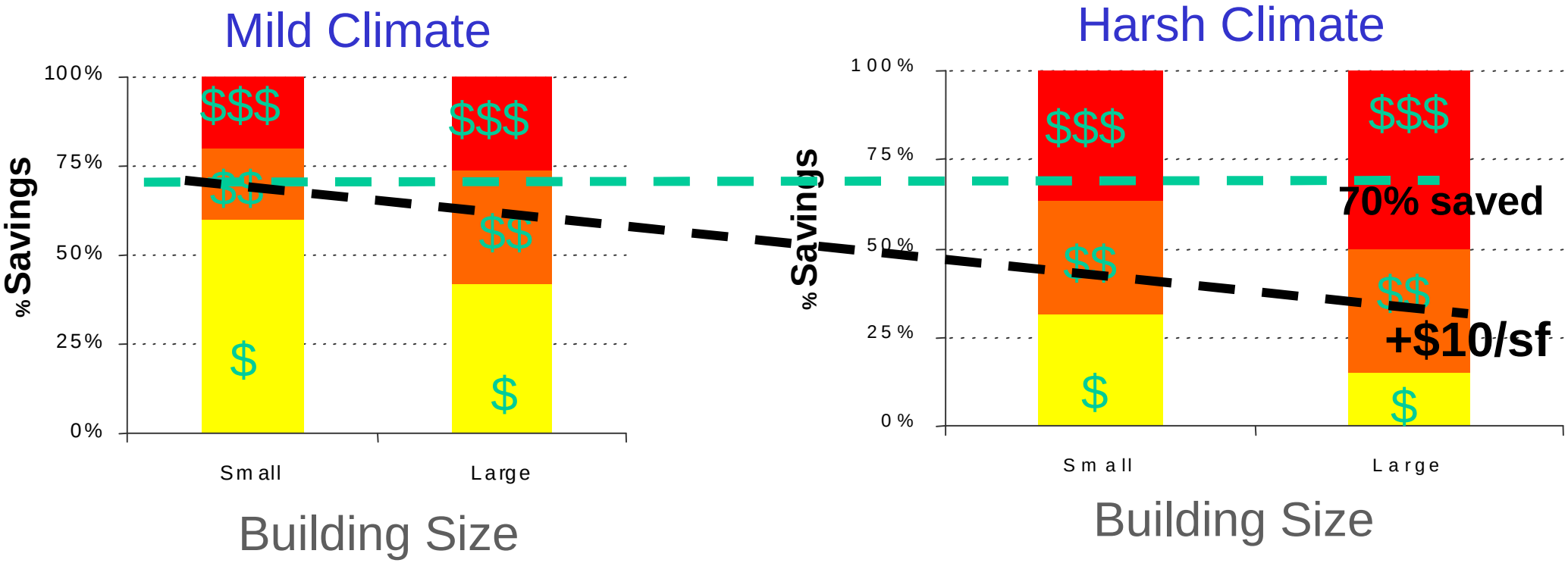
- Massive Reductions in Building Energy Use Needed
- “Net Zero Energy Buildings” is good long term goal
  - Need Interim goals, e.g. 50% savings, etc.
- Useful data exists on current energy use
  - Variety of metrics, snapshots of energy use
- Distinguish between “design intent” and “actual performance”
  - Shortcomings: Tools? Users? Construction? Operations?
- Very Challenging Goals
  - Fragmented, risk averse industry
  - Technically attainable - but only a few examples come close
  - Very Difficult to achieve in large scale - 100s out of 5M buildings
- What will it take to Accelerate Progress Towards Goals?

Zero Energy Commercial Buildings:
Status and Innovation Challenge

- **For some climates and building types we can design, build and operate a Zero Net Energy Building today**
  - **But Complicated, costly, unreliable, requires special attention,…..**
- **Research and Technical Innovation Challenge:**
  - **How to scale in depth and breadth**
  - **How to move from "one of a kind" to standard practice**
  - **How to Reduce cost, increase reliability**
  - **Address all climates**
  - **Address all building types**
- **Policy, Economic, Political Innovation Challenges**

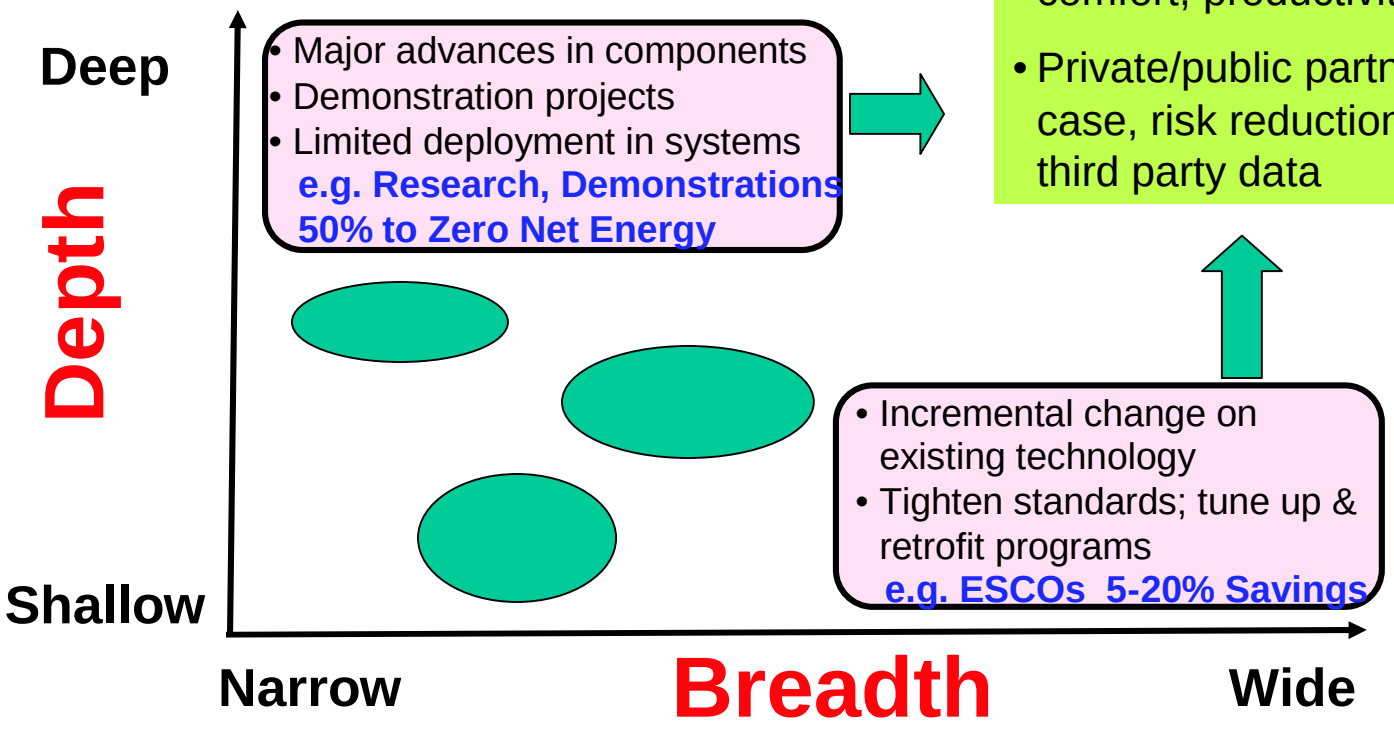
Sector Goal Analysis

- "How difficult is it to achieve large savings?"
  - Consider impact of market segment, climate, building size on cost of achieving a given savings level, e.g. 70% savings
  - Lay out programs on "investment basis", not savings basis?



Conceptual Approach for Achieving Nationwide ZEB Goals

- Systems approach: integrate advanced components, optimize energy, comfort, cost
- Capture social equity, health, comfort, productivity issues
- Private/public partnership - Business case, risk reduction and credible third party data



Projecting Energy Use (and Carbon) over Time

Total Building Sector Energy = Individual Building Energy Use, EUI × Building Stock × Stock Changes Over Time

- New construction
- Renovation
- Retrofit
- Tuneups

Individual Building Energy Use = [Owner × Budget × Type & Size] × [Climate Location × Site]

Renovation
Retrofit
Tuneups × Design Team × Emerging Technology × Construction × Operation × Use

Getting to ZNE Buildings: 7 Step Process

1. Define Performance Requirements
2. Minimize loads
3. Supply loads with Efficient Equipment and Systems (or without mechanical systems)
4. Design for Operations
5. Use Renewables
6. Monitor, Measure results
7. Provide Performance Feedback loops

Building Innovation "Game Changers" for ZEB (Examples follow)

Assumed: cheap, long lasting, reliable, specifiable, affordable, green, ….

MATERIALS AND SYSTEMS

- Smart Glass/Dynamic Facades
- High R Windows, Insulation
- Thermal Storage

- 200 lumen/watt lighting
- Daylight integration
- Dimming, Addressable Lighting Controls

- Task Conditioning HVAC
- Climate Integrated HVAC
- Building- and Grid- Smart electronics
- Electrical Storage

LIFE-CYCLE OPERATIONS

- Building Life Cycle Perspective
- Benchmarks and Metrics
- Building Information Models (BIM)
- Integrated Design Process and Tools
- Building Operating Controls/Platform
- Building Performance Dashboards

- Understanding Occupants
- Facility Operators

Successes in U.S. Window Markets

(Example: Residential market)

- **1973: Typical Window:**
  - **clear, single glazed,**
  - **double or storm window in north,**
  - **$U_{average}$ = .85 BTU/hr-F-sq.ft.**
- **2003: Typical Window:**
  - **95% double glazed**
  - **50% have a low-E coating**
  - **30-65% energy savings vs. 1973**
  - **$U_{average}$ = .45 BTU/hr-F-sq.ft.**

- **2030: Future Window:**
  - **Zero net energy use (typical)**
    - **Net winter gain; 80% cooling savings**
  - **$U_{average}$ = .10 BTU/hr-F-sq.ft.**
  - **Dynamic solar control**

1973: the Ideal Window

Glazing and Window Technology:
Changing "Scale" and Function for R&D

"1μ" coating

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

"1mm" glass

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

"1m" Envelope, shading

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

Intelligent Control of Dynamic Conditions, Properties:

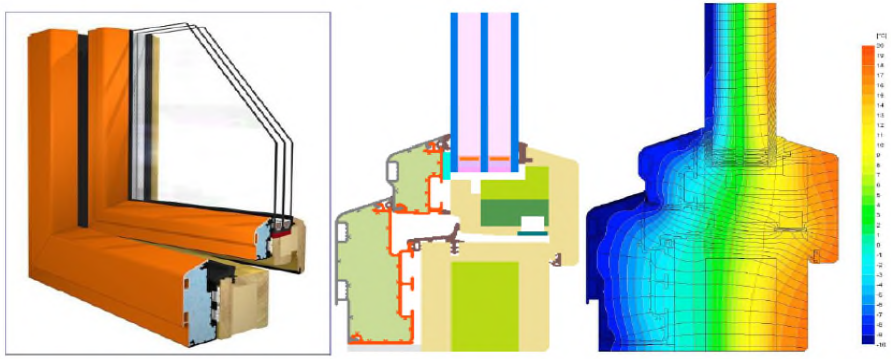
Thermal flows: U value

Daylight/Solar Gain: SHGC, G, Tv

- Intensity
- Spectral content, color
- Directional

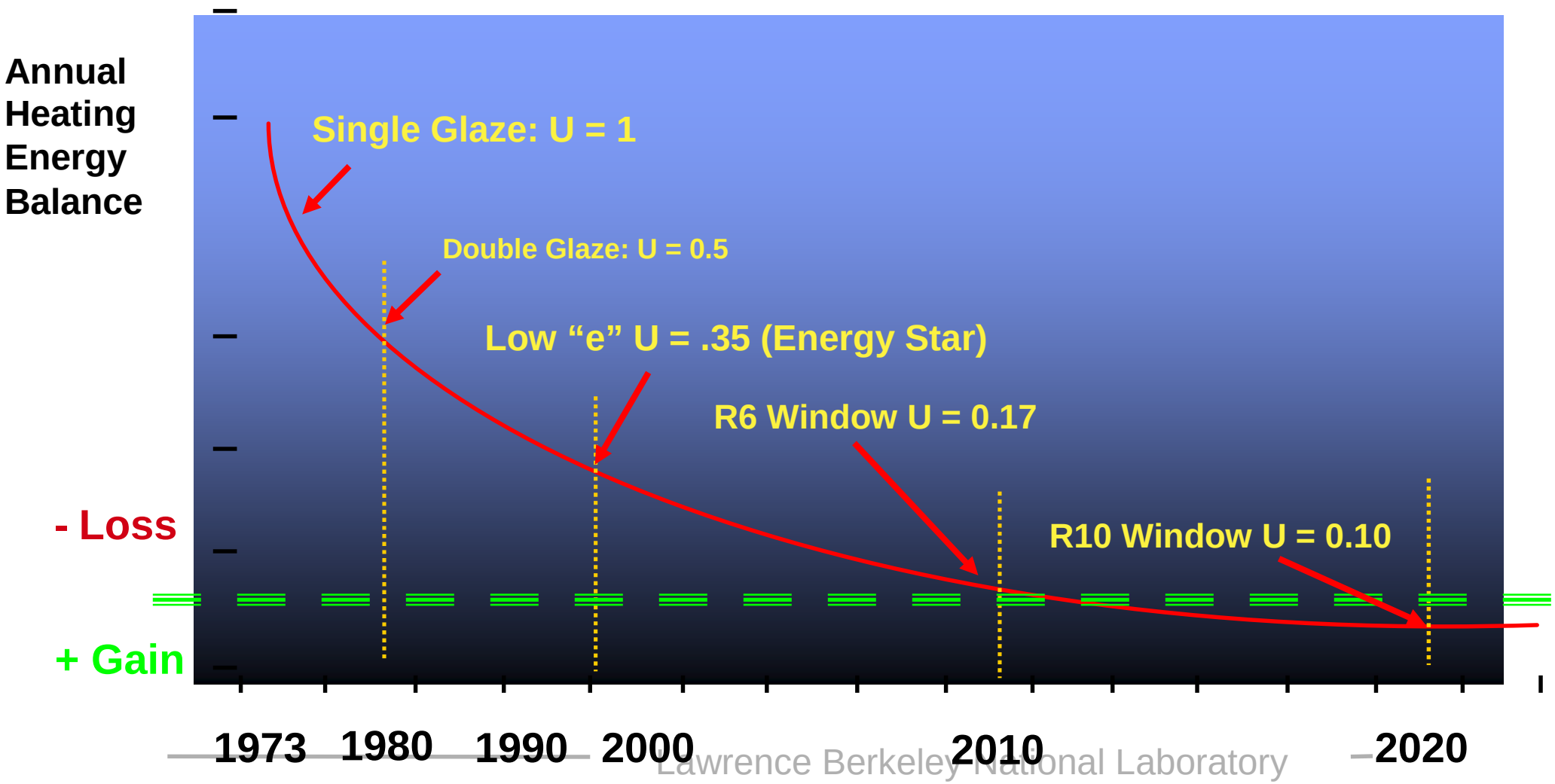
“Evolution” of Advanced Windows

- **Highly insulating systems**
  - Reduces winter heating loads
  - Multiple technologies
    - Aerogel
    - Vacuum glazing
    - Multipane, low-E, gas fill
  - Climate dependence
  - Cost



- **Dynamic windows for solar control**
  - Dynamic optical switch from high transmission to low transmission
  - Reduces summer cooling load; reduces glare
  - Multiple technologies
    - Electrochromic, thermochromic, photochromic, LCD,…
    - Interior, exterior, between glass shading
  - Integration with window, building
  - Cost

Advanced Windows Can Become Net Energy Producers



What are the Best Solar Optical Properties for a Window Anywhere in the U.S.?

Varies with Location and Orientation.

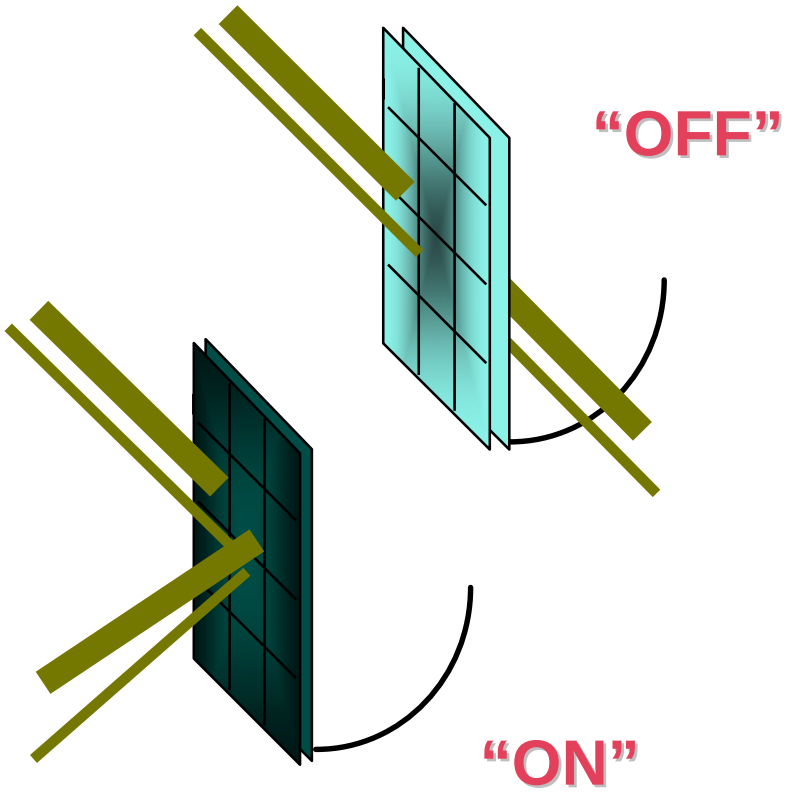
Varies with Season and Weather.

Varies with Occupant Use Patterns

So the best solution is a window whose solar-optical properties are "**variable**" and "**controllable**".
"HOLY GRAIL" of the Glass/Window Industry

Smart Coatings for Dynamic Control of Windows
Balancing Cooling and Daylighting

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



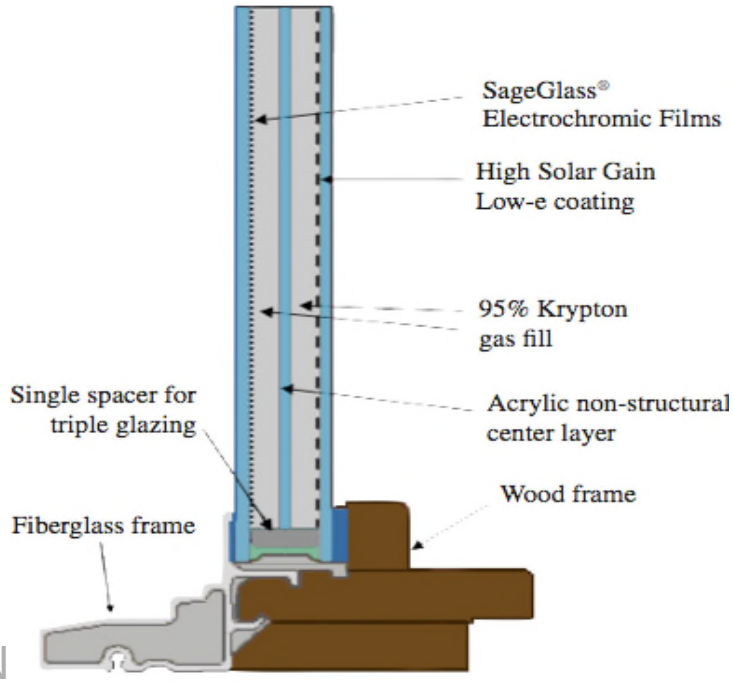
Next Generation Prototype "Zero Energy" Window

Current Prototype

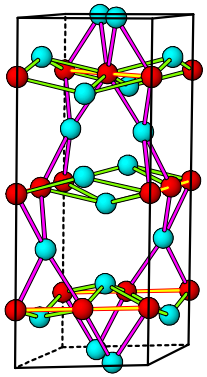
- Dynamic Glazing; SHGC (0.04 – 0.34)
  - Electrochromic glazing
- Highly Insulating; U Value 0.18, R 5.6

Ongoing R&D

- Increased dynamic range
- Cost-effective production
- Frame heat transfer R&D (50% of heat lost through 20% of area)
- Systems benefits:
  - Better comfort
  - No perimeter ducts
  - No central heating system??

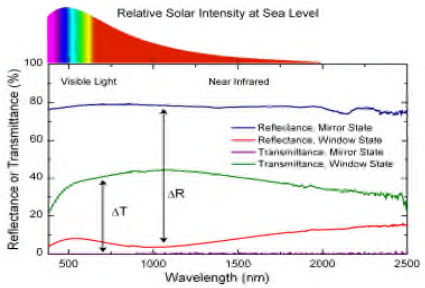


Integrated R&D Program for Smart Glazings

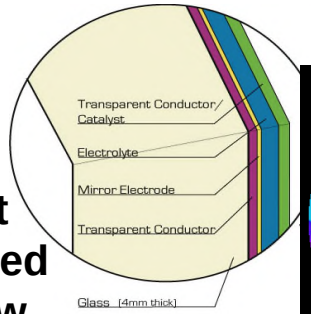


Mg_2Ni

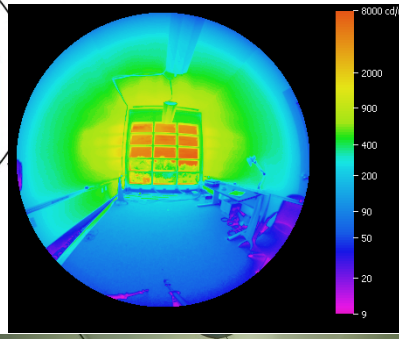
Invent New Materials

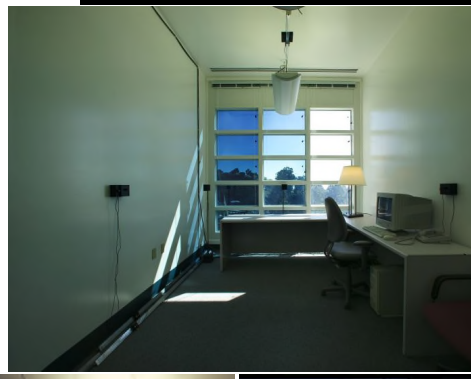


Characterize Coating Performance



Invent Integrated Window

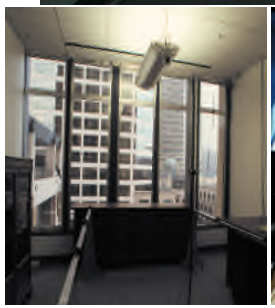


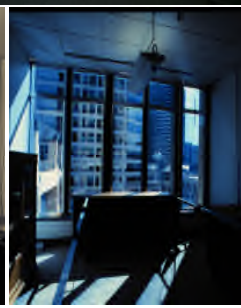


Assess Human Factors

Assess Savings

Invent Innovative Manufacturing Process

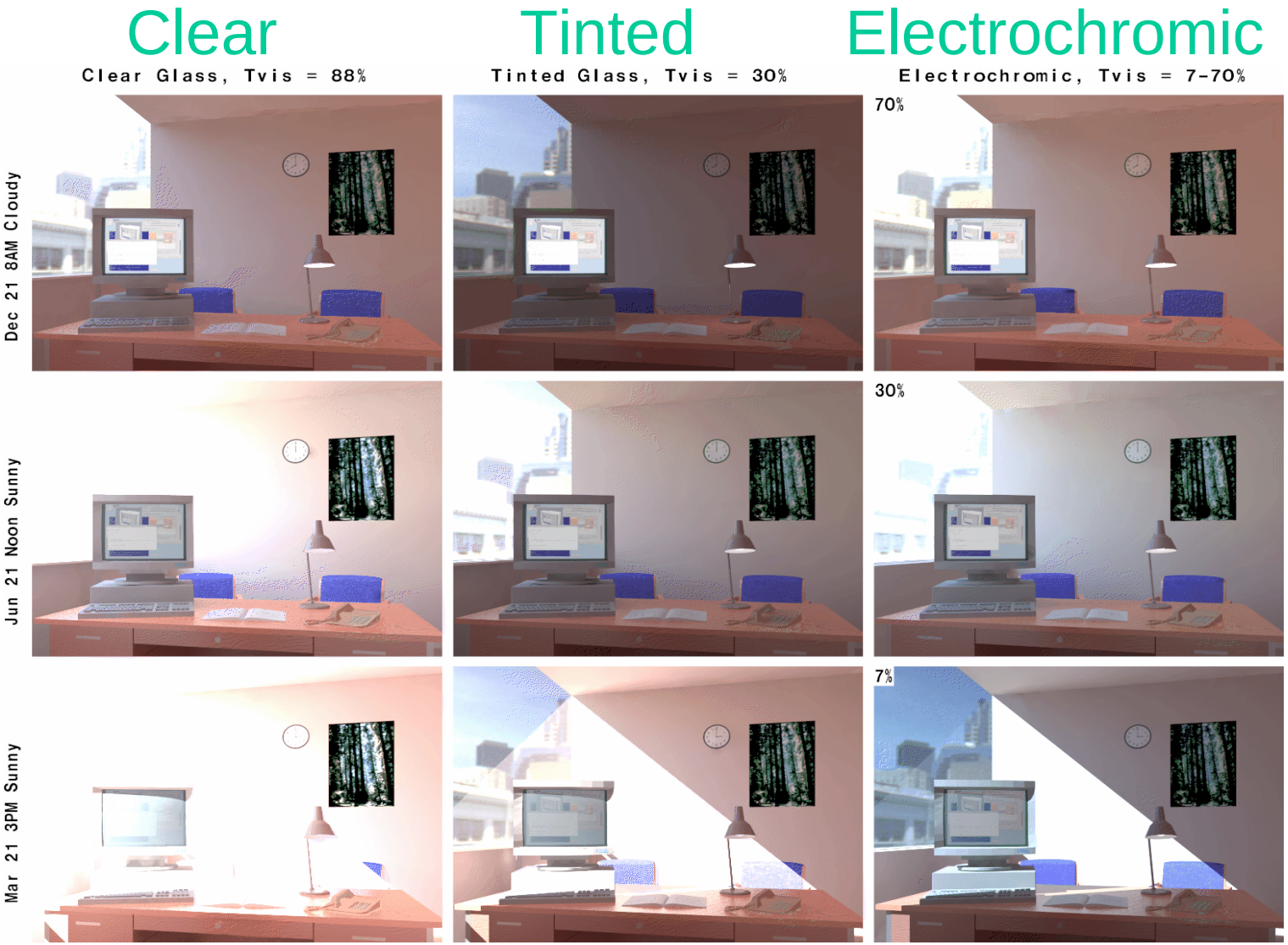




Invent/Test Integrated Systems

Modeling visual performance and comfort

RADIANCE simulation of conventional and electrochromic windows for different day types and seasons in Phoenix, Arizona.

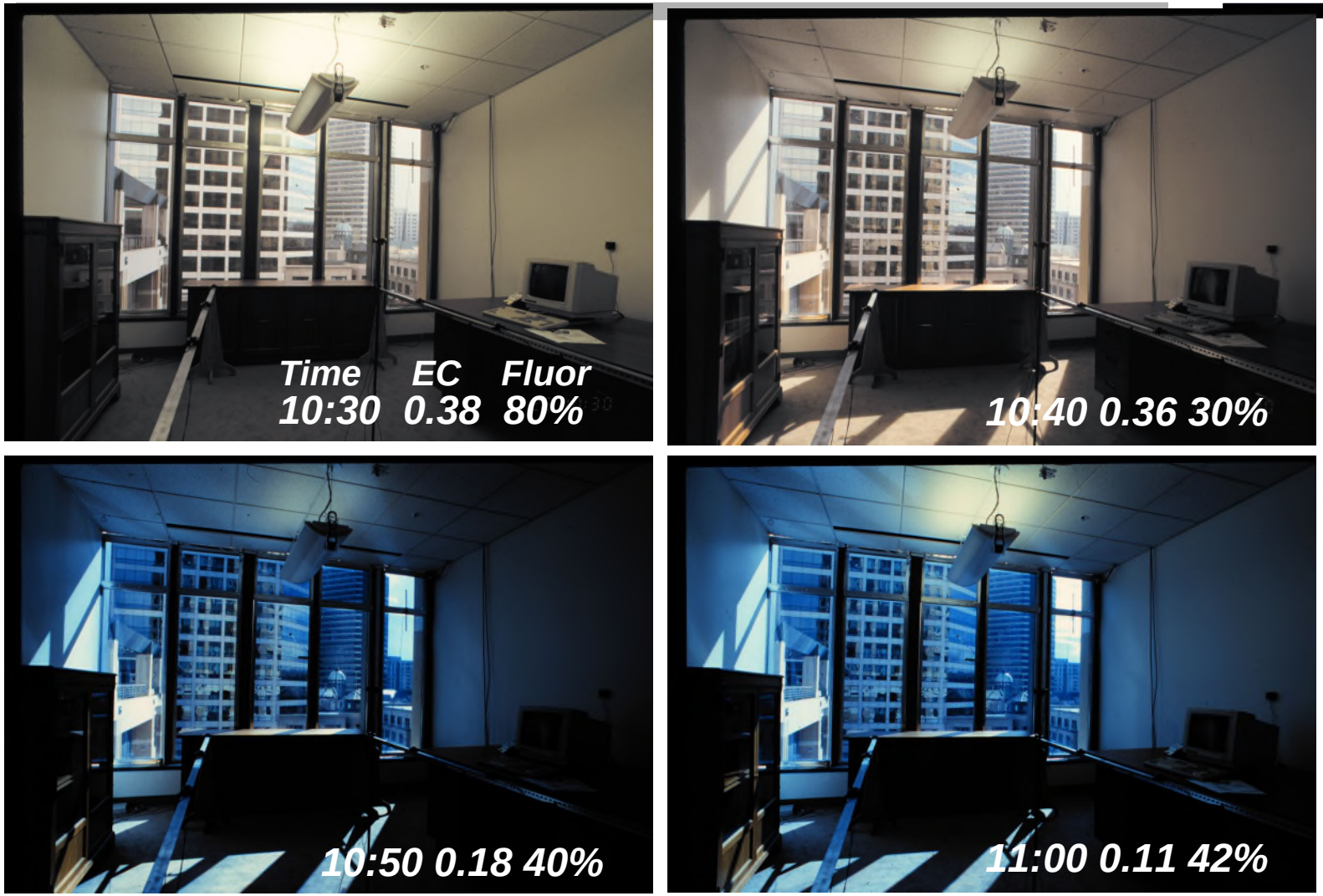


Cloudy

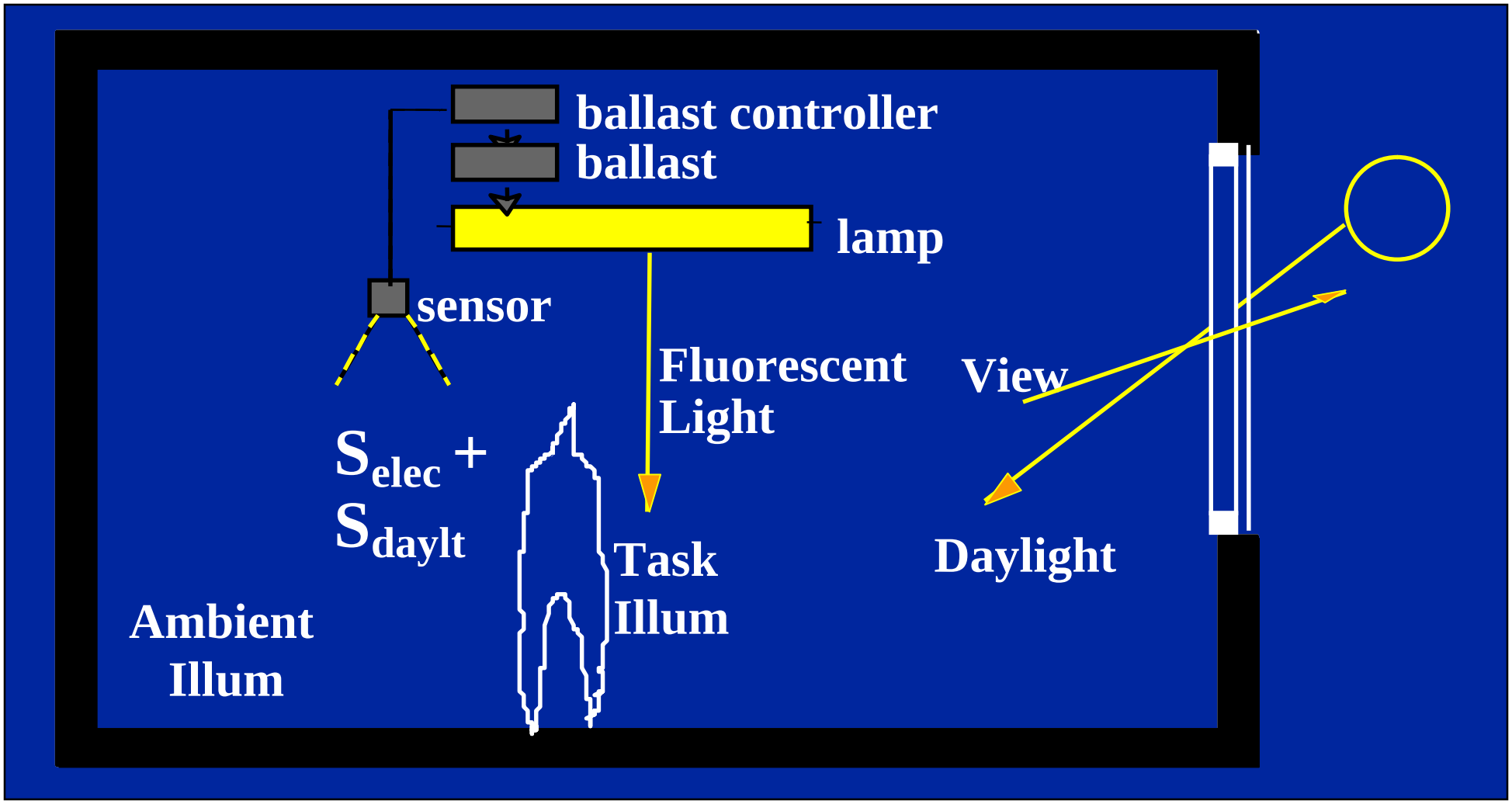
Sunny, high sun

Sunny, low sun

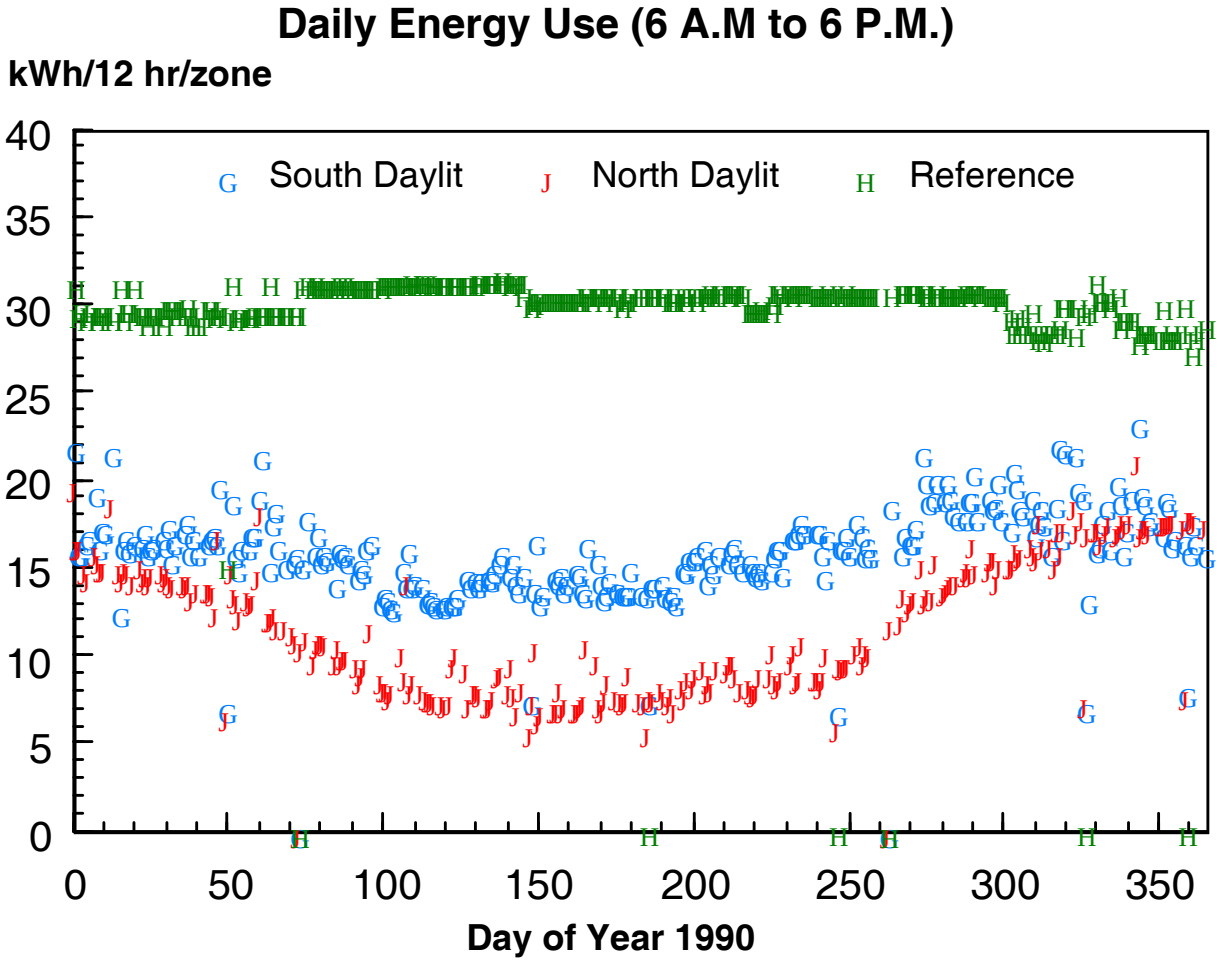
Field Tests: Smart Window Switching on a Partly Cloudy Day



(Day)Lighting Control Elements



Good Lighting Controls Work
(but too much light can be a problem)



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

Lessons:
Its not just the lighting controls…
Need smart shades

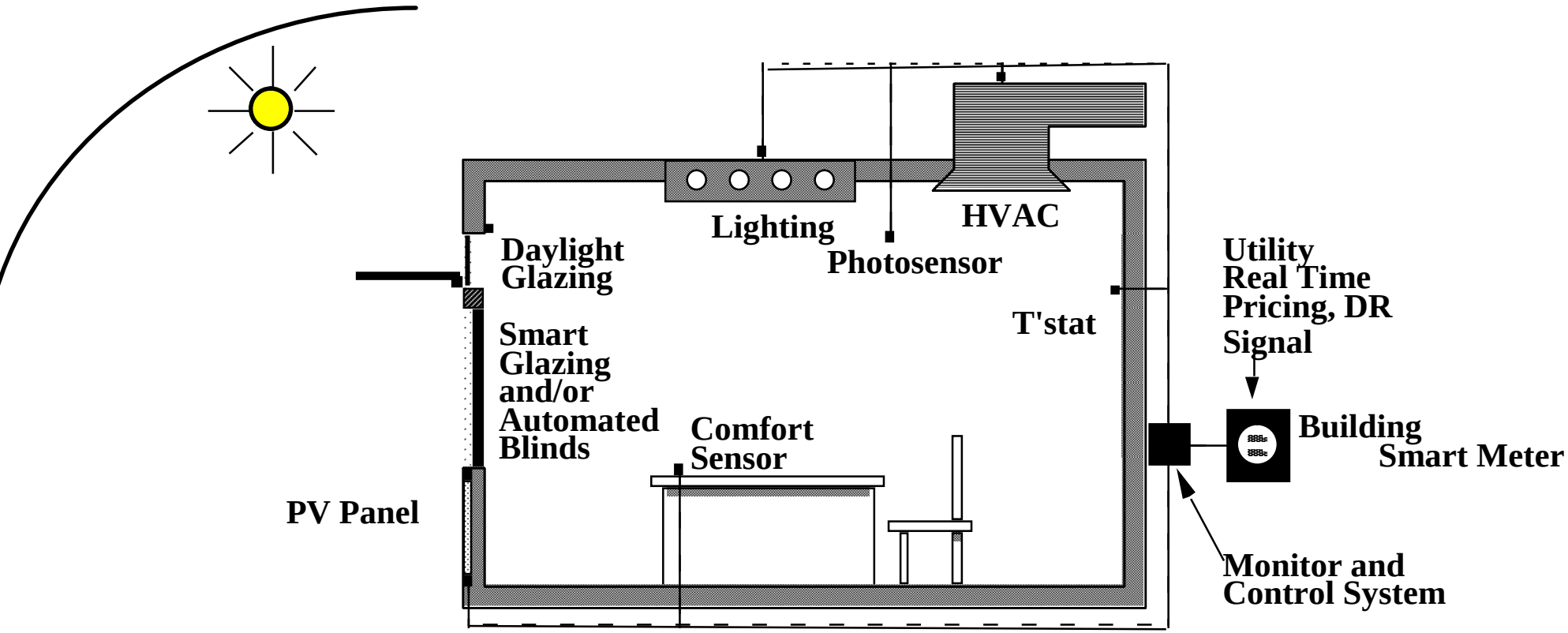
New Daylighting Technologies and Systems

- **Potential: 100% increase in potential perimeter savings**
- Improve visual comfort in perimeter zone -> greater acceptance
- Improve uniformity of daylight in perimeter zone
- Extend the impact of daylight from 5m deep to 10-15m

Existing solutions need improvement:

e.g. Using 19th century reflective and refractive optics

"Module" for a Net Zero Energy Building:
Performance Issues for Intelligent Facades/Lighting/HVAC



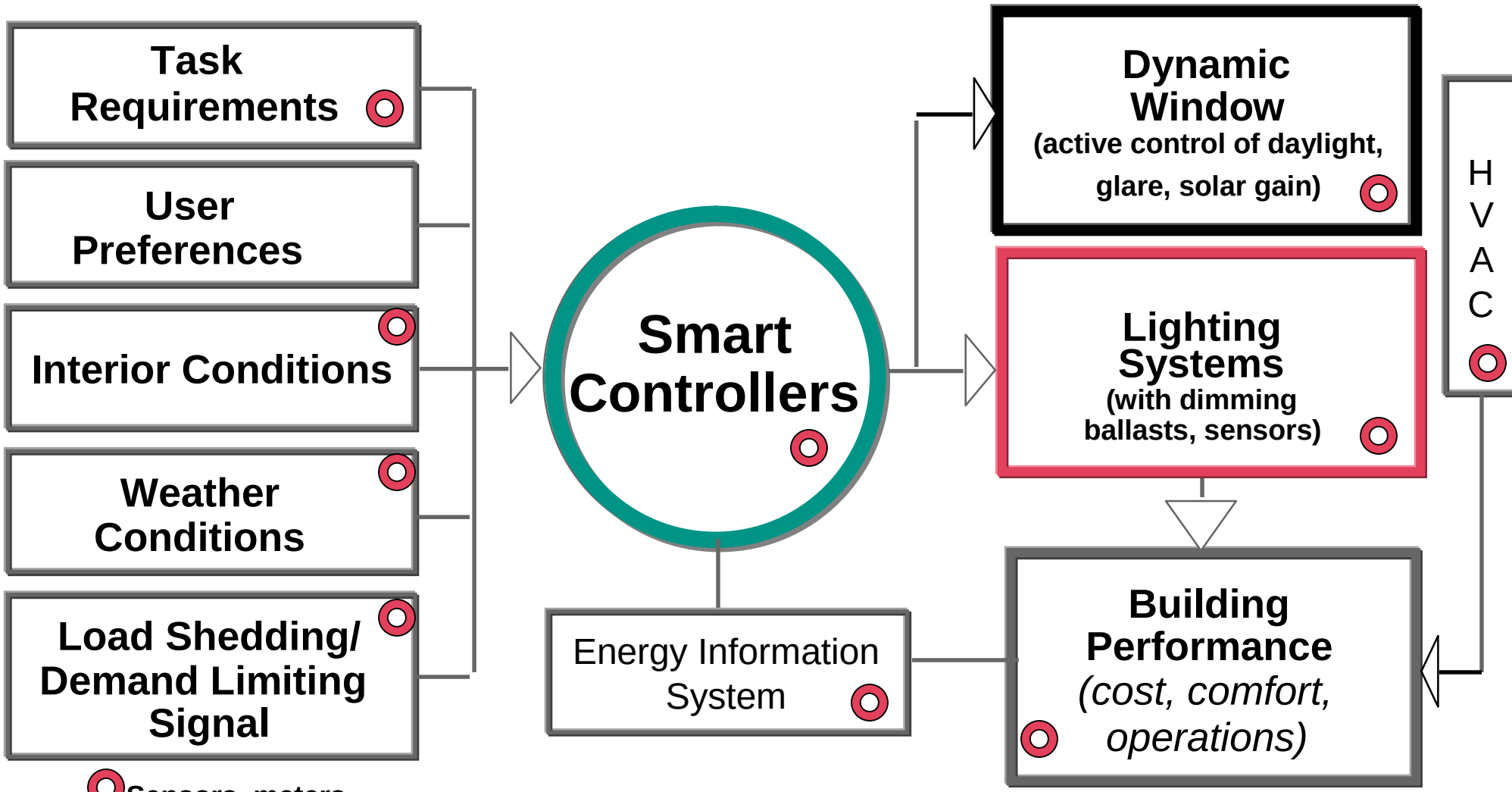
Metrics for "Energy Performance"

1. Energy
2. Electric Demand
3. Carbon impact
4. Cost - $$

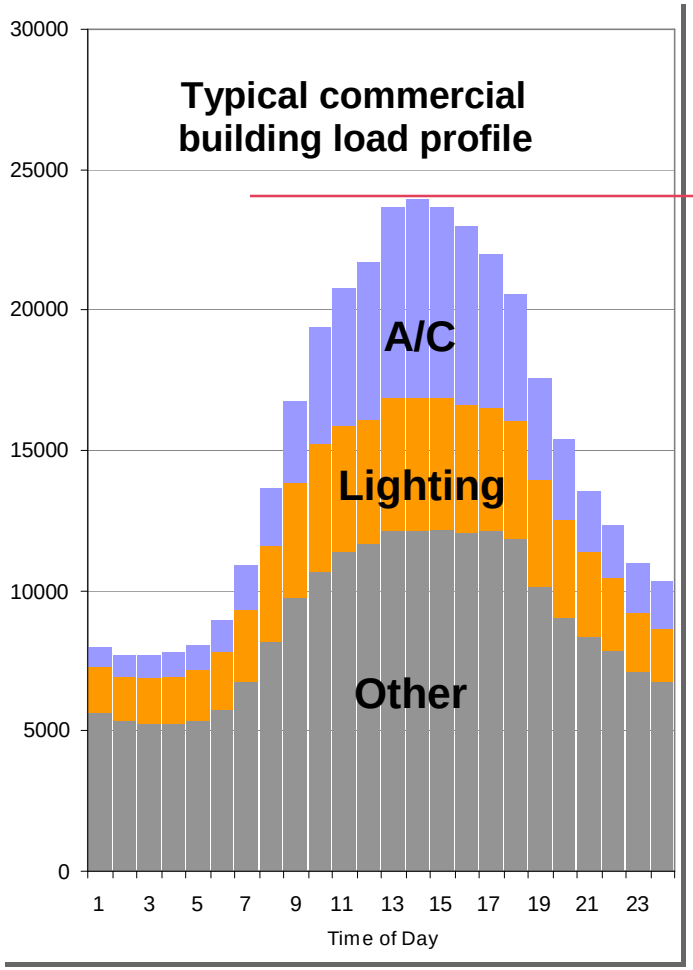
3 Pathways for Use of Glass in Commercial Buildings

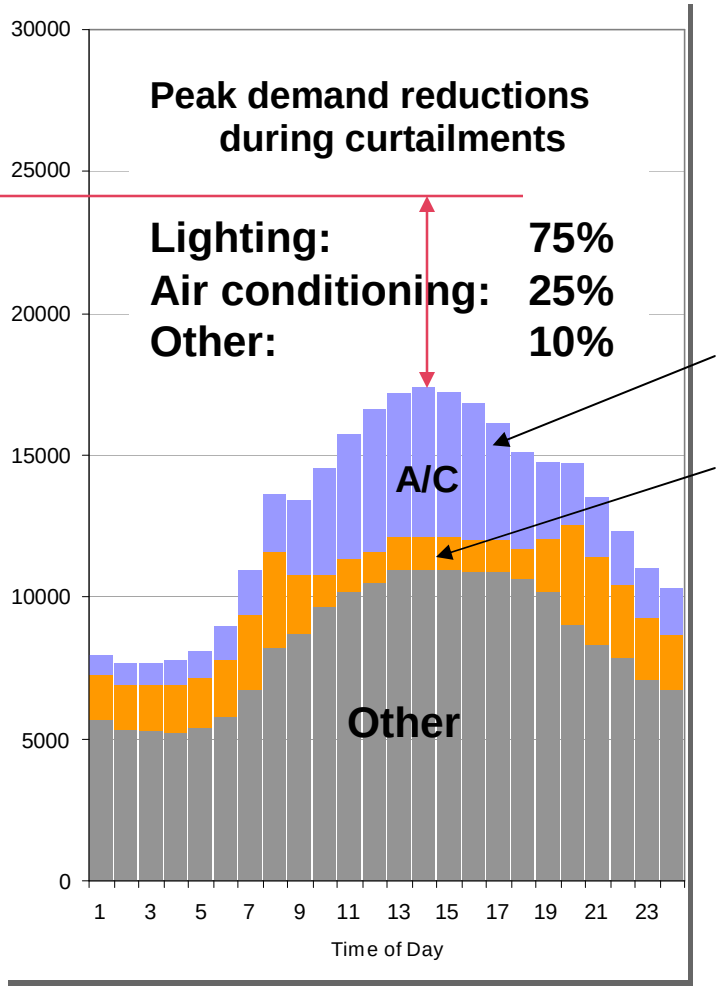
- **Just meet the code**
  - Small Windows, prescriptive properties, e.g. double
  - No special shading or daylighting
- **Conventional "good" solutions: (prescriptive packages)**
  - Modest sized windows, skylights
  - Double glazing
  - Spectrally selective glass
  - Manually operated Interior shading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

Exploring Intelligent Control Systems



Energy/Demand Management with Active Façades+ Daylighting Controls





Reduced Solar Gain

Dimmed Lighting

Exterior, automated shading systems

LBNL Façade Test Facility

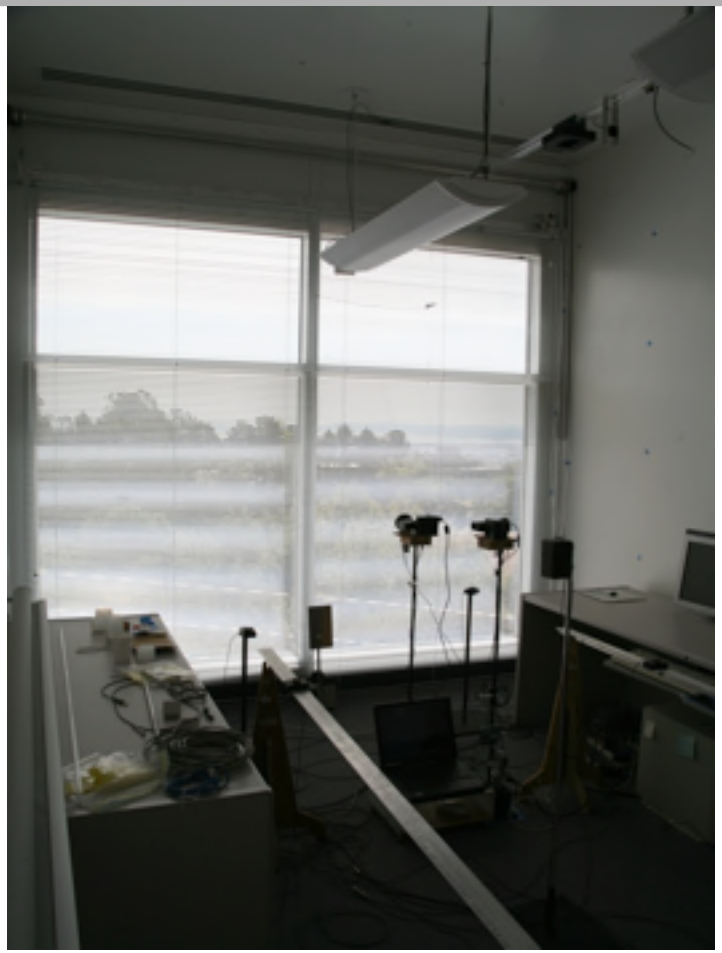
Exterior venetian blinds

- Automated exterior blind
- Static 3-zone blind with bent slats

Façade Testing with Split Blind

(fixed relationship between upper & lower slats

Upper: -45 ° / Lower: 0°



Upper: horiz/ Lower: +30°

Upper: +60° / Lower: +closed

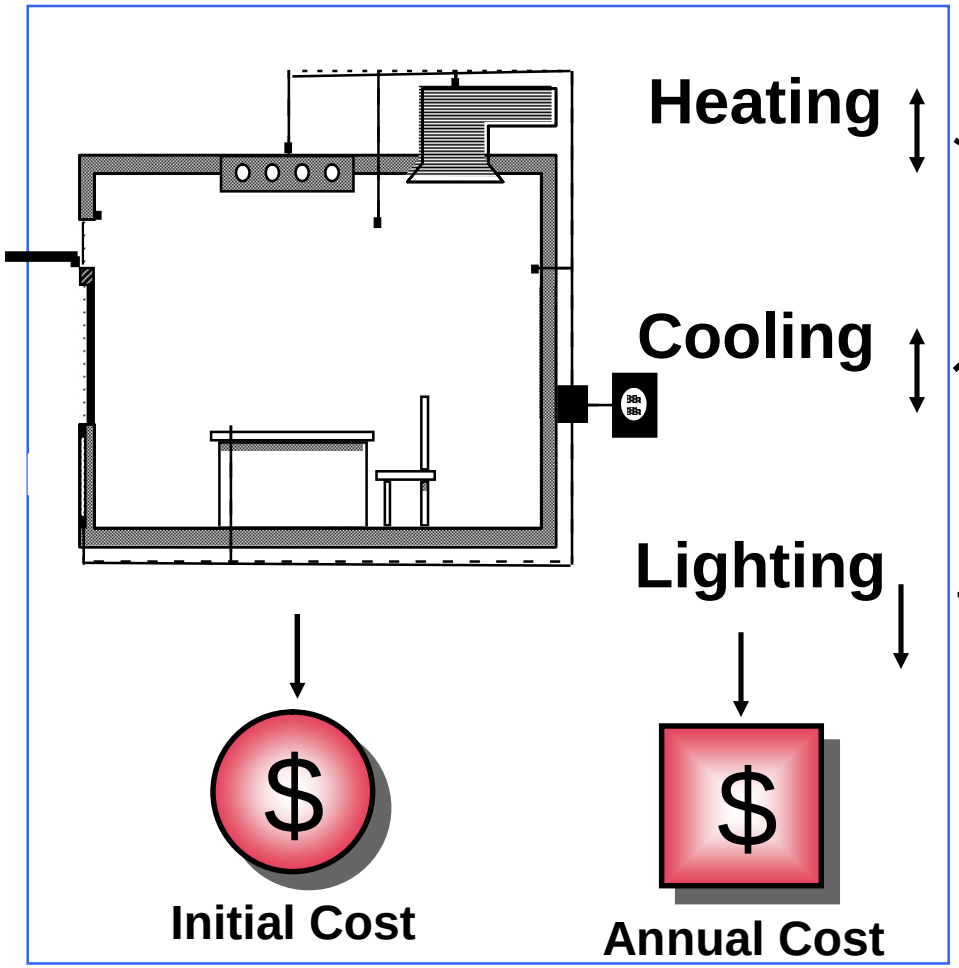
Time Lapse Movie: Interior Room Luminance over the Day with Dynamic Shading Control

QuickTime™ and a
Video decompressor
are needed to see this picture.

High Dynamic Range (HDR) time lapse imagery in LBNL Façade Test Facility

System integration: Cost tradeoffs

Expanding the "System" boundaries



Office Eq.

Peak Cooling Load

Chiller Size

Lighting Design Strategy

Energy, Peak Electric Demand, Load Shape

Onsite Power Generation

Central Power Generation

Annual Energy Costs in Perspective

Cost / Sq. Ft. Floor -Year

- **Energy Cost: $2.00**
- **Maintenance: $3.00**
- **Taxes: $3.00**
- **Rent: $30.00**
- **"Productivity" $300.00**

Concept ---> Reality
The New York Times HQ Building

wners program:

Highly glazed façade gives workers views and allows the city to see “news” at work

But glare, cooling, visibility etc

eed/Goal:

Develop integrated , automated shading and dimmable lighting system

- Affordable, reliable and robust

hallenge:

How to develop a workable integrated hardware/software solution

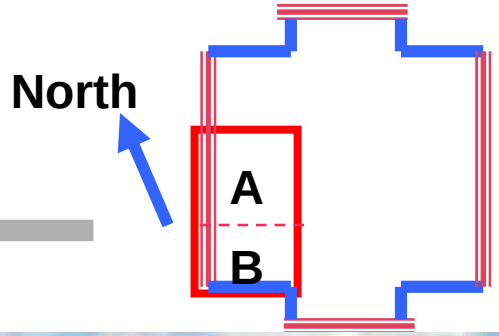
How to “guarantee” that such a solution will work in practice

Scale- Transform the market- push/pull these solutions toward widespread use

upport

NYSERDA, DOE, CEC, NY Times

Approach: Test Performance of Systems Options in a Full-Scale Mockup of part of a floor



Evaluate Shading, daylighting, employee feedback and constructability in a ~4500 sf testbed

Fully instrumented; 1 year testing

Concerns with glass facade:
- Window glare (Tv=0.75)
- Control of solar gain/cooling
- Daylight harvesting potential

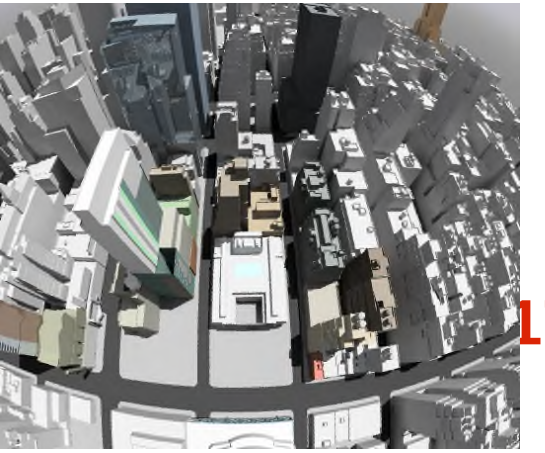
Lighting Systems
- Daylight dimming
- Addressable systems
- Task tuning
- Load Shed/DR

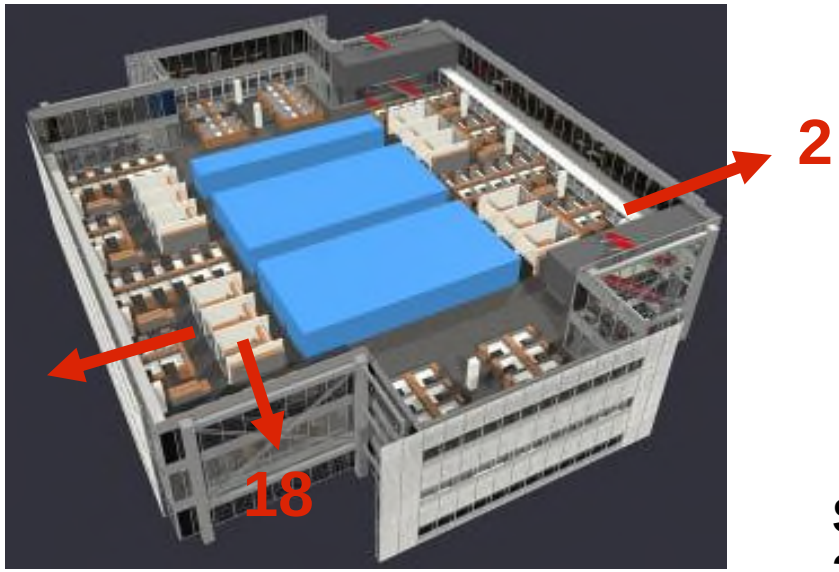
Real sun and sky conditions, 12-month monitored period

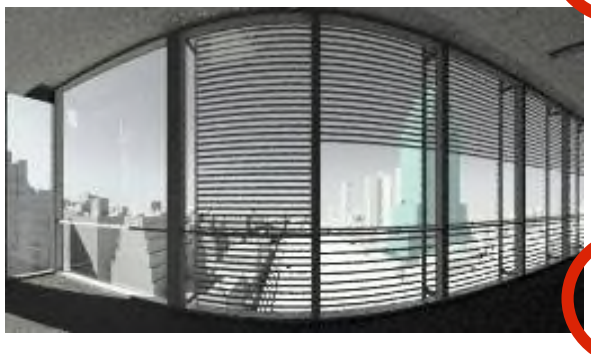
Extrapolating Results from 5000 sf Testbed to 1,500,000 sf Building

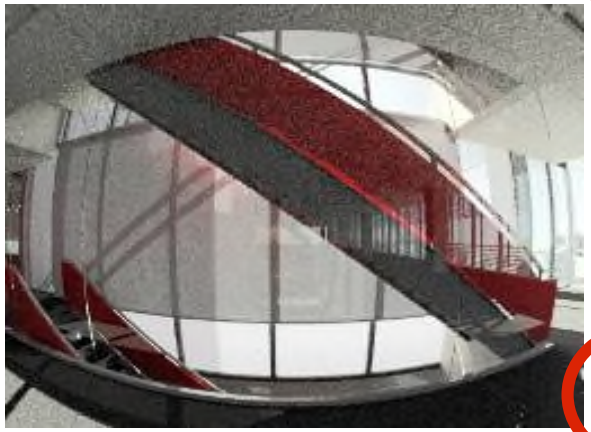
dvanced Simulation to Explore Shade Control trategies for Motorized Shades

- Each shade system has its own sensor and motors
- Performance will vary with floor elevation, view out, and neighboring buildings.
- How to address this variance?
- Build a virtual model of the building in its urban context using hourly weather data simulate performance

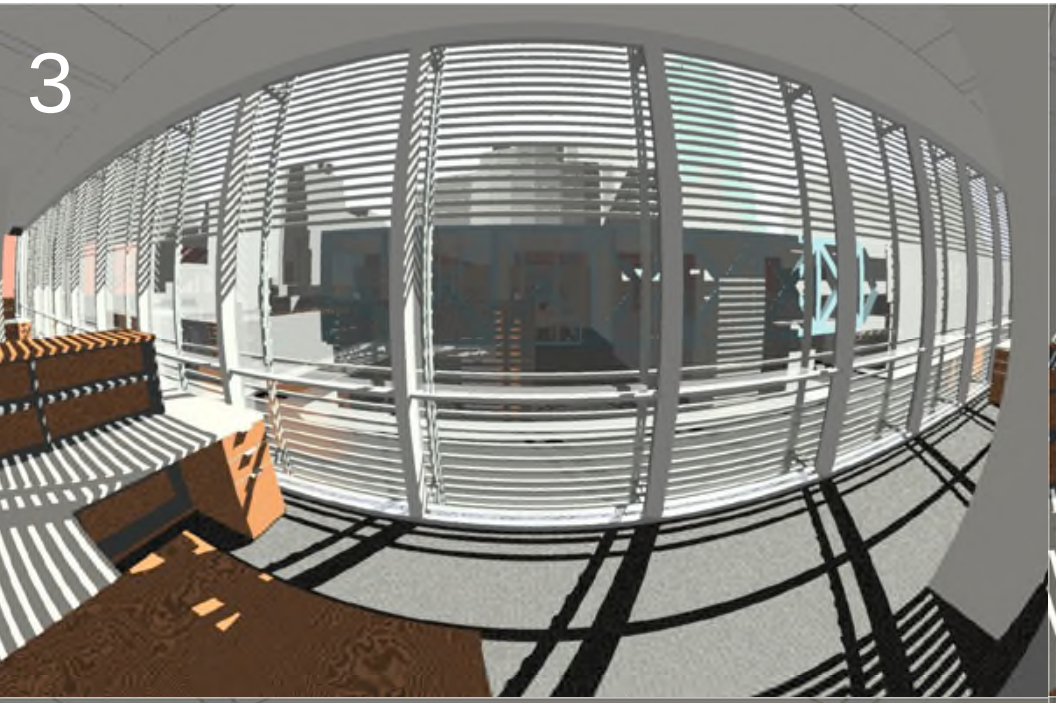








Simulated Views from 3 of 22 view positions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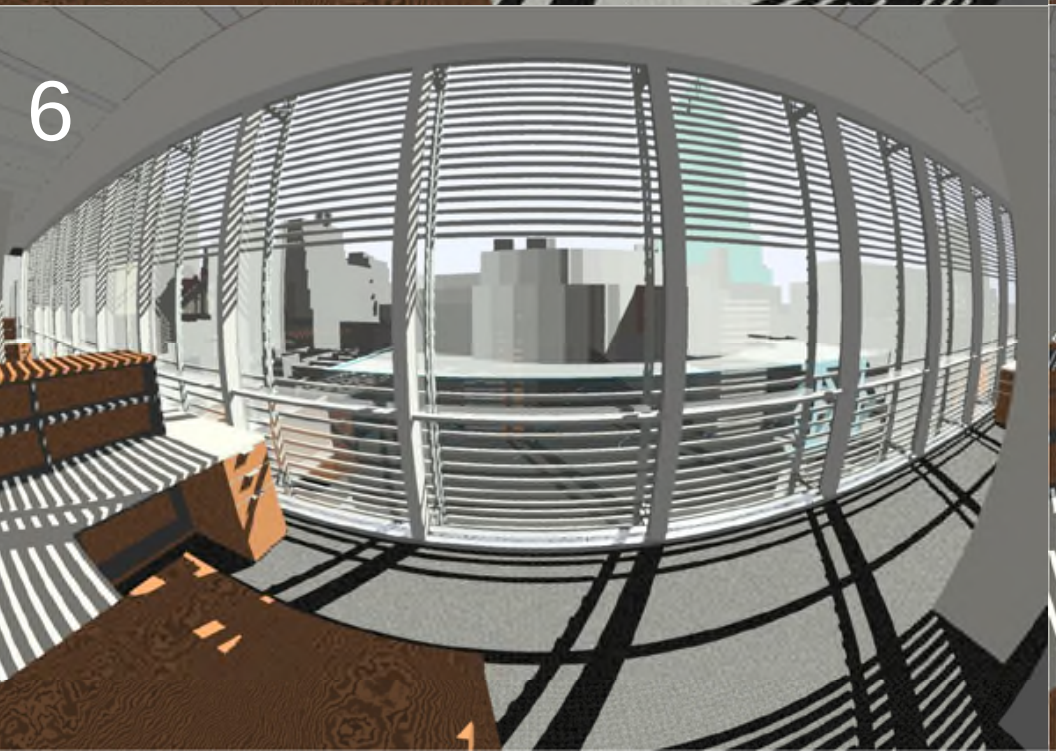
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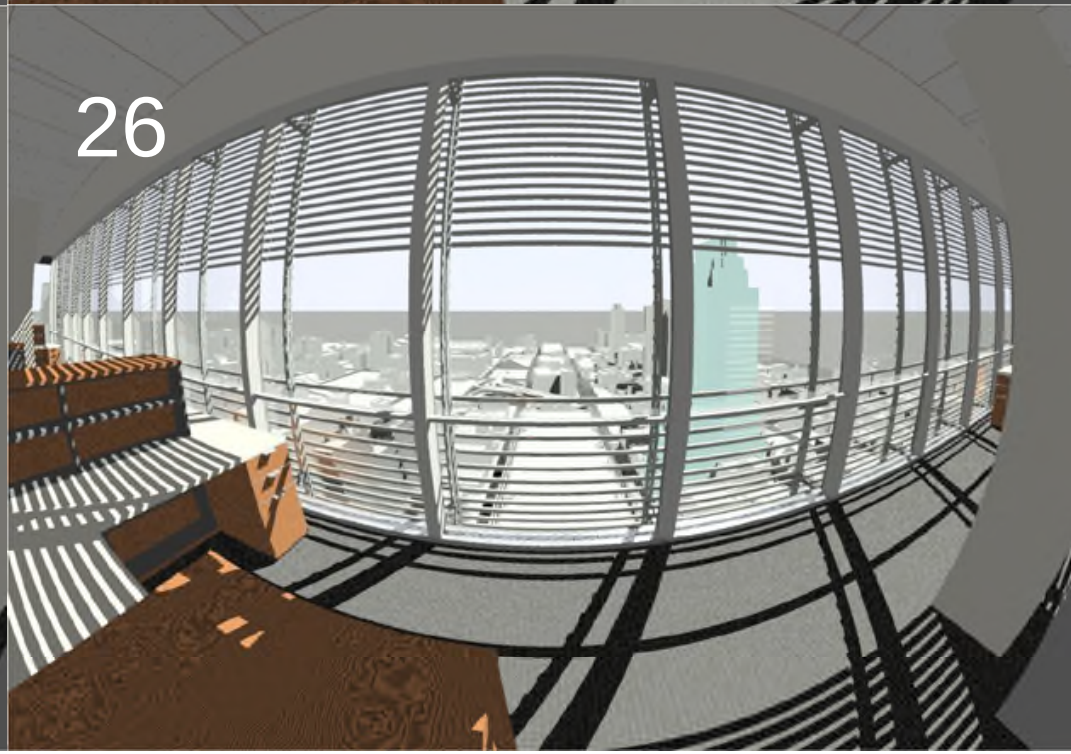
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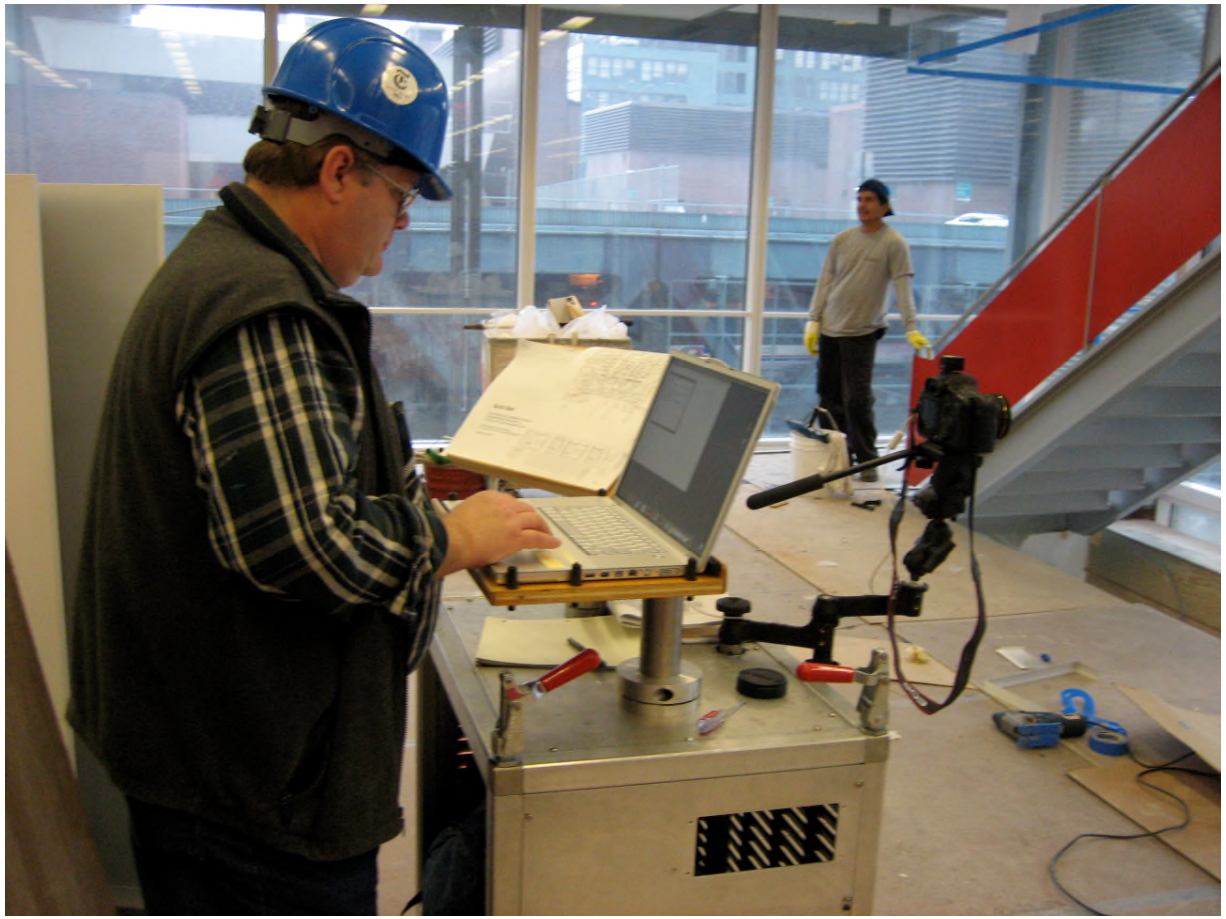
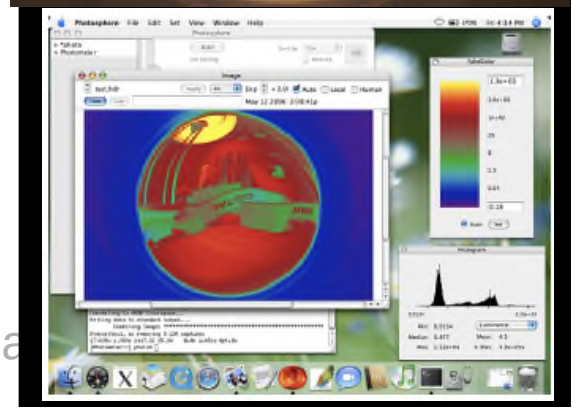
The New York Times building:

Automated, Motorized Shade Commissioning Tool being Used to Check Shade Operation



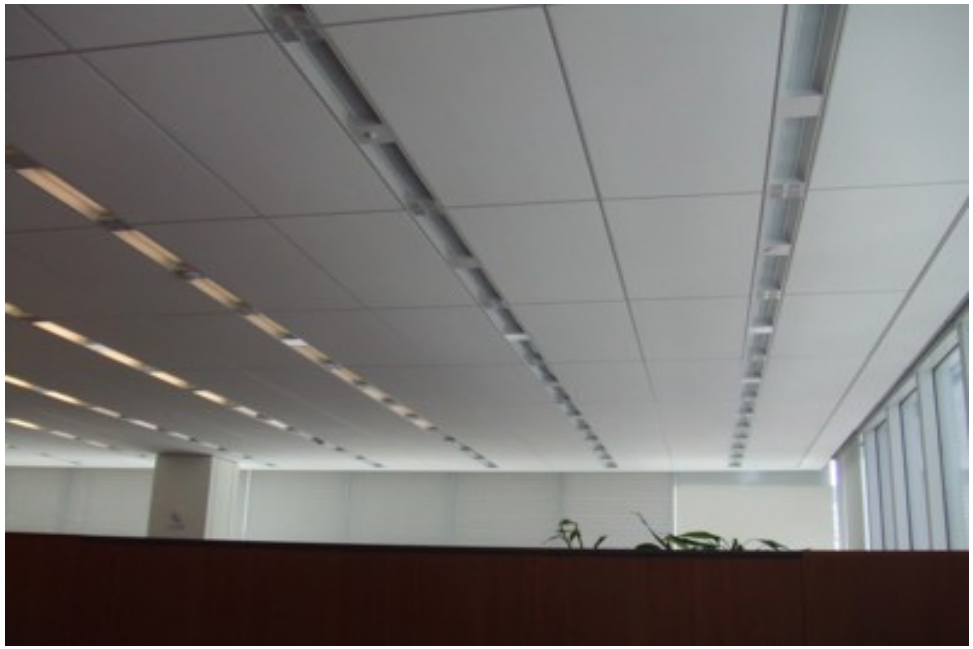


Mobile cart with CCD camera and real time software determines whether sensor calibration is correct

Intelligent Lighting and Shade Control

Occupied 2007

- Dimmable lighting
  - Addressable
  - Affordable (1/3 original cost estimate)
  - Multifunctional
- 1.25W/sf installed vs .38W/sf measured
- Automated Shading
  - Cooling load control
  - Glare control

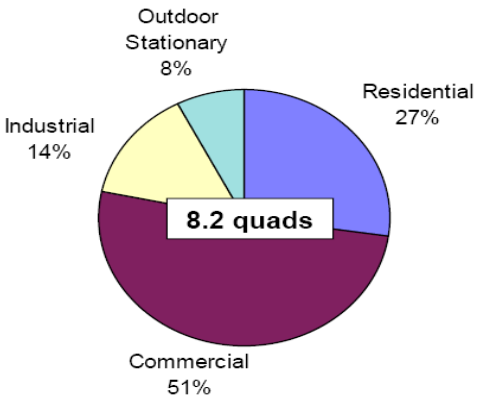


New York Times office with dimmable lights and automated shading

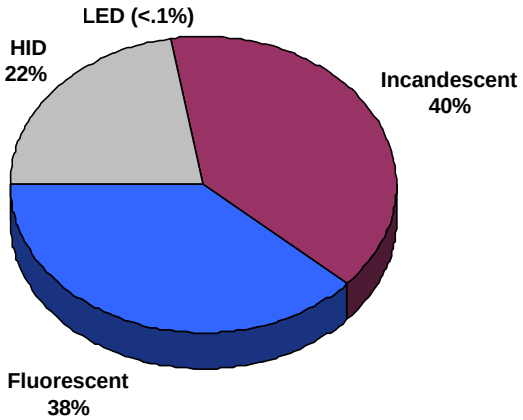
Significant Market Outcomes

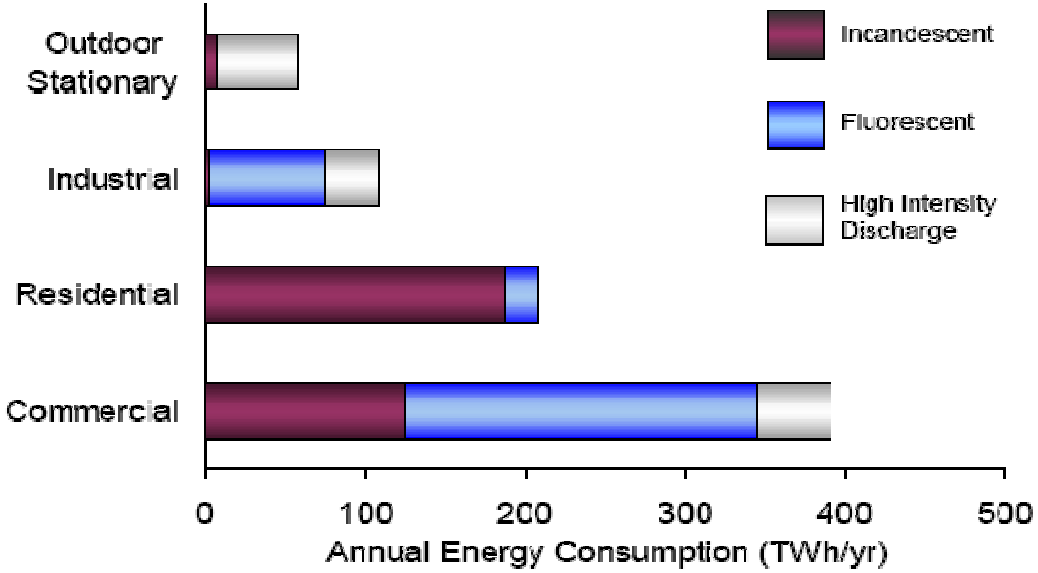
- **Single, largest procurement** of automated shades and daylighting controls in the U.S.
- Tremendous industry response: significant change in product offerings, features and capabilities at lower cost
  - **Dimmable lighting controls**:
    - From: fixed topology 0-10 V systems
    - To: digitally-addressable, open protocol systems with individual fixture control capability → enables zone reconfiguration, photosensor tuning, demand response, setpoint tuning all via software
  - **Shading controls:**
    - From simple direct sun control
    - To direct sun, solar heat gain, glare, view, and daylight control optimization
- **Competitive pricing** for both material and installation costs
- **Procurement specifications, tools,** and performance evaluation publicly available

National Lighting Energy Consumption



390 Billion kWh used for lighting in all commercial buildings in 2001





Lighting Energy Consumption by Major Sector and Light Source Type

Breakdown of Lighting Energy

Source: Navigant Consulting, Inc., U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and, Energy Consumption Estimate, Final Report for US DOE, 2002

Reducing Lighting Energy Use by a Factor of 5: "New" Approaches to Efficient Lighting

1. **Use more efficient lamps and fixtures**, best suited to specific tasks

2. But, **Lighting design, operation and energy use** (**should also**)
   - **Vary with task**
     - Task lighting needs- e.g. talking on phone vs brain surgery
     - Task vs Ambient lighting needs
   - **Vary with location in building**
   - **Vary with user**
     - Age, use of glasses, medical conditions,….
   - **Vary with time**
     - e.g. available daylight, load management need,….
     - Contrast: night vs day
   - **Address perception in the space** as well as more easily measurable engineering units, e.g. lux or footcandles

----> "Adjust quantity/quality of light to varying needs"

"Communicate with every light fixture"

"Control its light output"

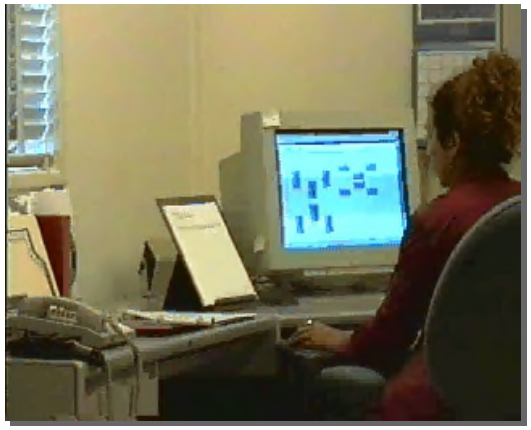
Lighting wastes energy because dimming lighting controls are not widely used

All Lighting Should be:

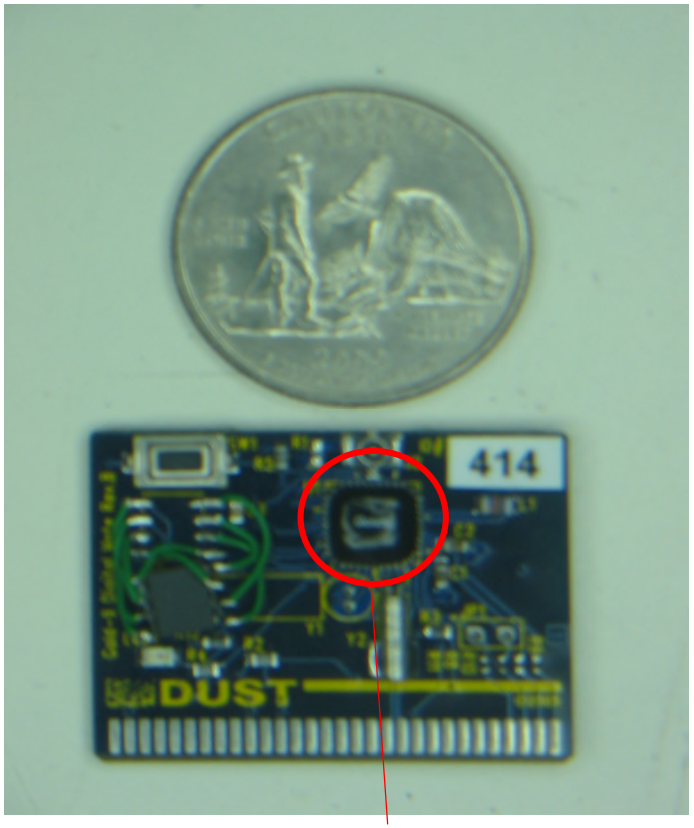
- **Dimmable**
- **Addressable**
- **(Affordable)**

Major Lighting Control Strategies

- Vacancy Detection or Scheduling
- Automatic Dimming with Daylight
- Tuning Strategies
  - Personal dimming controls
  - Institutional requirements
- Lumen Maintenance
- Demand Response

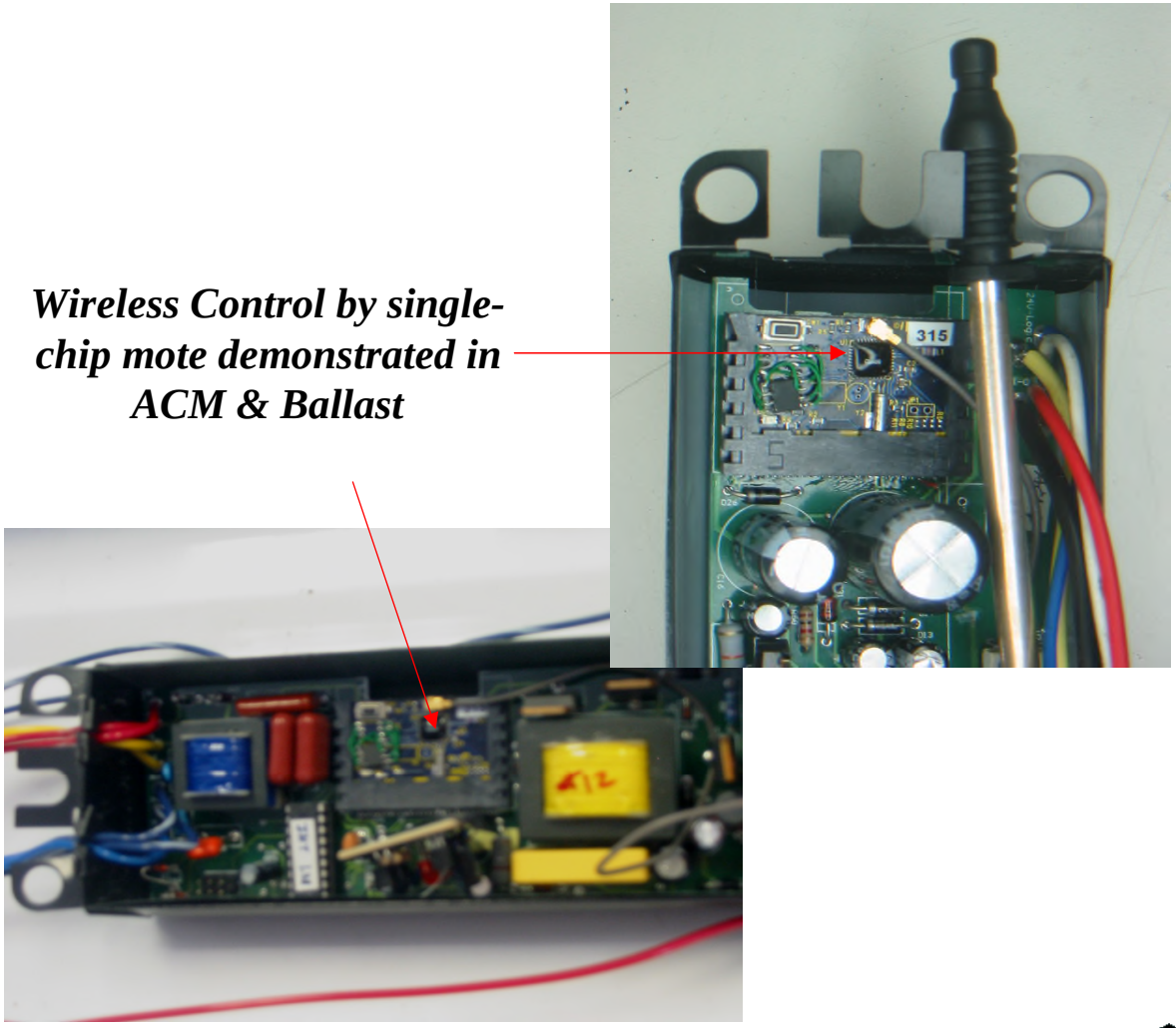


Making Lighting Intelligent: Wireless Control Chips

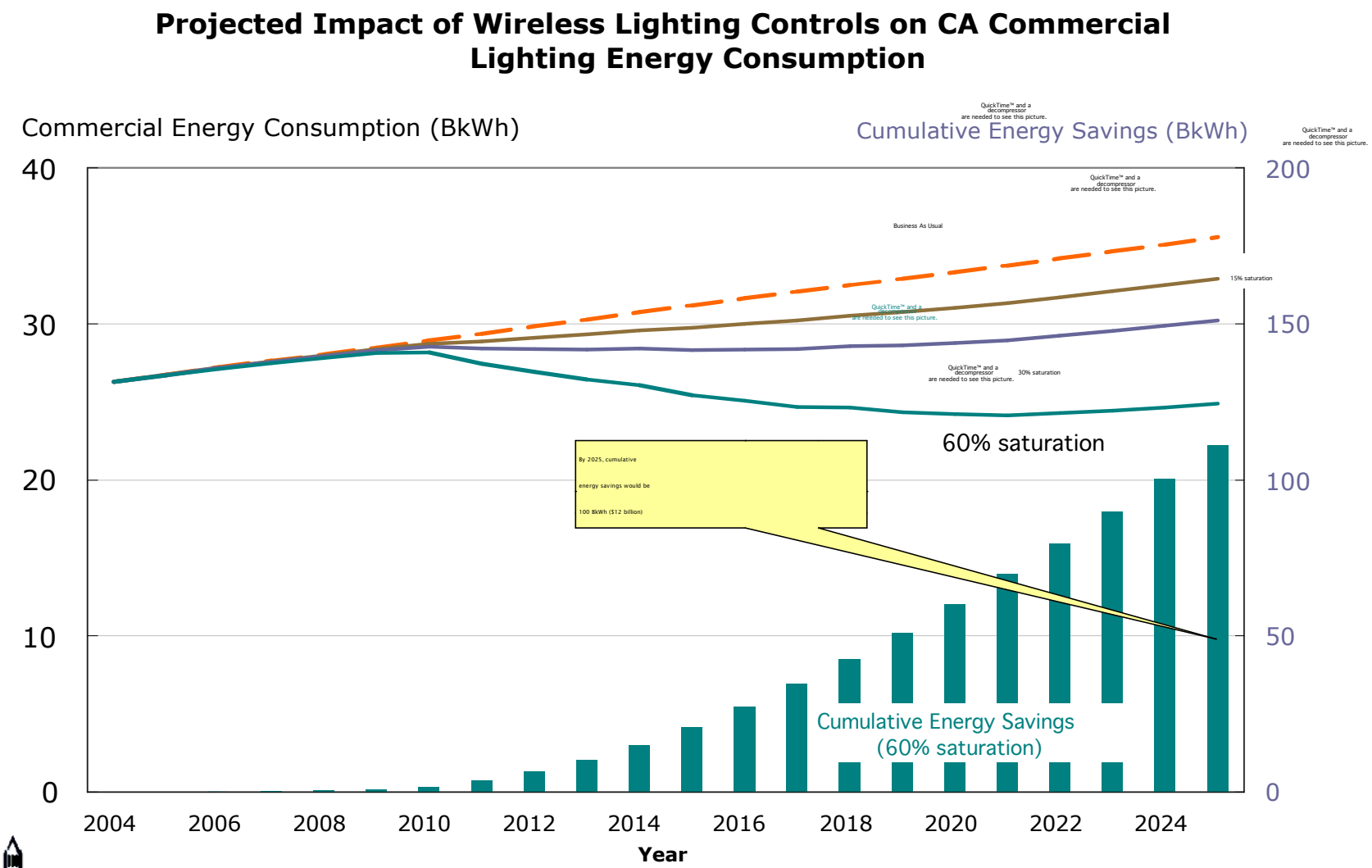


Single Chip mounted to a board for integration with lighting components

Wireless Control by single-chip mote demonstrated in ACM & Ballast



Potential Impacts of Applying Smart Lighting Controls to CA Buildings



Integrated Smart Grid Considerations

Transmission

- Real time system improvements
- Congestion control
- Intelligent Agent integration and application
- Implementing RPS
- Advanced grid communications and control
- Extreme event planning and response
- CA ISO market redesign (MRTU)
- Automatic network reconfigurations
- Rapidly deployable systems
- Self healing grid

Distribution

- Distribution automation
- Advanced grid communications and control
- Congestion control
- Self healing grid
- Implementing Microgrids
- Integration of DER
- Reliability, availably, PQ improvements
- Reduce peak demand
- Low carbon network benefits

DER Integration

- Integrating renewables
- Integration of DER
- Implementing Microgrids
- Advanced grid connected power electronics
- Advanced communications and control

Demand Response

- AMI systems and implementation
- CAISO MRTU Implementation of DR
- Advanced communications and control
- Integration of DR automated technologies
- Development of enabling DR technologies

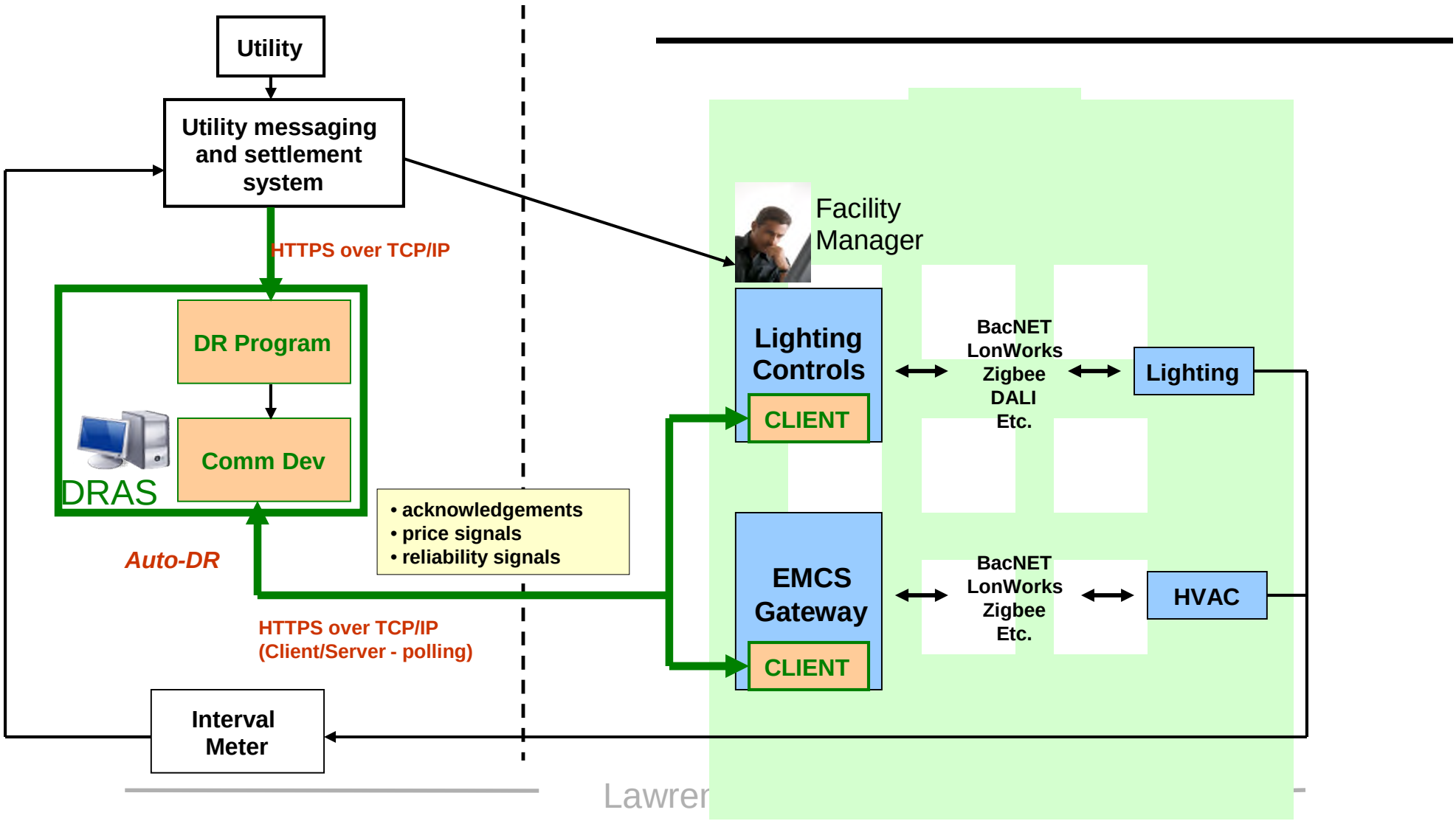
Energy Storage

- Renewable firming and dispatchability
- Reduce peak demand
- Low carbon network benefits
- Advanced grid connected power electronics
- Advanced communications and control

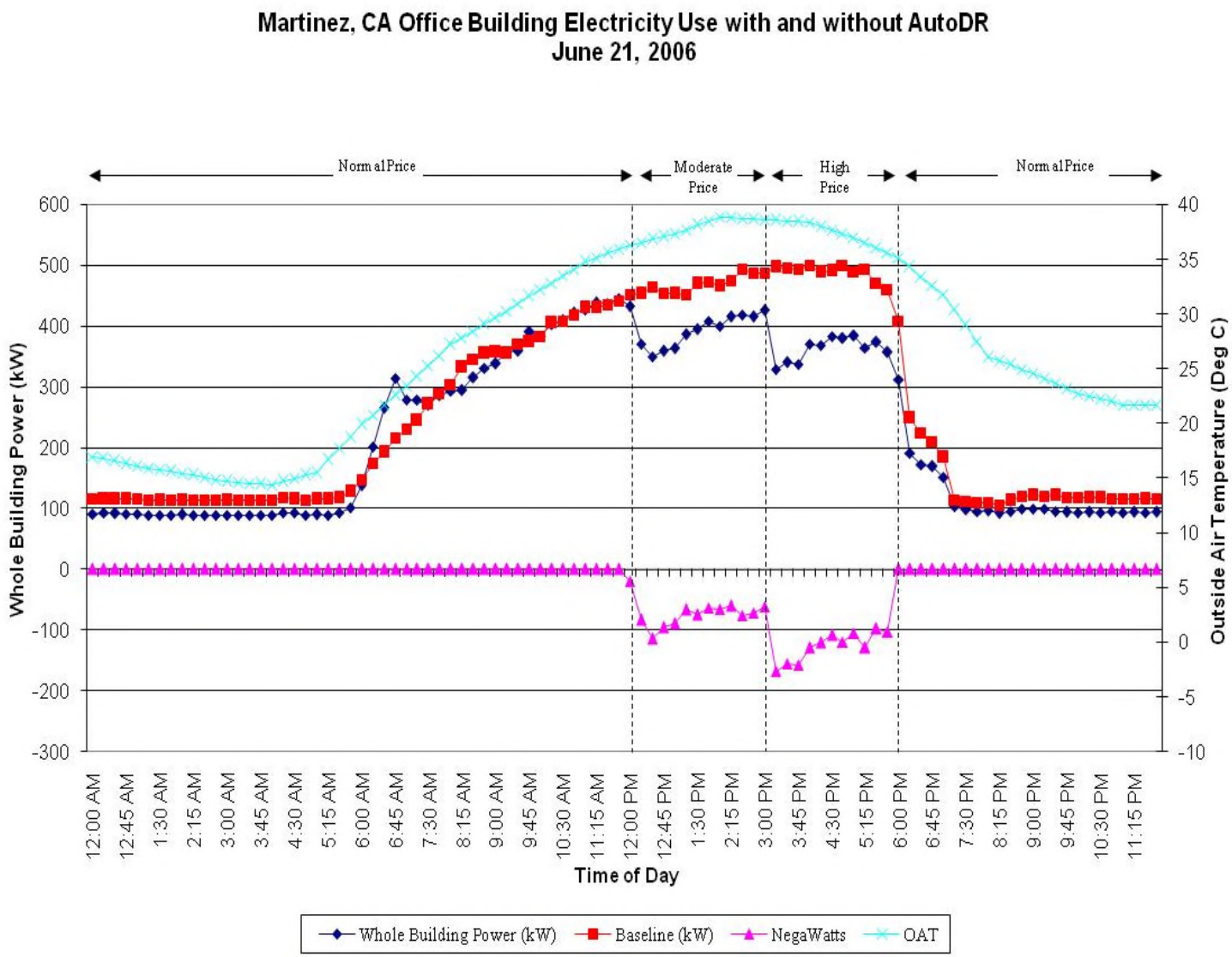
Security

- Wireless Network Field Demo
- Network survivability
- Self healing systems
- Rapidly deployable systems
- Automatic network reconfigurations

Automated Demand Response (DR)
Server and Software Client



Fully Automated Electricity Demand Response
in 130,000 ft² County Office - Current Practice

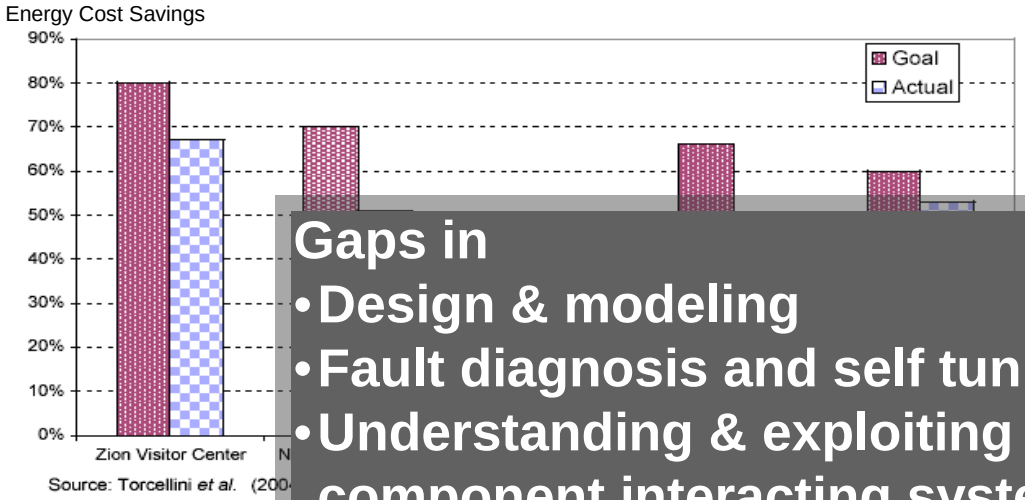


http://drrc.lbl.gov/

Faults in *Operation* of Buildings

Gaps between predicted & actual performance

Models over-predict savings by ~20-30%



Source: Torcellini *et al.* (200

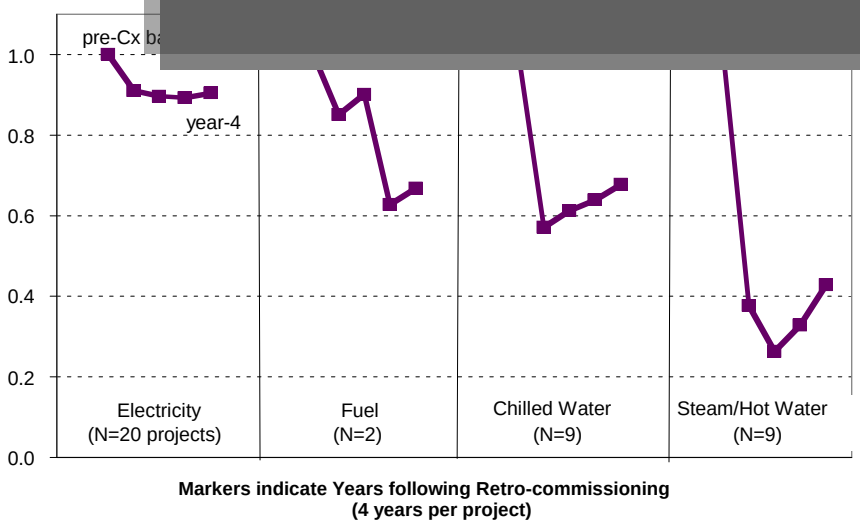
Operational faults waste ~20% energy

- HVAC – air distribution
- Operations and control

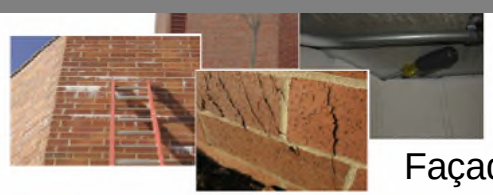
Cycling Controls

Gaps in

- **Design & modeling**
- **Fault diagnosis and self tuning**
- **Understanding & exploiting dynamics and control in complex multi-component interacting systems**



Source: "The Cost Effectiveness of Commercial Buildings Commissioning," LBNL, 2005.

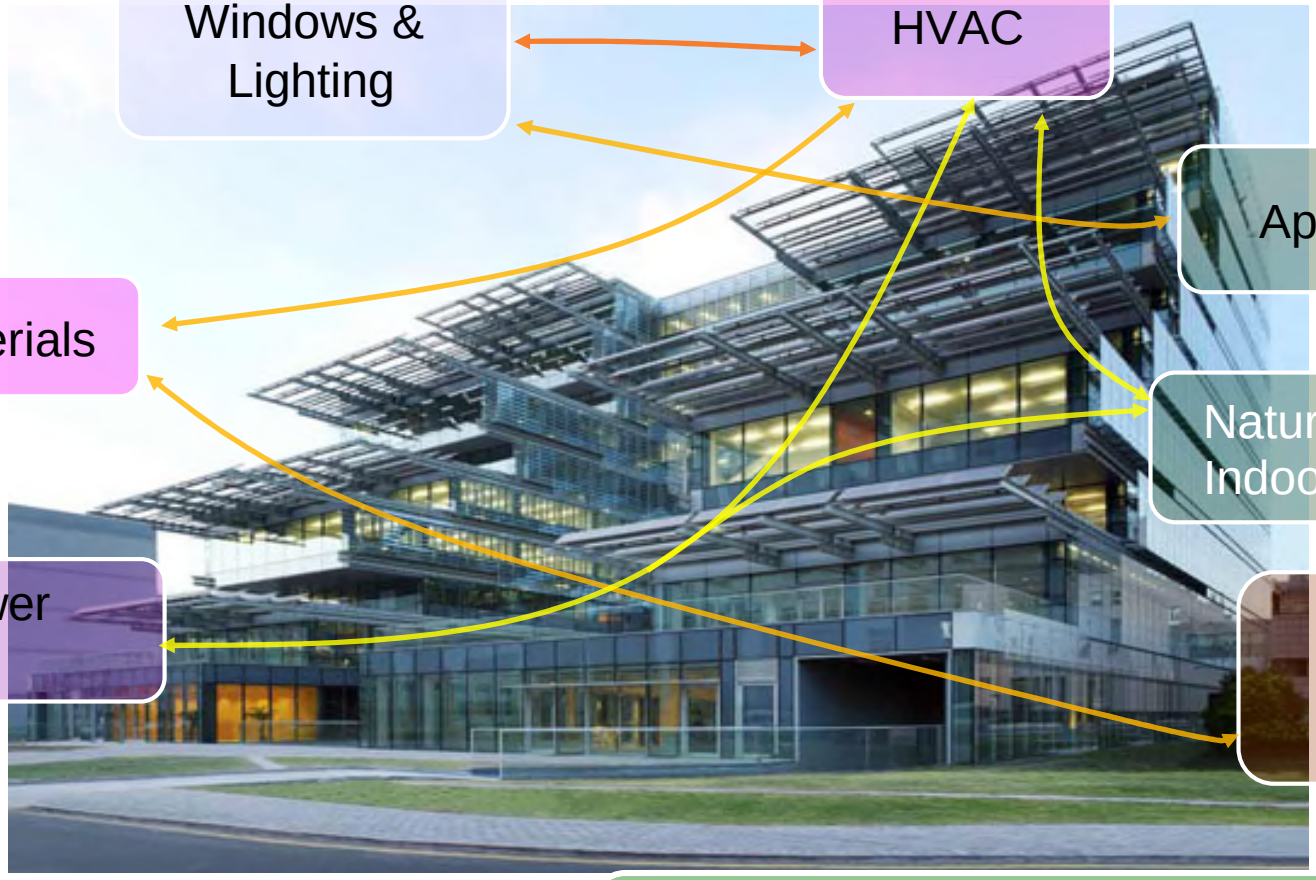


Façade Damage

Many of these faults are invisible.

System of Systems

Integrated Whole Building Approach



Building Design Platform:
Tool for Architects to Design New Buildings
With Embedded Energy Analysis

Building Operating Platform
Sensors, Communication, Controls,
Real-Time Optimization for Cost, Energy Use, CO_2 Footprint

Integrated Approach

BUILDING

Dyanamic Info
- Occupancy
- Temperature
- Humidity
- Air Quality
- Light
- Appliances

Static Info
- Architecture
- Floor Plan
- Orientation
- Structure
- Materials

Monitoring & Diagnostics
Sensors; Communication

Analysis & Modeling

Occupancy/Environment Based Energy/Exergy Modeling & Analysis

Systems Analysis

Based Solutions

Systems Control & Optimization
Feedback/Feedforward control to maintain Occupancy Based Comfort Vector (Temp, Humidity, Lighting, CO2 level,..)
Real-Time Optimization for Energy Consumption/Cost

Design/Performance Based Options for Components
Architecture
Building Materials (Frame/Walls/Insulation/Windows/Glazing)
Heat & Cooling
Ventilation
Lighting
Daylighting/Facades
Onsite Power & Heat
Battery Based Storage
Thermal Storage
Control Systems
Sensors & Communication
Appliances

Visualize Energy

Real Performance

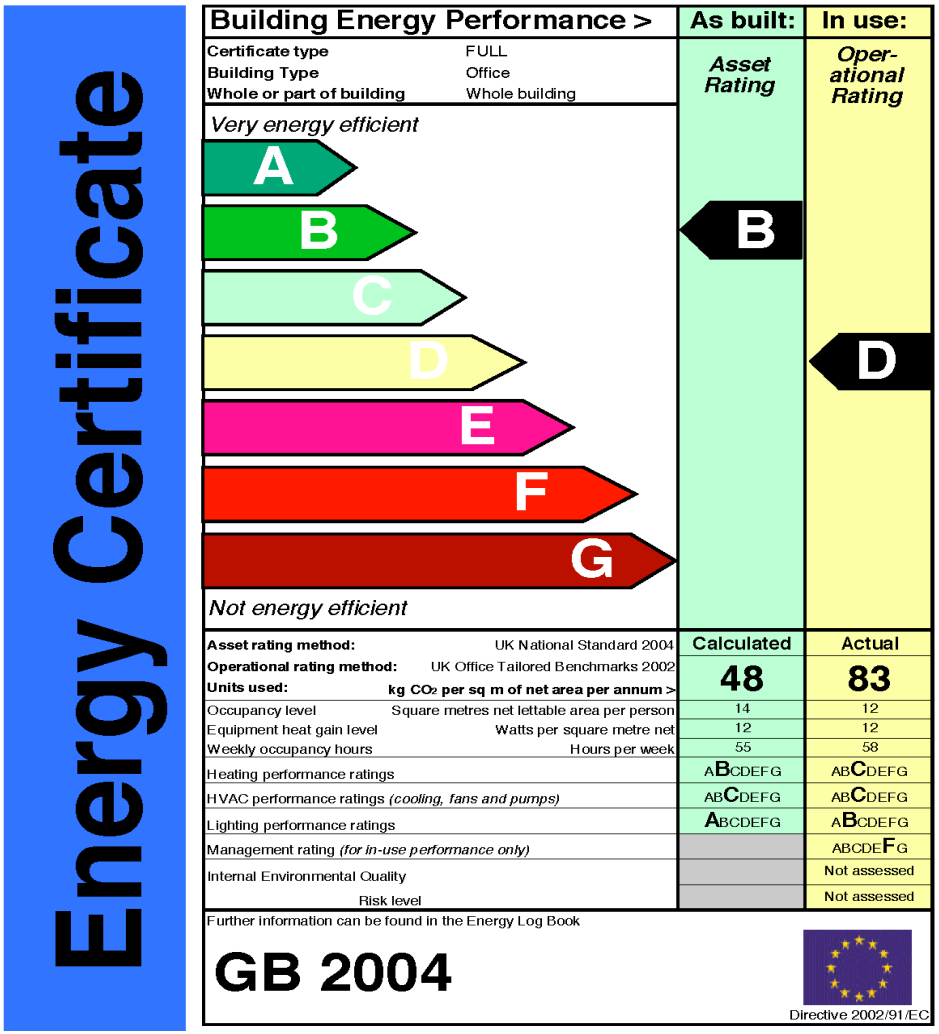
Compare and feedback

Designed Performance

Making Performance Visible

Ex: European building energy certificates

- Display energy certificates based on actual energy use, not just theoretical. *We need to save real, not virtual emissions.*
- Transparency between expectations and outcomes.
- Multiple performance indicators
- California is launching similar initiatives, e.g. AB1103
- **Subtleties:**
  - **Asset Rating**
  - **Operational Rating**



Energy IQ

ACTION-ORIENTED ENERGY BENCHMARKING FOR NON-RESIDENTIAL BUILDINGS

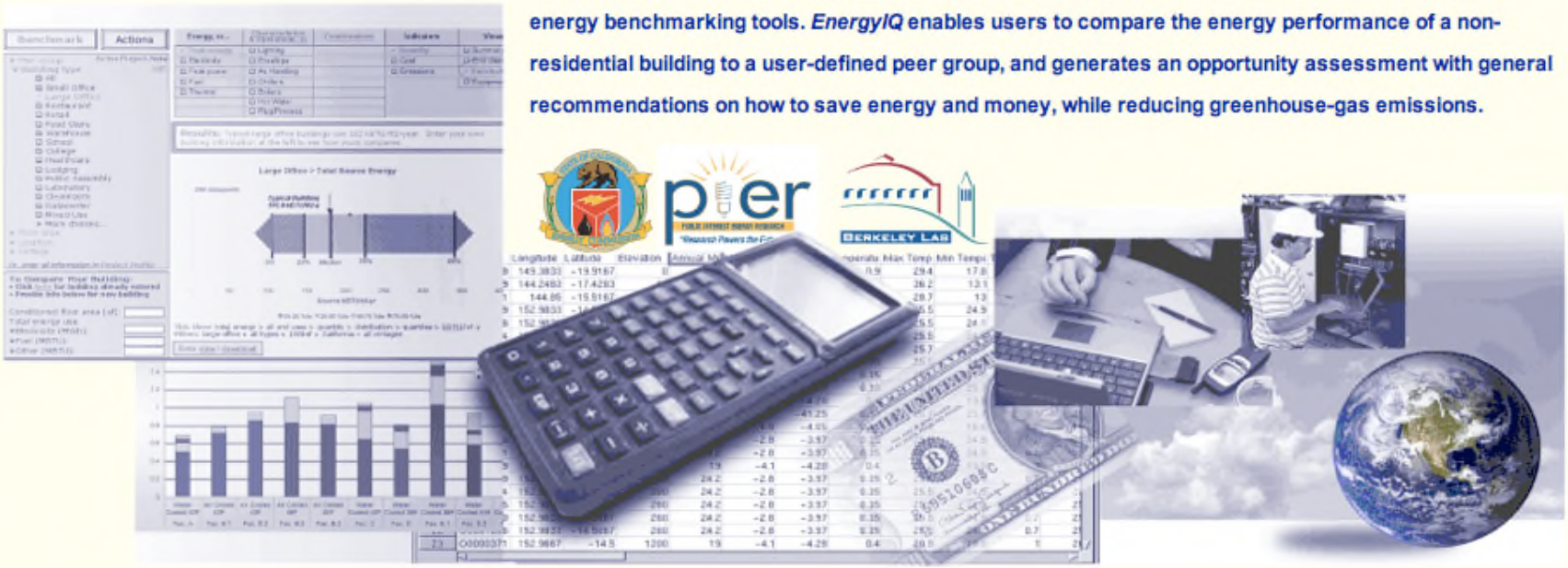
About *EnergyIQ* | How to Use | HELP

Reading Room | Decision Support | Developers | What's New & Next | Glossary | MyIQ

Start your *EnergyIQ* here > GO < Benchmark your building NOW: save energy, save money, and calculate your carbon emissions

EnergyIQ

With sponsorship from the California Energy Commission's Public Interest Energy Research (PIER) program, the Lawrence Berkeley National Laboratory has created a new generation of non-residential energy benchmarking tools. *EnergyIQ* enables users to compare the energy performance of a non-residential building to a user-defined peer group, and generates an opportunity assessment with general recommendations on how to save energy and money, while reducing greenhouse-gas emissions.



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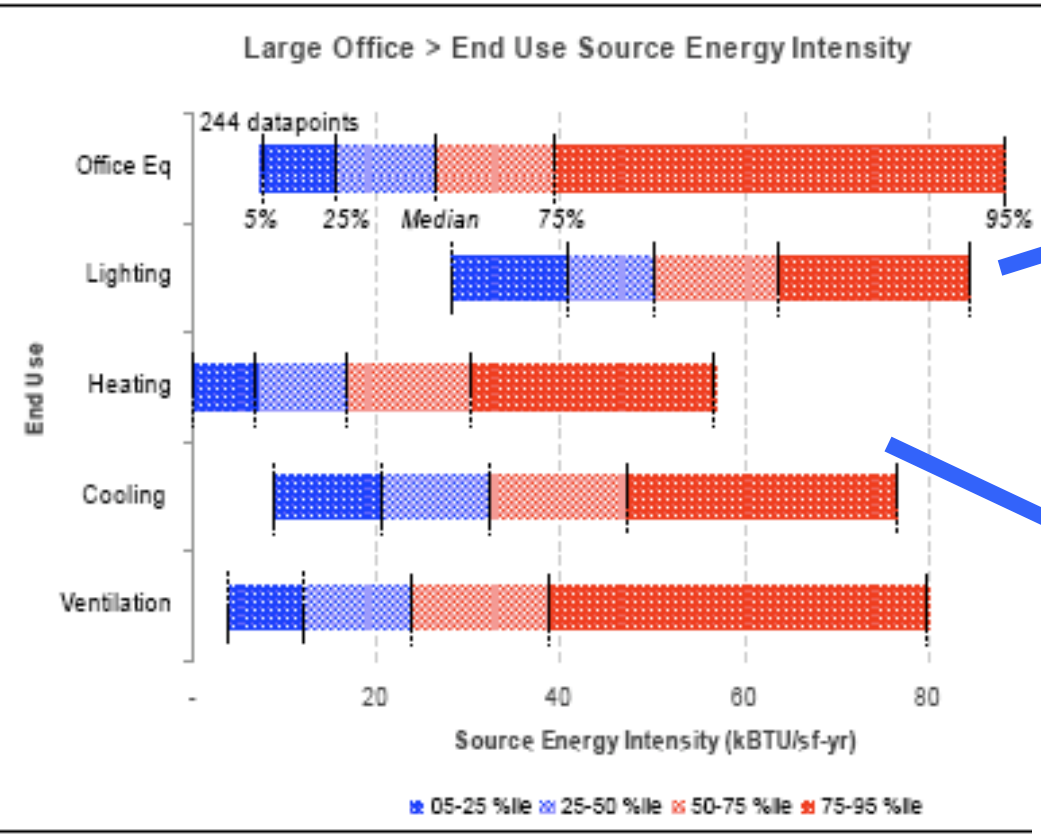
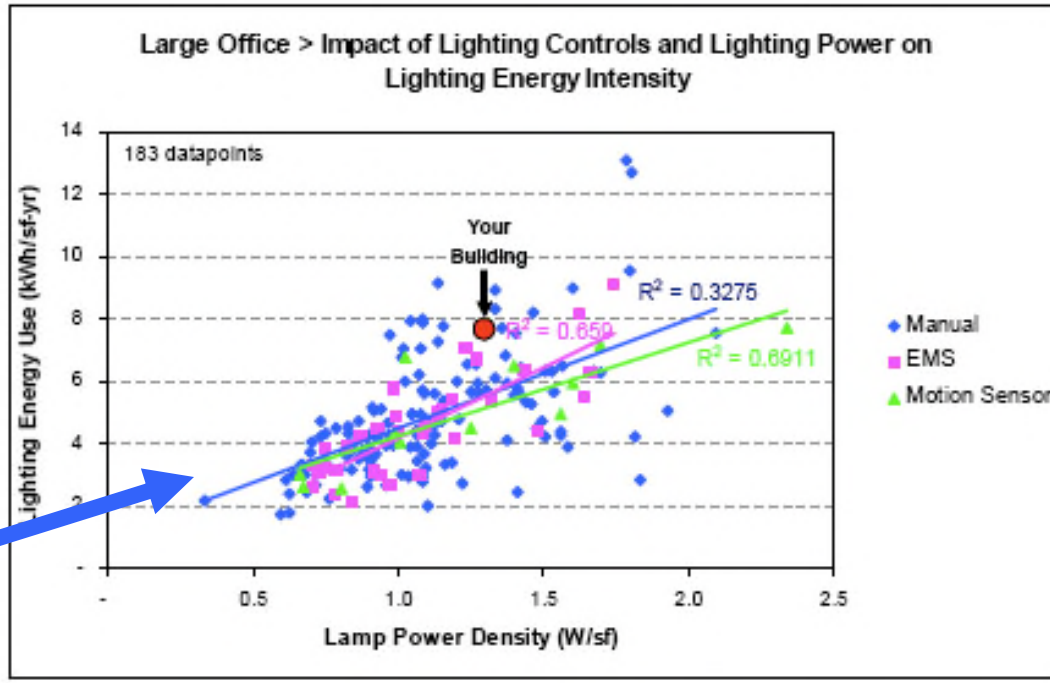
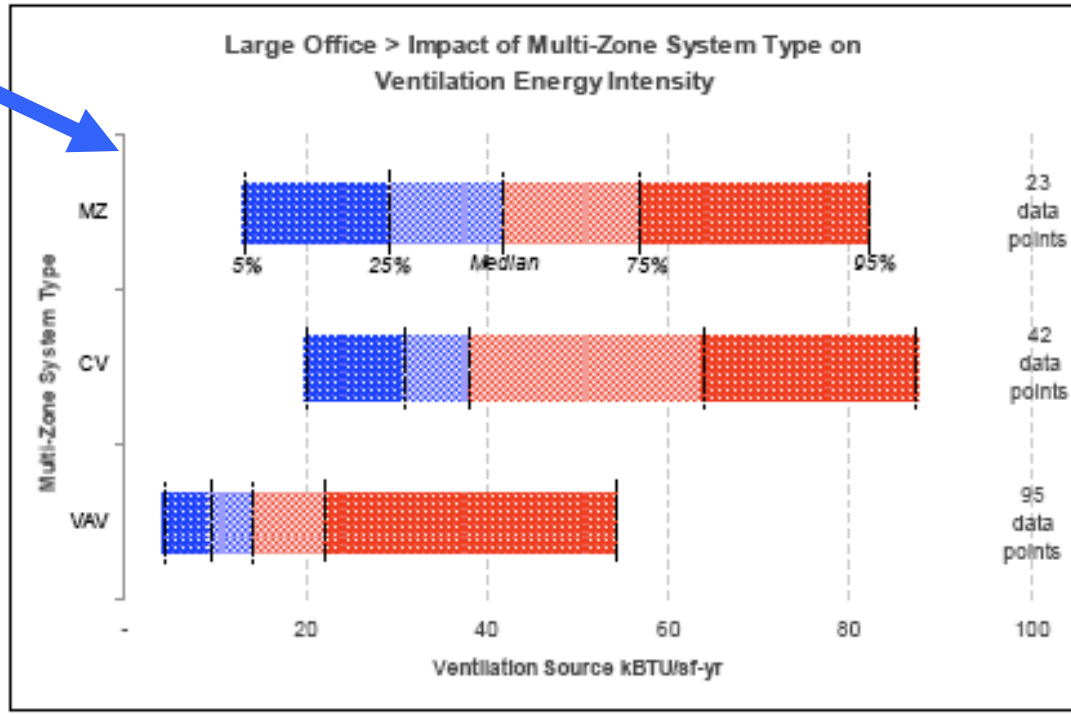
EnergyIQ.lbl.gov

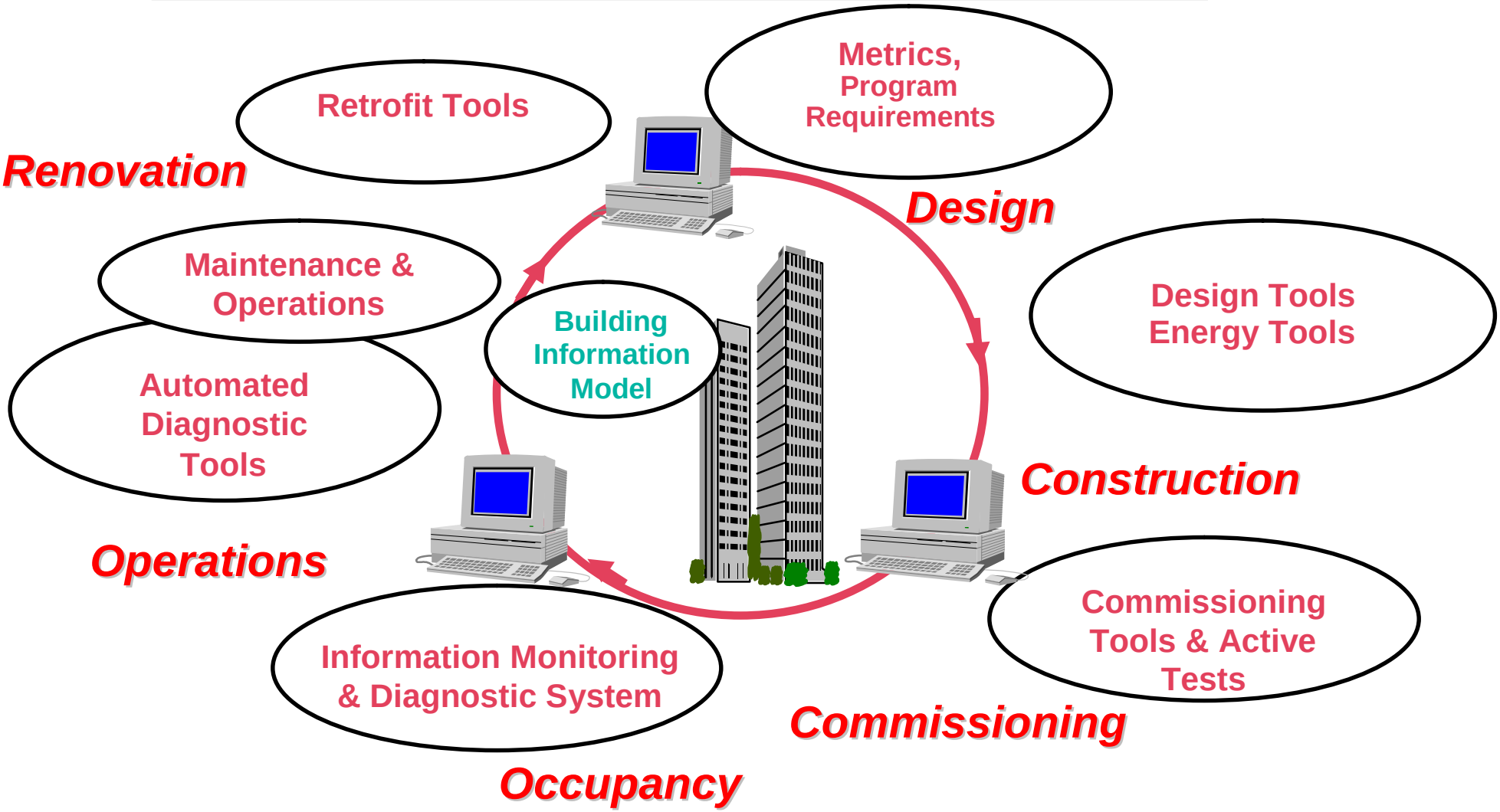
Measured Performance Insights





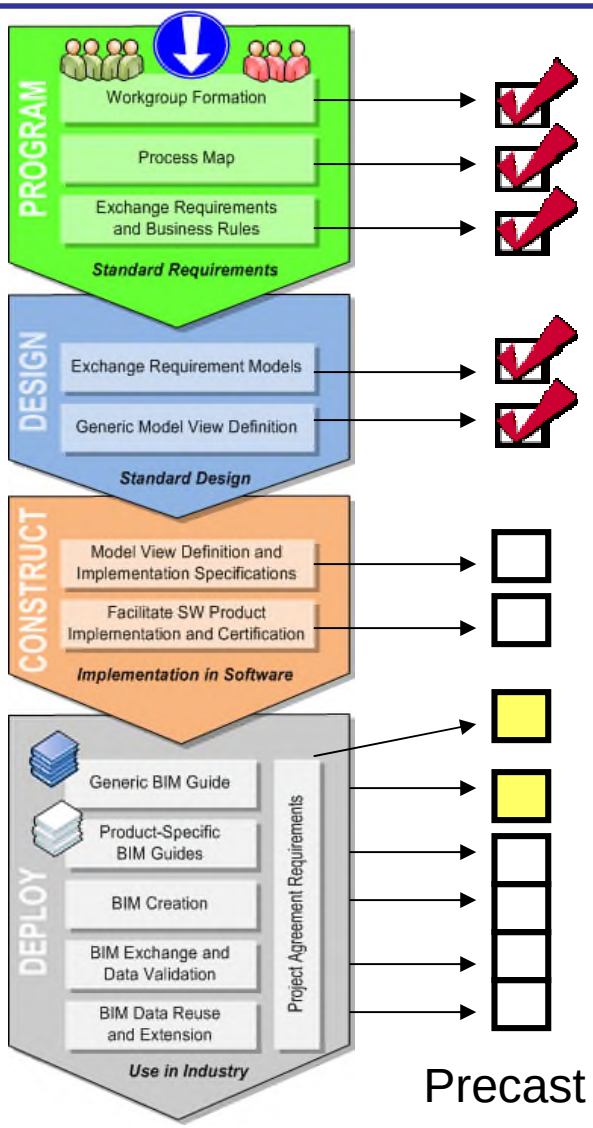


Information Technology-based Building Life-Cycle Integration View



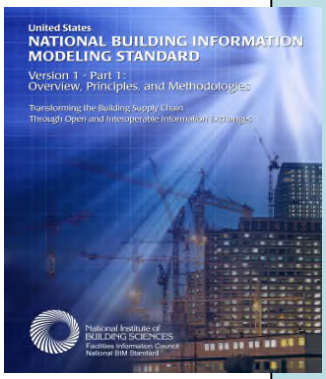
National Institute of BUILDING SCIENCES

Business Process



Precast

International Open Standards Based Technology
Ifc, IDM, ERM, MDV, and IFD Library



National
BIM Standard

Requirements
Definition

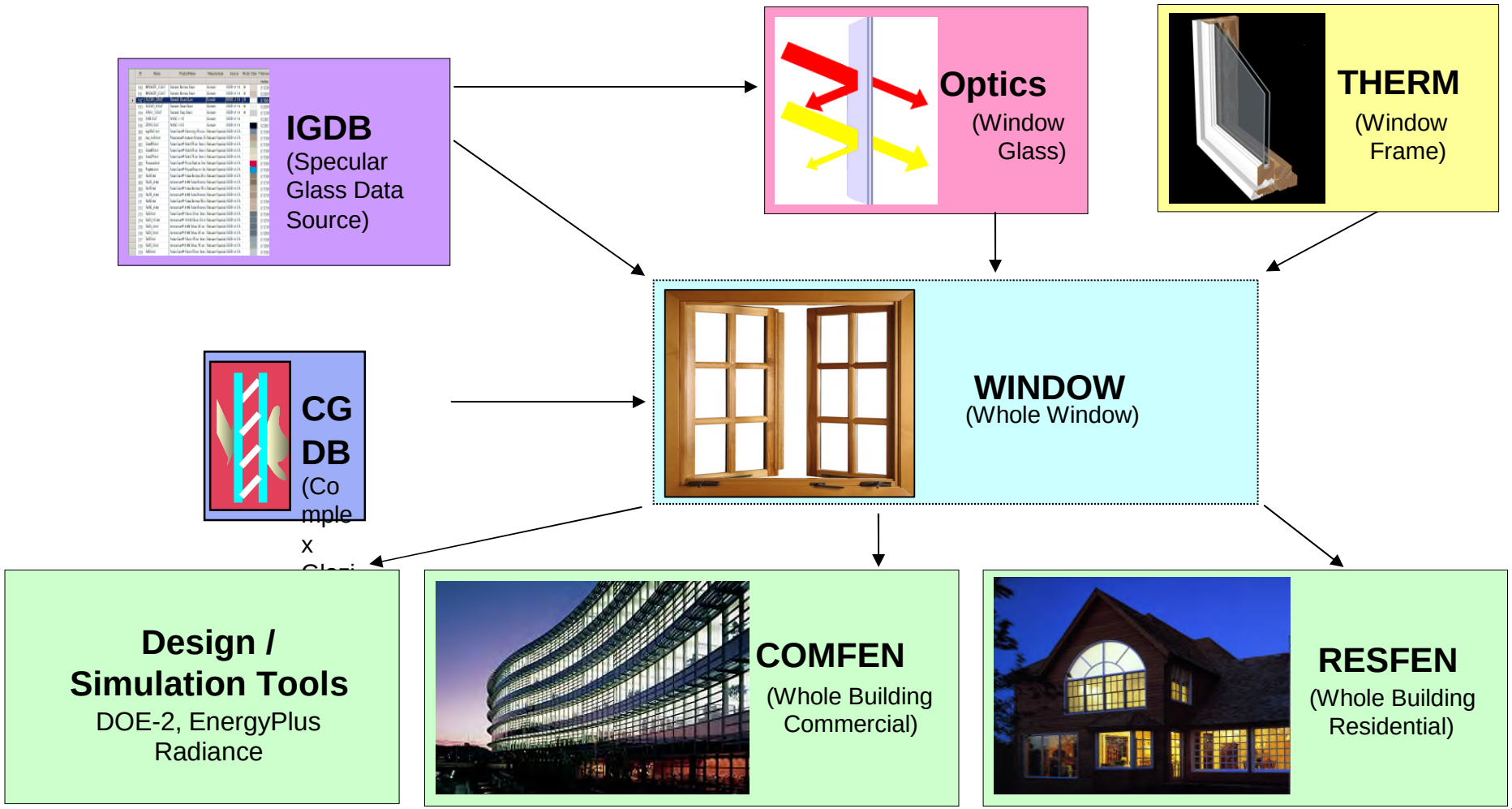
OGC Testbed

Vendor delivered product

buildingSMARTalliance™

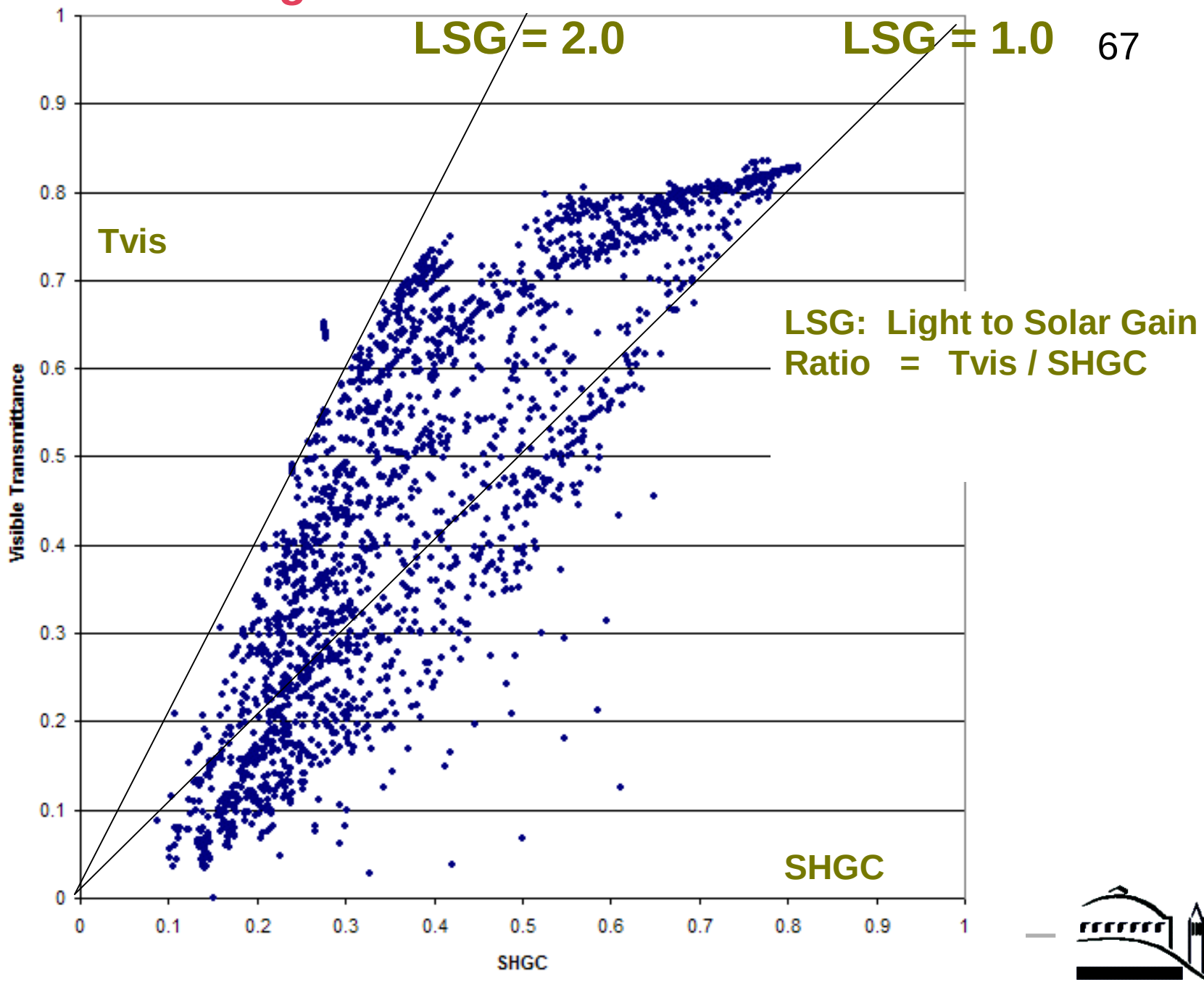
© 2008 NIBS

Software Tools



Light to Solar Gain Ratio

Light to Solar Gain Ratio for insulating glass units for all glasses in LBNL IGDB



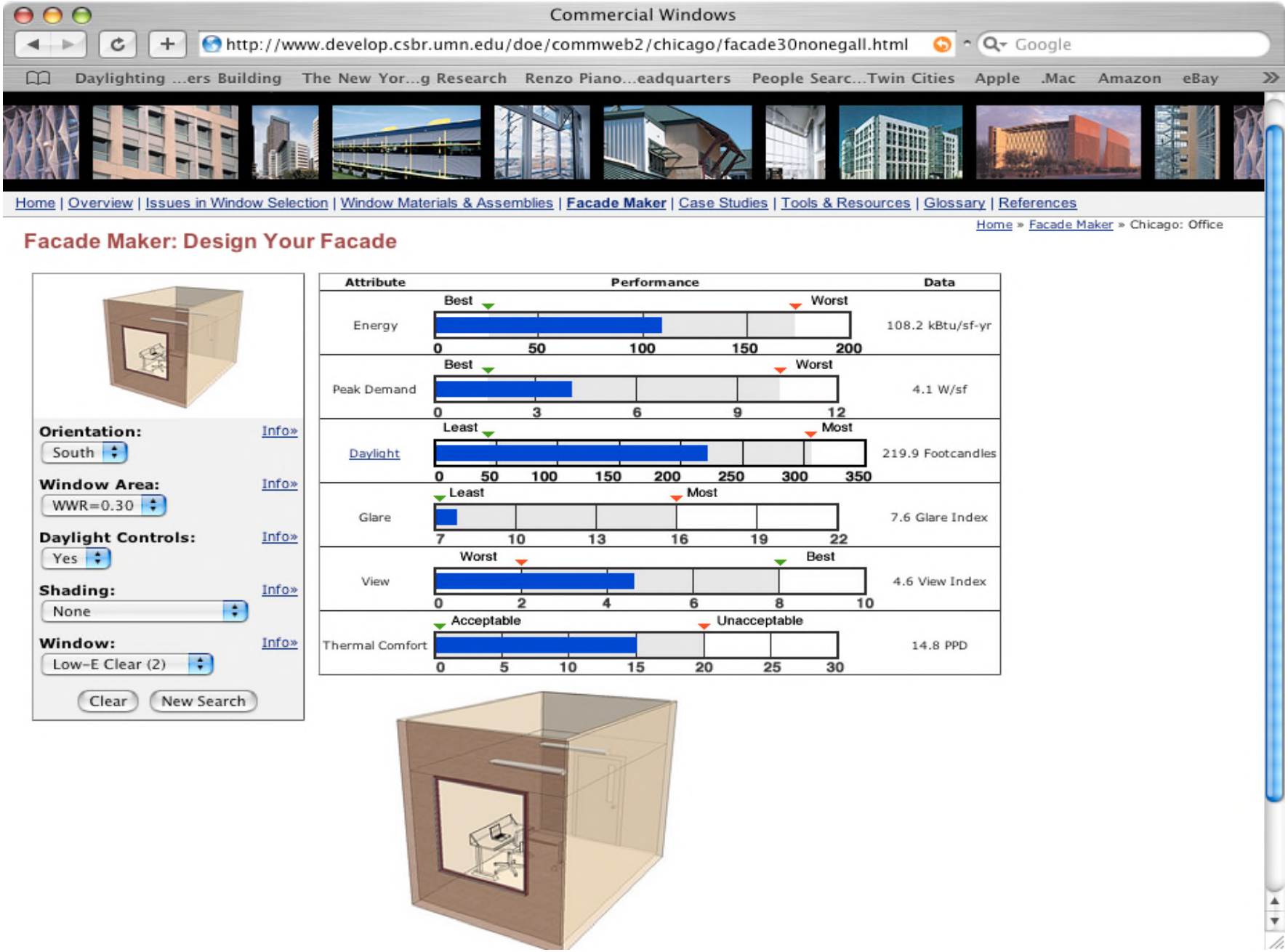
“Intelligent Lighting Design” with Radiance

“What you see is what you experience”

- Photometrically accurate evaluation of quantitative and qualitative daylighting and electric lighting performance
- Make design decisions based on lighting quality

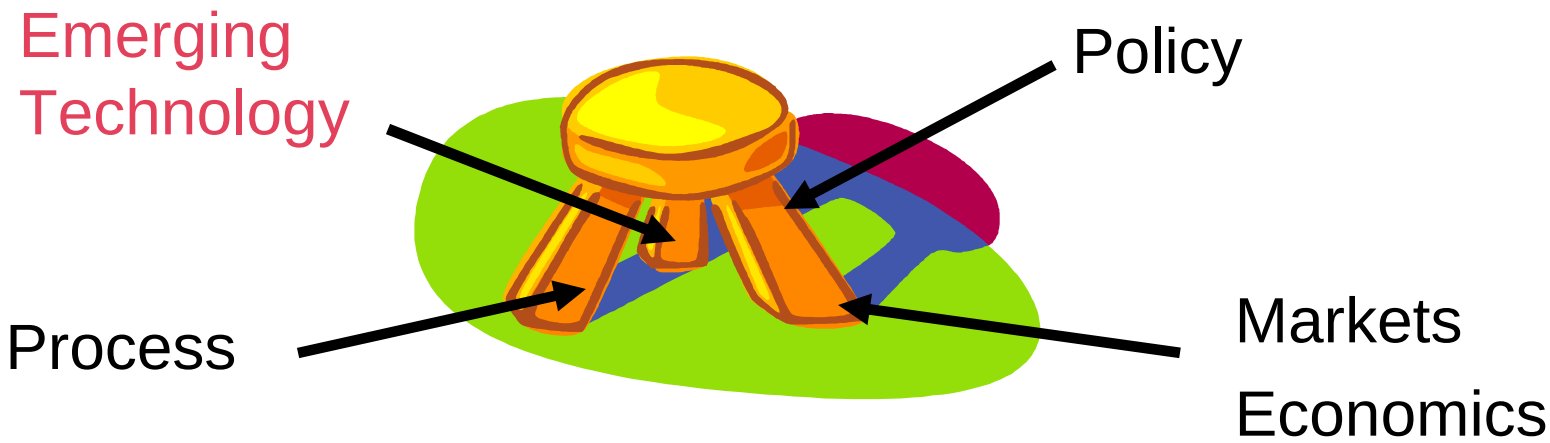
- New developments:
  - Until recently, *Radiance* lacked efficient facilities for annual simulation: *rtcontrib*
  - Developing the capability to accept BSDF data from Window6

Commercial Windows Website



Importance of Comprehensive Balanced Program for ZNE

To deliver high performance, zero energy buildings we must find a balance between:



Solutions fail without this balance

ZNE Buildings "Grand Challenge"

- Focus on Life Cycle of the Building
  - Design --> Construction --> Operations w/ BIM
- Focus on Integrated Smart Building Systems
  - Materials --> Devices --> Integrated Systems --> Buildings
- Focus on "intersection" of Technology and Policy
  - Innovative, Disruptive technologies

    +
  - Occupant behavior, life style, satisfaction, comfort
  - Investment and Decision making
- Focus on Measurable, Documented Energy Impacts
  - Make performance visible and understandable

Role of Innovation vs Standard Practice

- Faster, Better, Cheaper….
- Incremental <--> Disruptive; Local <--> Widespread
- R&D Generates "New and improved" options
  - **Building Technologies and Systems**
  - **New Analysis Tools**
  - **New Business Processes**
  - **New Benefits- e.g. environmental quality**
- R&D Reduces Negatives**:**
  - **Risk and Uncertainty**
  - **Time**
  - **Cost**

What Do We Need to Do?

- **Take the Longer view: Define aggressive vision for action over time to 2030**
  - Deployment Action to Capture the first 20-30% savings now
  - Demonstrate what it takes to get 50% in near term
  - Research what it takes to get 70+% savings in longer term
- **Make performance visible and understandable**
  - "Can't manage what you can't measure"
  - More focus on how buildings actually operate
- **Assess, Evaluate, ACT: "Learn by doing"**
  - What works --> Promulgate and deploy
  - What doesn't --> Fix and Deploy
- **Focus more on the facility owner/operator/owner perspective**
  - Drive decision making, investments and manufacturers offerings

"Think Big, Start Small, Act Now"

- Challenge of launching a large scale, long term, national program, blending policy, economics and technology
  - Other examples??
- NOT Apollo moon project
  - More like eradicating smallpox or polio
  - Technology component, enabled by policy
- Public - Private partnership
  - Who pays? Who benefits? Who controls?
- Tracking progress over 10-20 years? (Marathon, not a Sprint)
  - Measurable milestones….
  - Making Performance "Visible"
  - Maintaining focus, investment, etc over time

Benefits of High Performance Building Systems

Improve Occupant Comfort, Satisfaction and Performance

Occupant

Add Value, Reduce Operating Costs

Building Owner

Reduce Greenhouse Gas Emissions

Planet