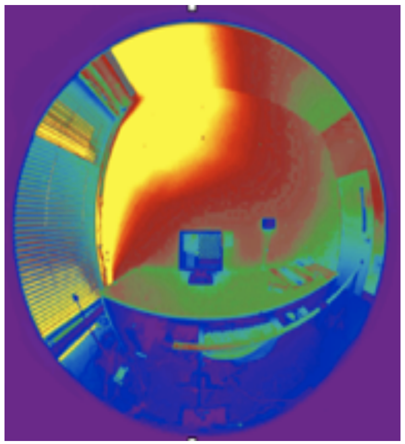
BEST LBNL 1/6/2016

The
High Performance, Net Zero, Green Building….
Vision:
Progress and Challenges

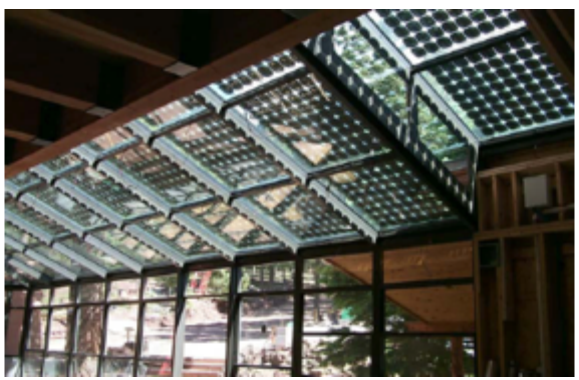


Stephen Selkowitz

Senior Advisor, Building Technology and Urban Systems

Lawrence Berkeley National Laboratory

seselkowitz@lbl.gov



Presentation Outline

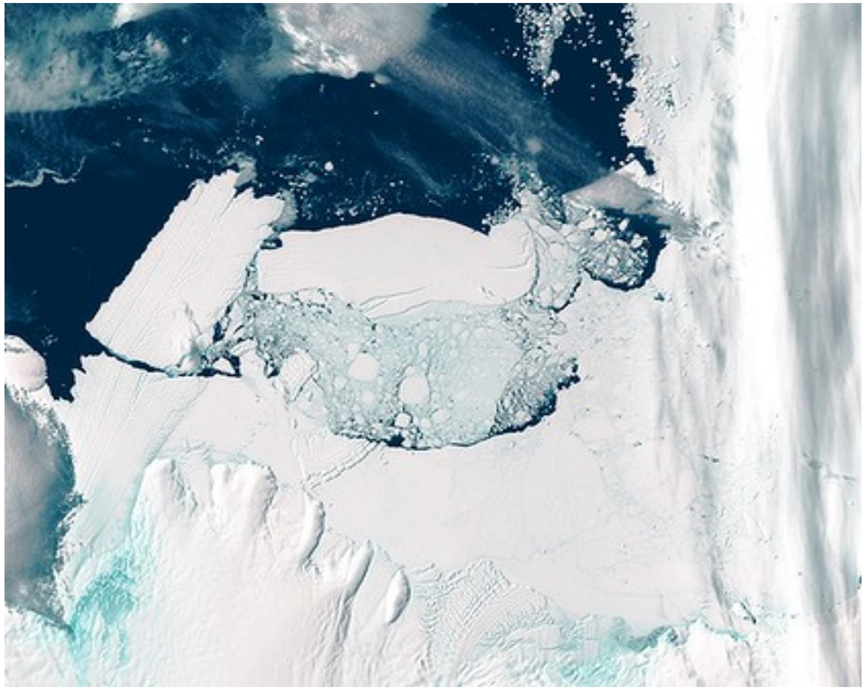
1. Framing the Energy/Carbon Challenge
2. Framing the Building Performance Challenge
3. Lighting
4. Windows
5. The Case for Integrated Systems
6. What Now?

~1960 – Early R&D on Low Carbon Energy Supply

Motivation for Action?
Carbon and Climate Change

Greenland Glaciers

+



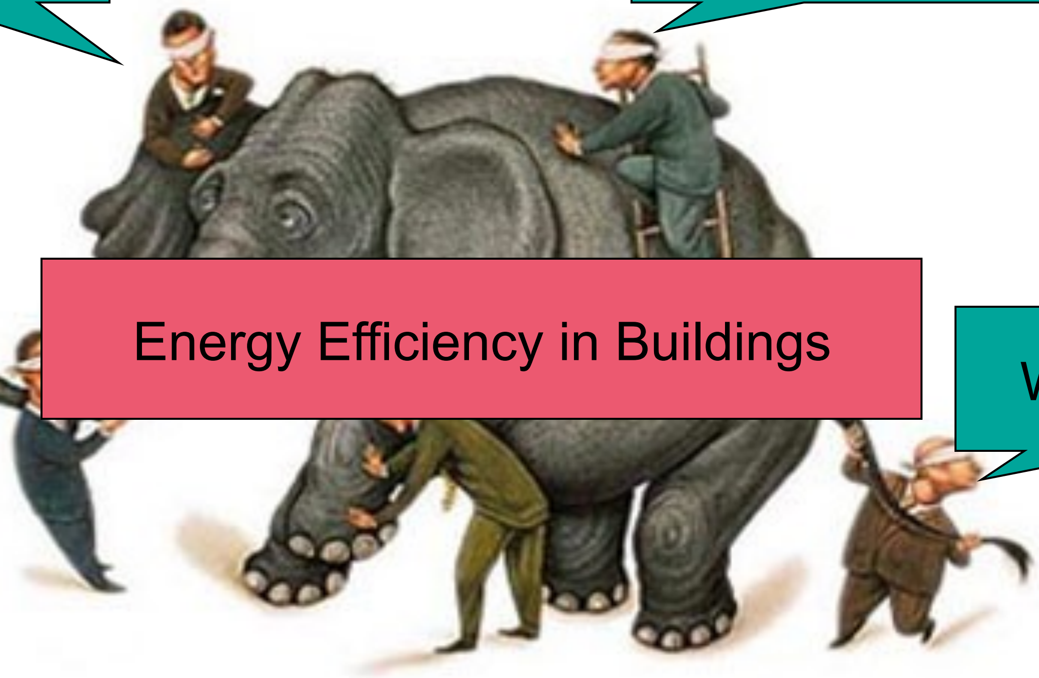
Antarctic Ice Shelf


2015 -> 2100 ?

Health Impacts of Energy Use – "Red Alert" Beijing

Lawrence Berkeley National

Defining the Energy/Climate Change Problem:

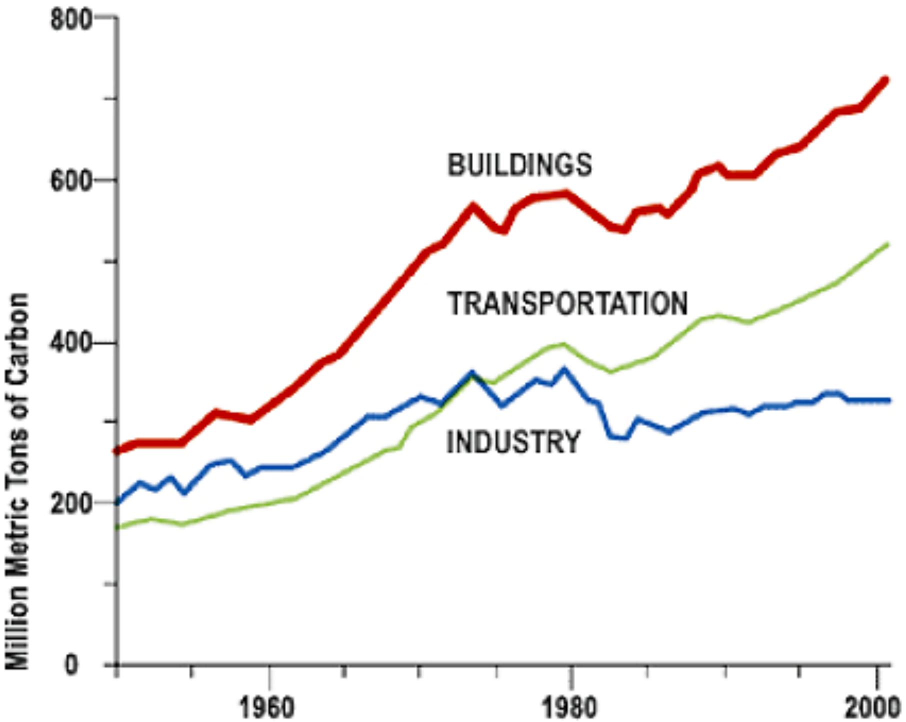


Why Focus on Buildings??
Total Building Energy Use; End Use Consumption

Building sector has:

Largest Energy Use!

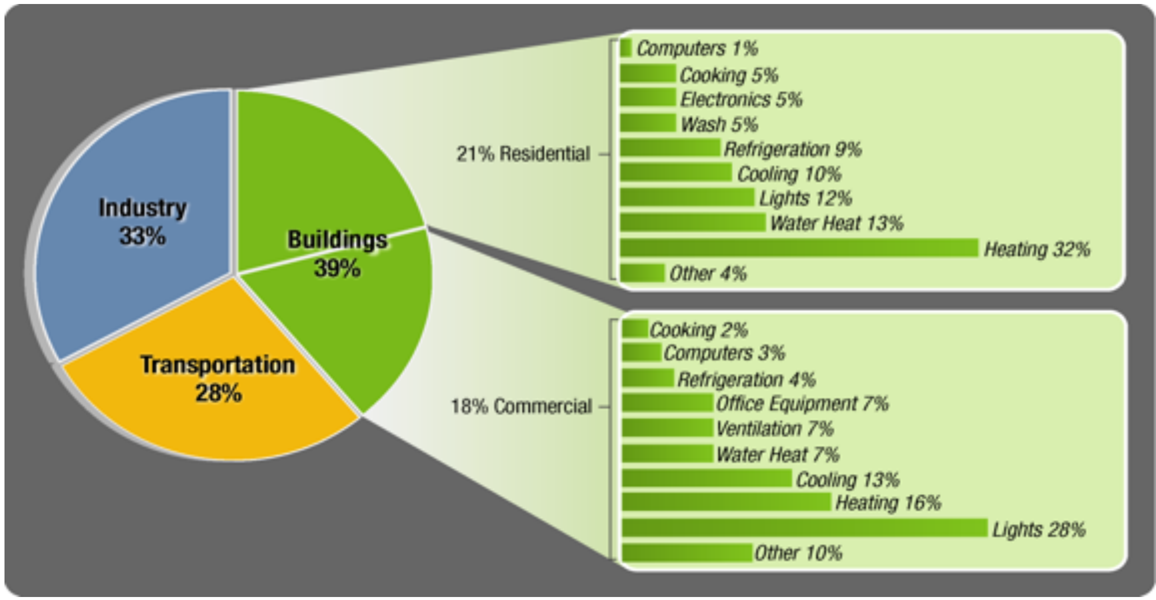
Fastest growth rate!



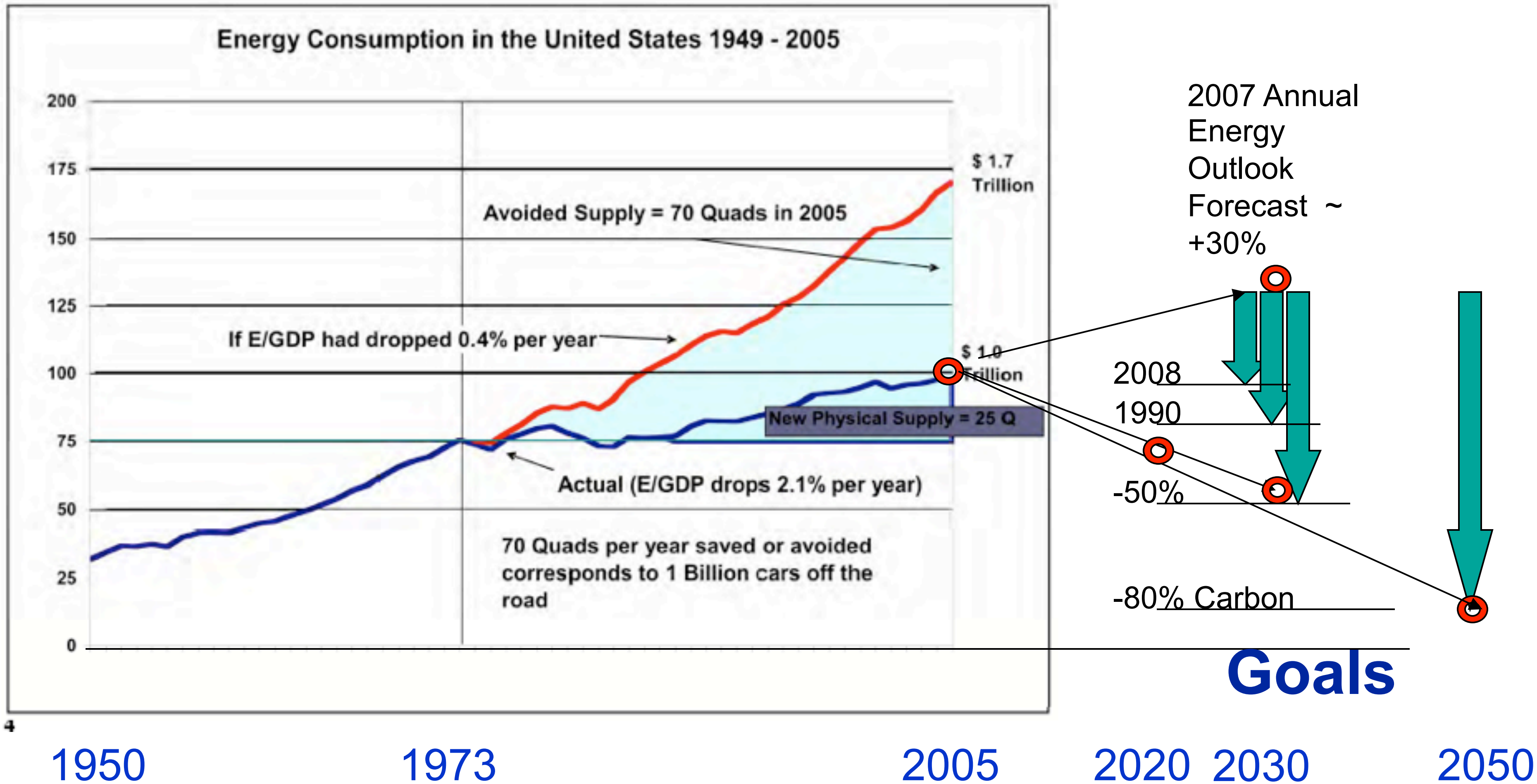
Buildings consume 40% of total U.S. energy

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

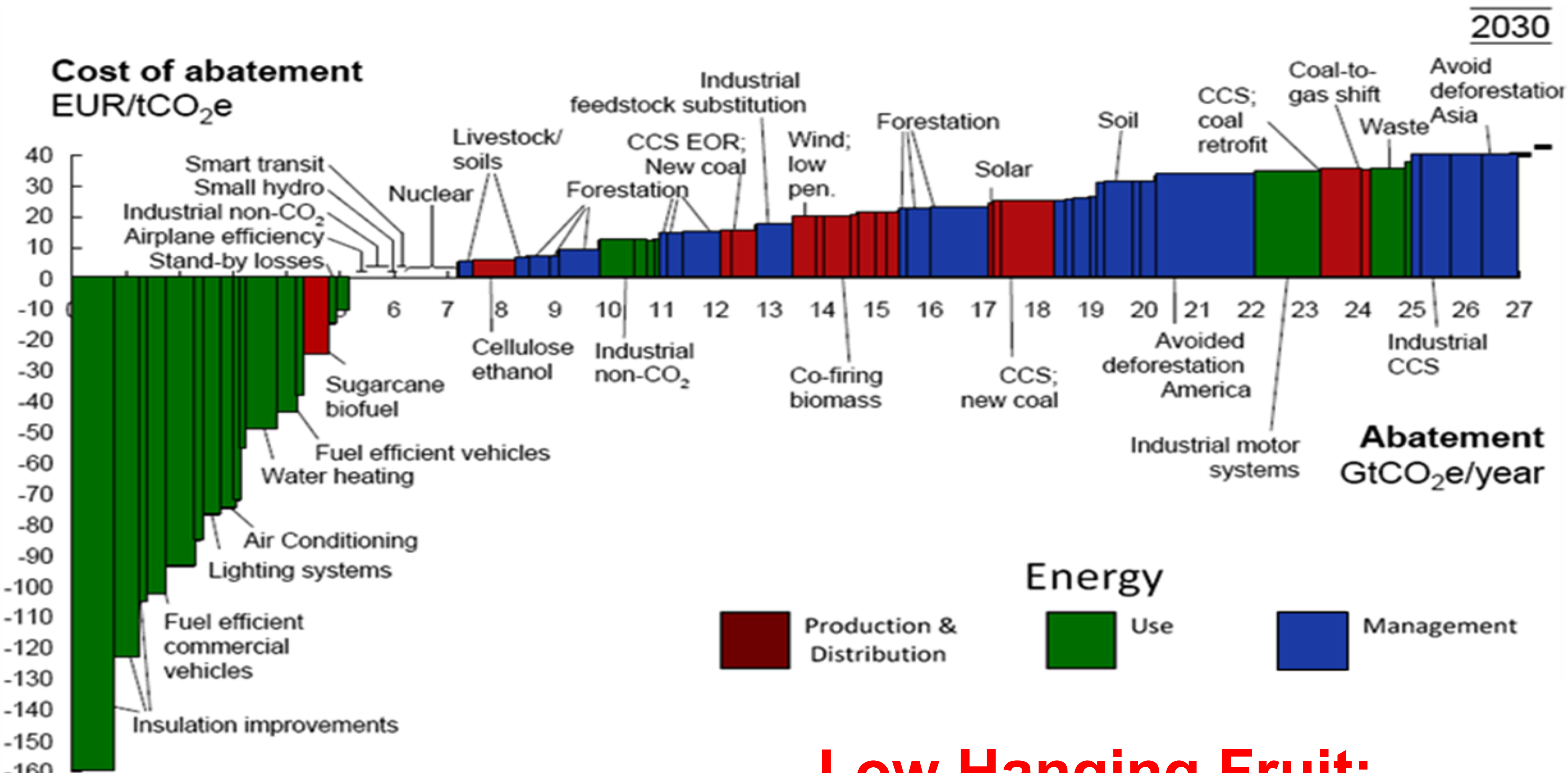
No Single End Use Dominates



U.S. Energy Use: History and Aggressive Future Goals



Saving Carbon vs. Energy Sectors
Production, Distribution, Use



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

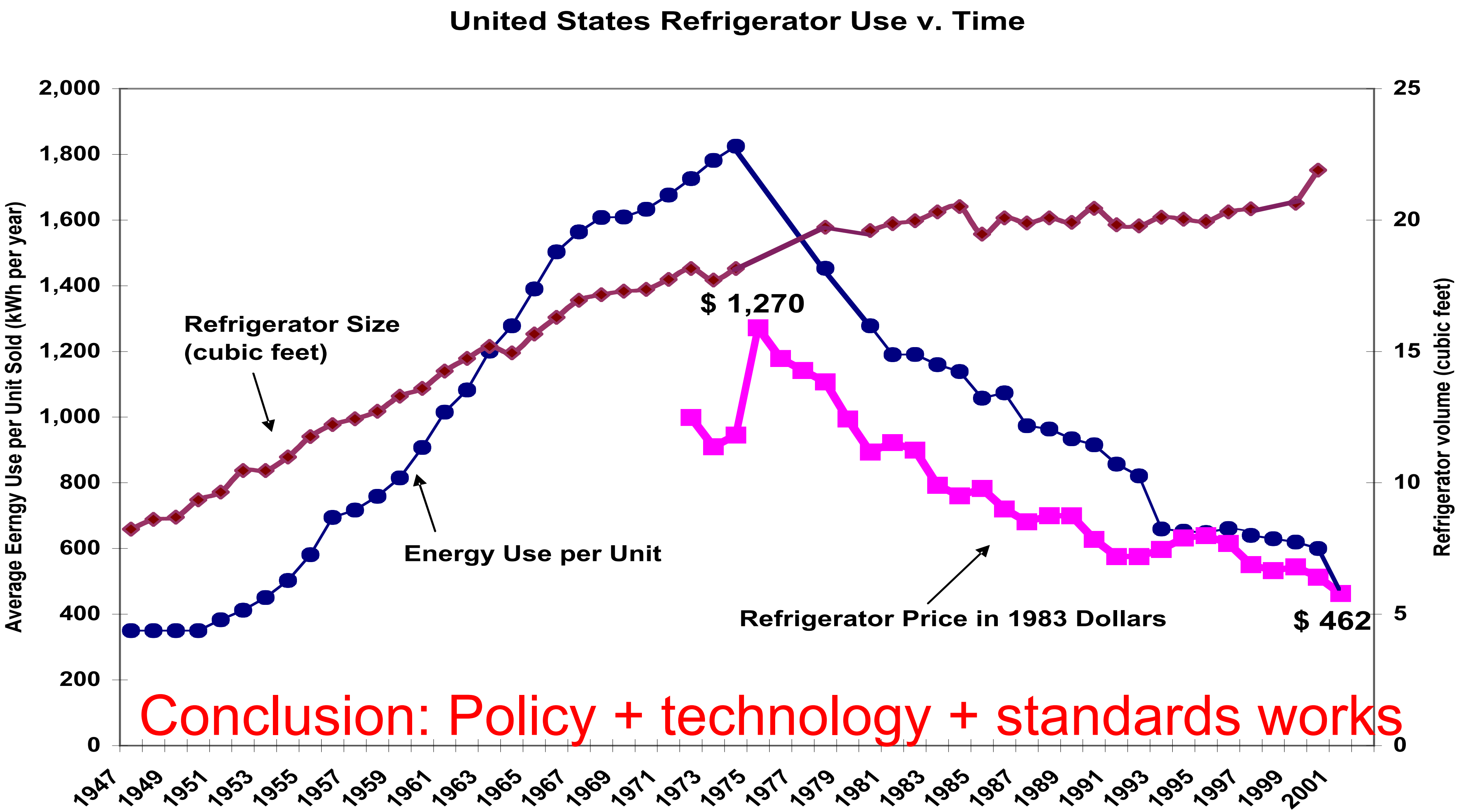
Low Hanging Fruit:
Energy Efficiency Pays for Itself

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

1. Optimize "Lifestyle" to Minimize Energy Services and Needs
   - Buildings…
   - Make cities walkable, food,…
2. Maximize Efficient Use of Energy
   - LED light bulbs,…..
3. Decarbonize energy sources
   - Solar energy,…..

But more difficult to plan, execute and scale

U.S. Refrigerator Energy Use vs. Time

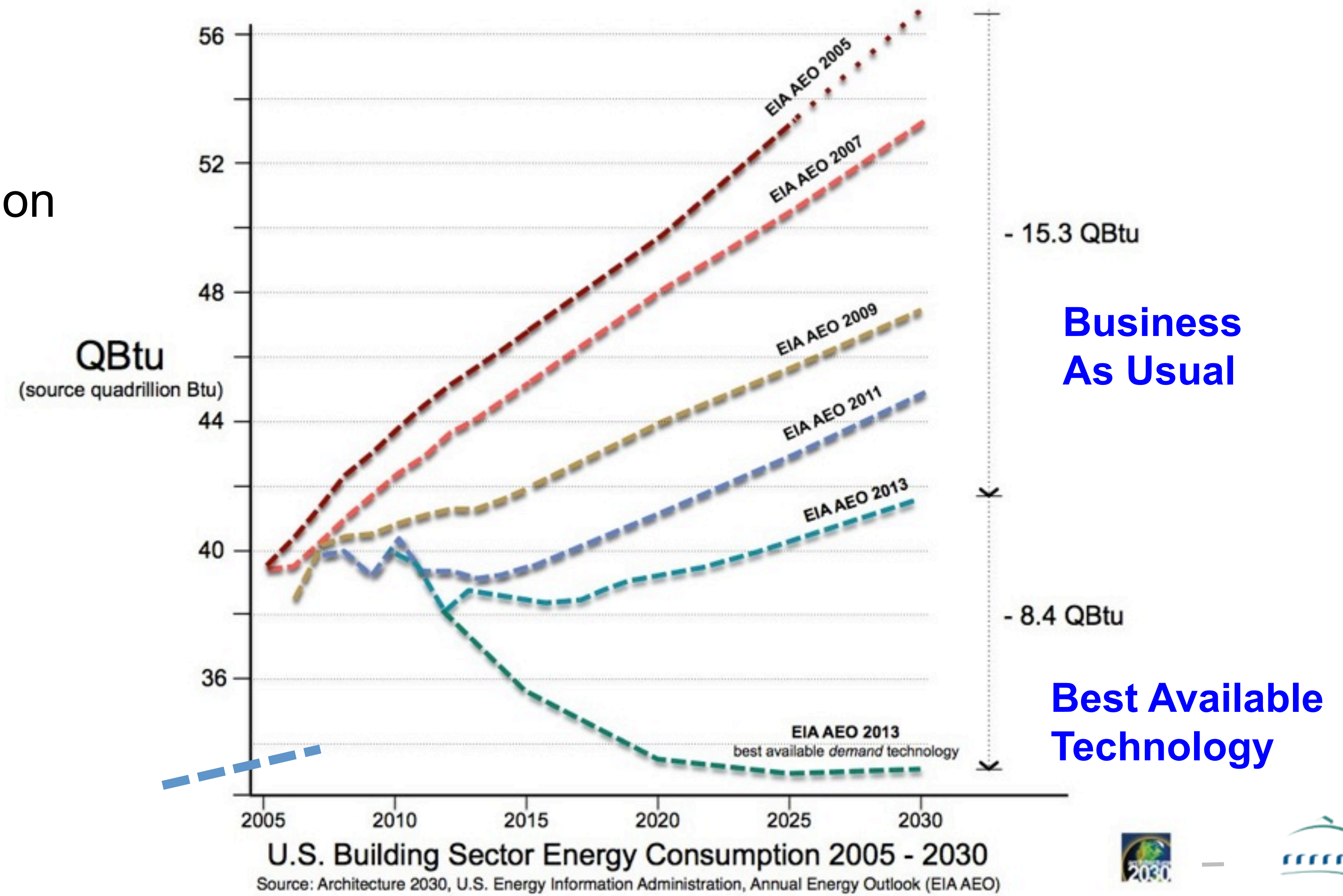


Conclusion: Policy + technology + standards works

U.S. Building Energy Projections Declining

EIA:
Energy Information Agency

AEO:
Annual Energy Outlook

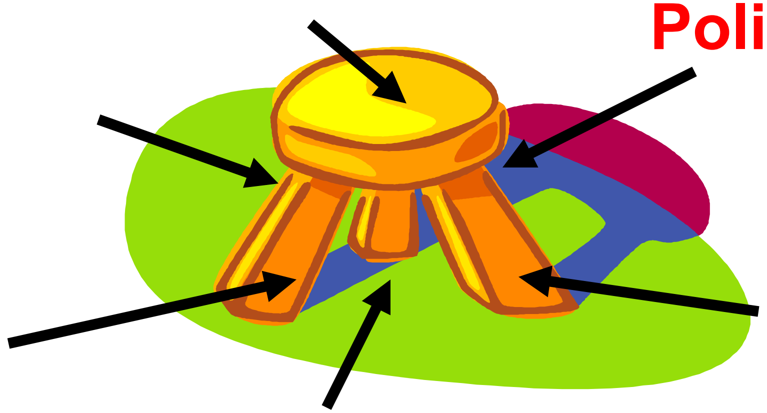


Addressing the Building "Grand Challenge"

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

Significant Impact Comes Only from Comprehensive Balanced Program

To routinely deliver high performance, low-energy buildings we must find a balance between:



Solutions fail without this balance

"In theory, there is no difference between theory and practice.

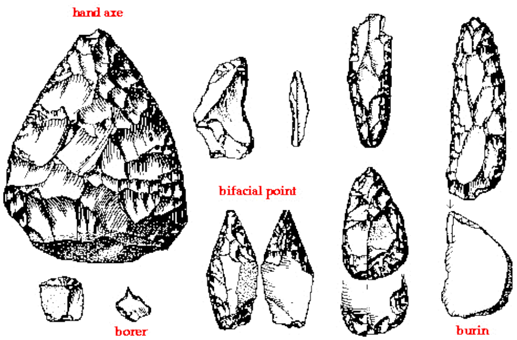
But in practice, there is."

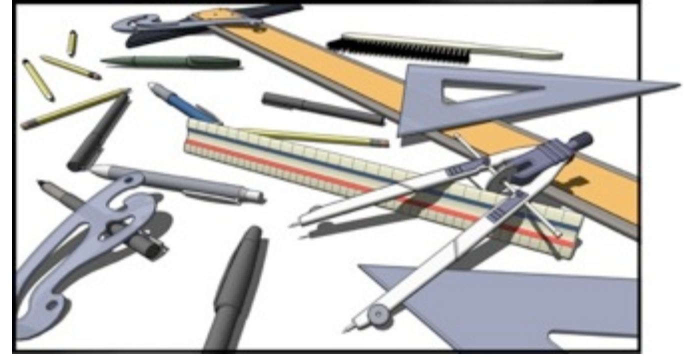
– Yogi Berra

Addressing Global Energy Challenges Requires Translating Theory and Potentials into Robust, Practical, Scalable Solutions

"Do It Now" vs "Wait and Do It Better Tomorrow" Why Not Do Both!

- **Increase Rate of Adoption of Existing/Emerging Technologies**
  - Operational improvements
  - Better Design and Selection Guidance
  - New Market channels
  - New Voluntary and Mandatory Programs
  - Education: best use for a particular application (climate, etc.)
- **Create Pipeline of New Technology Options and Business Models:**
  - **Incremental improvements** to technology available today
    - Performance enhancements but Cost reductions
    - New features
  - **Breakthrough R&D**
    - Innovation- new products, new applications
  - **Components → Integrated Systems**
  - **"Net Zero Buildings" – Efficiency + Energy Generation**

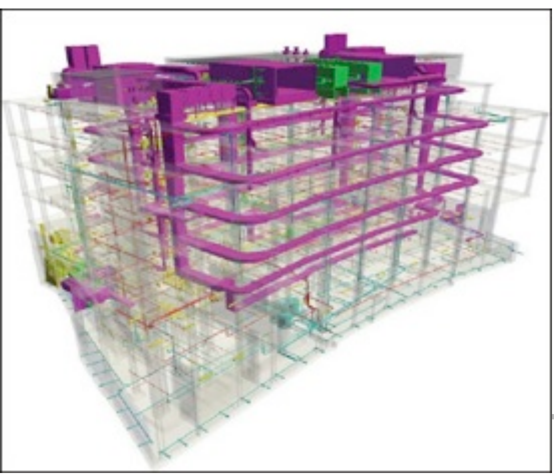


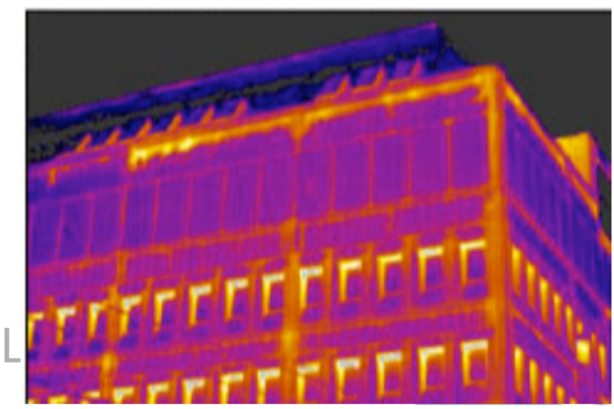


Data, Models and Tools

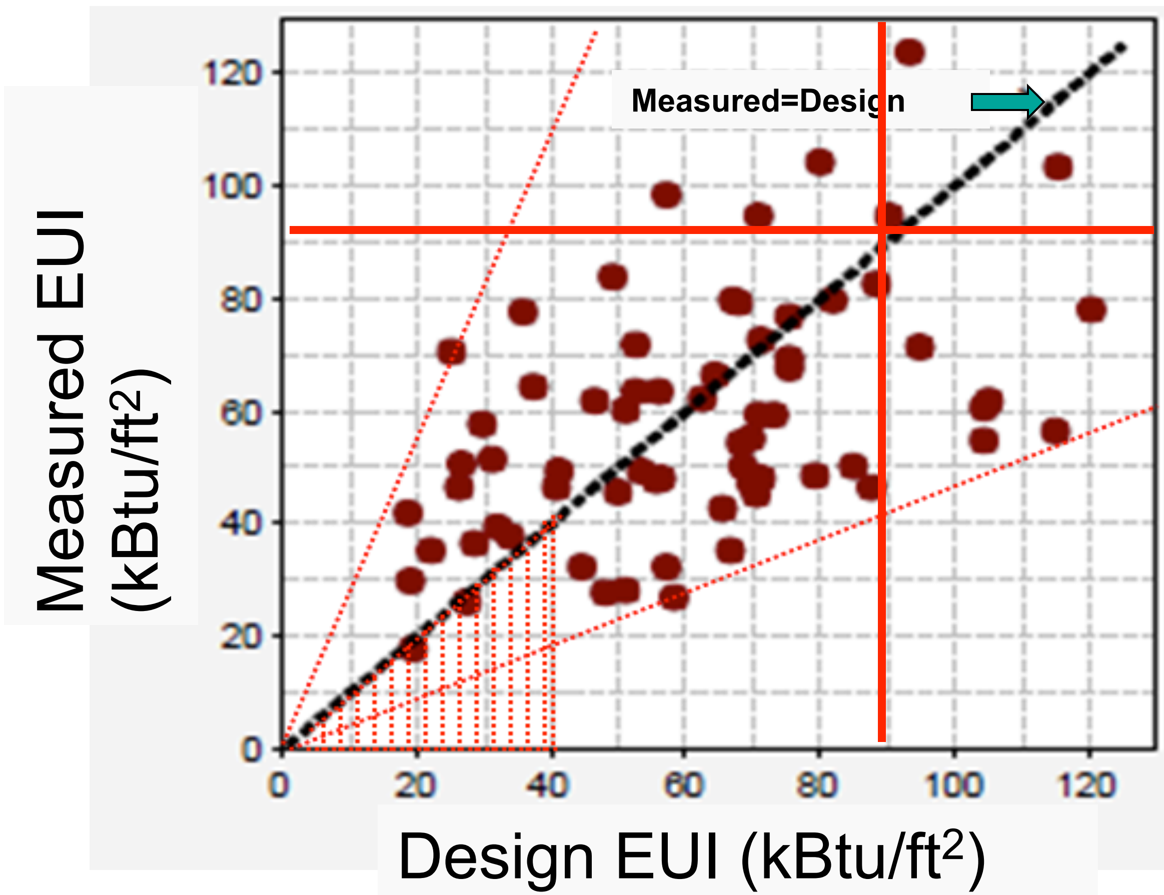
"All Simulation Models are Wrong, But Some are Useful"

How do we ensure our tools/data are useful?





The Challenge:
Design Goals vs Measured Performance



Source: Energy performance of LEED-NC buildings, NBI, 2008

<u>Observations</u>:

1. Various building types, ages, locations
2. Average over all projects is not bad
3. Max over-predict by **120%**
4. Max under-predict by **65%**
5. **Almost all under-predicted for low energy designs**
   (red triangle: EUI <= 40)
6. Uncalibrated simulated results

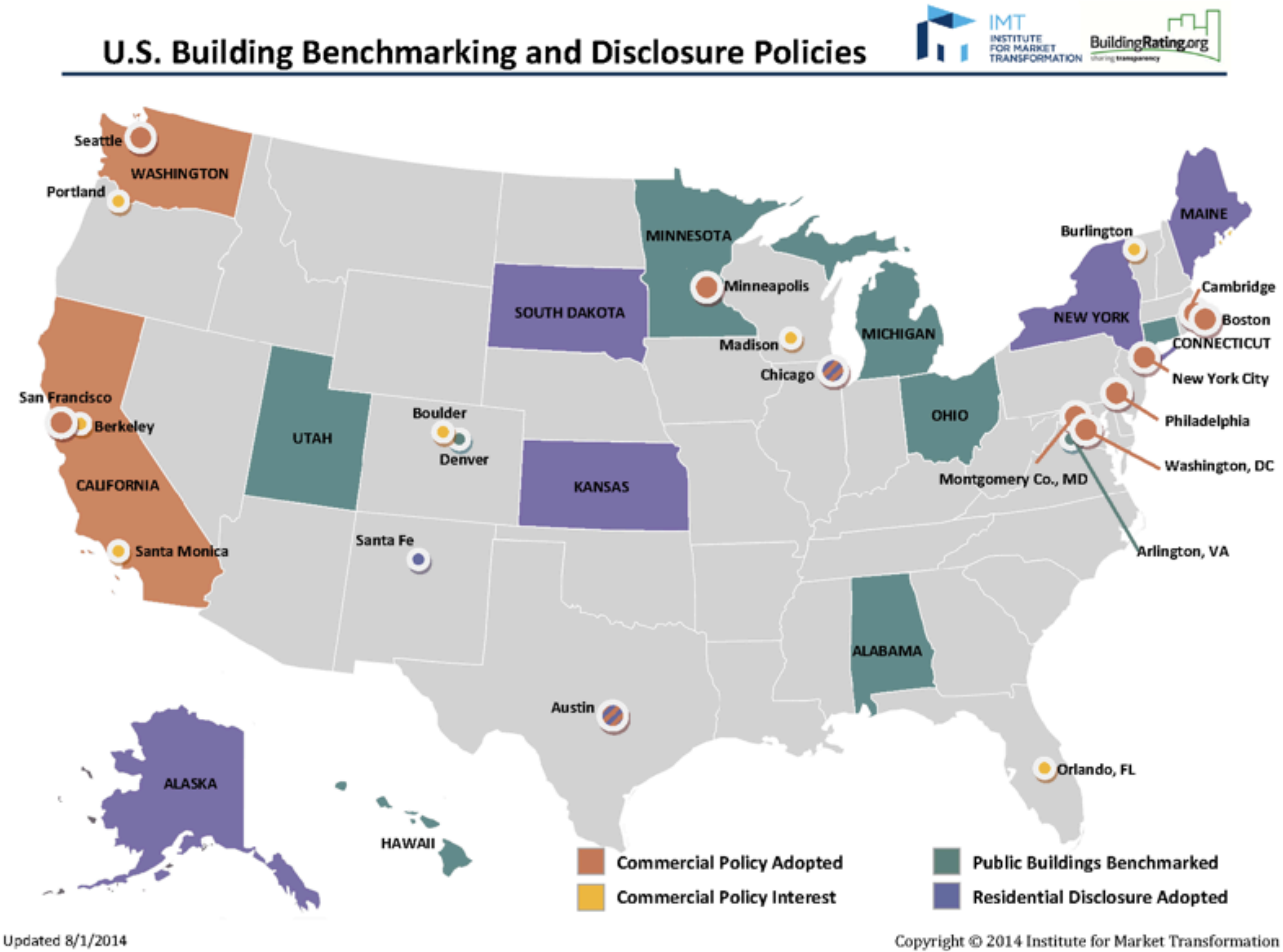
New R&D: Tools and Data

- **EnergyPlus engine** development:
  - New features to model low energy designs
  - Speed-up, Technical support and maintenance
- EnergyPlus Graphical User Interface
- EnergyPlus derivatives: special purpose tools
  - e.g. COMFEN- façade early design tool

- **Building Controls Virtual Test Bed** – co-simulation, real controls

- **New Simulation/Data apps:**
  - Design assistance
  - Real-time performance assessment
  - Operation/Behavior modeling
  - Fault Detection and Diagnostics
  - Retro-commissioning
  - Codes and standards development
  - Interoperability
  - Benchmarking
  - Ratings, Labels

Quantifying and Exposing Performance: Disclosure Legislation



Meters-> "Big Data" Comes to the Buildings World: Energy Analytics for Buildings

DOE/EERE Building ***Energy Data Initiatives***

Actionable information to support investors, owners, operators, designers.

DOE BUILDINGS PERFORMANCE DATABASE

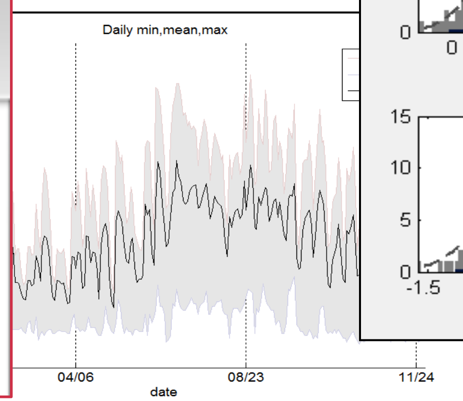
Standard Energy Efficiency Data (SEED) platform

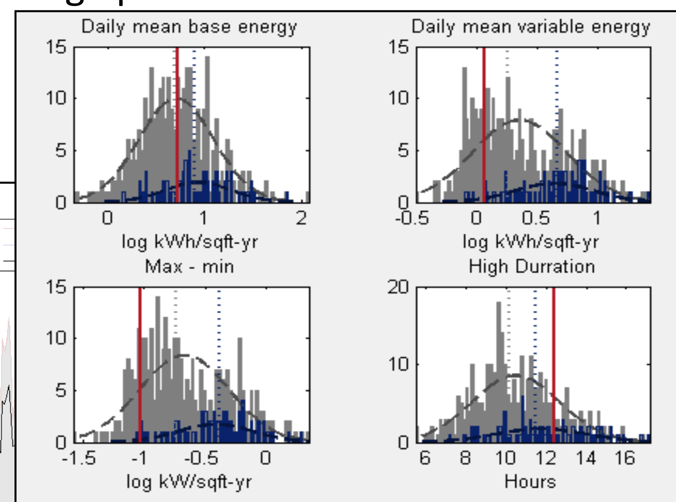
EnergyIQ Benchmarking Tool

- Seminal work on building commissioning cost-benefit analysis of >600 buildings
- Energy Information & Benchmarking Systems for commercial, residential

Advanced statistical methods

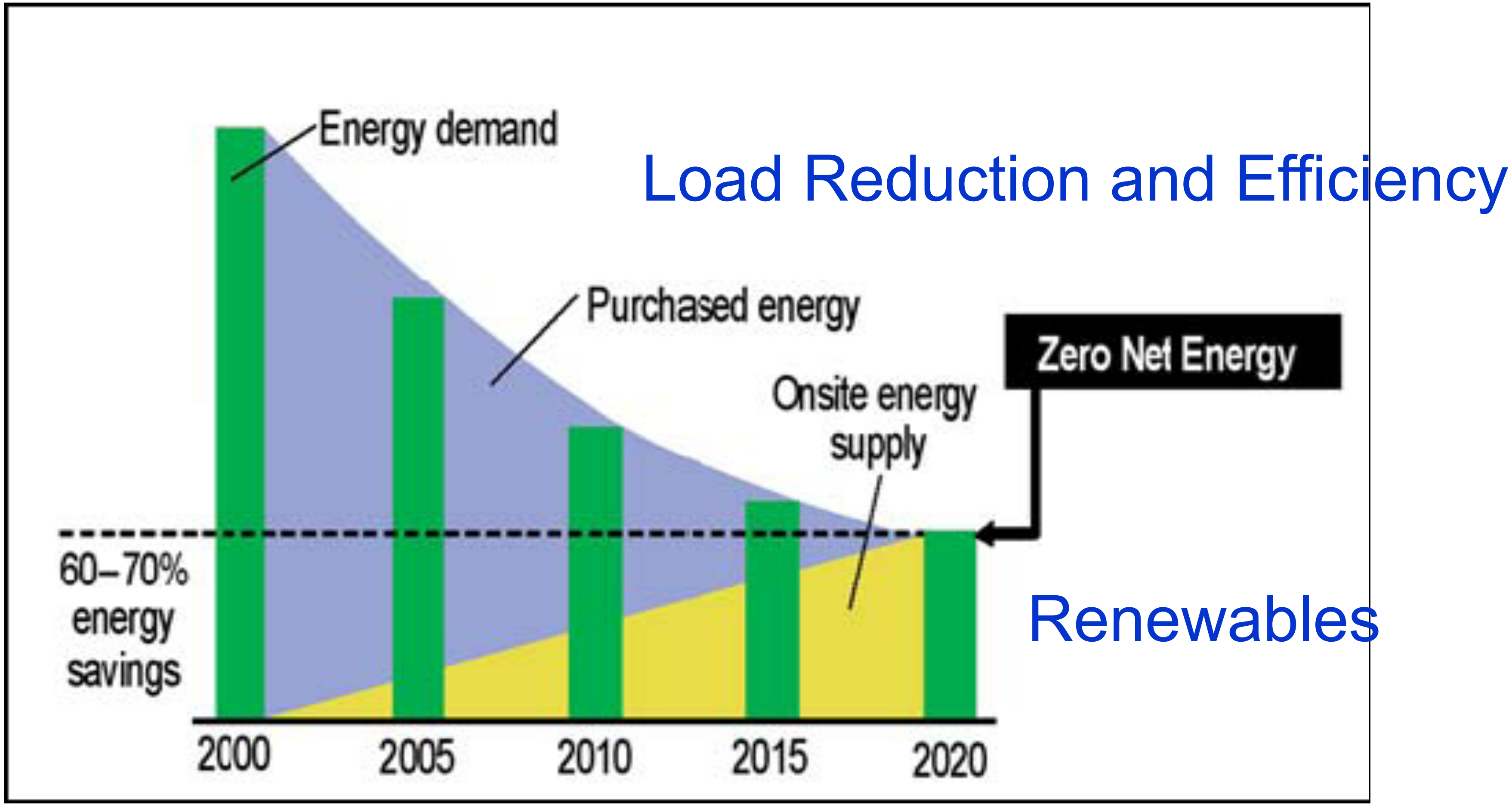
to analyze emerging "big data" from data-rich buildings and large portfolio datasets





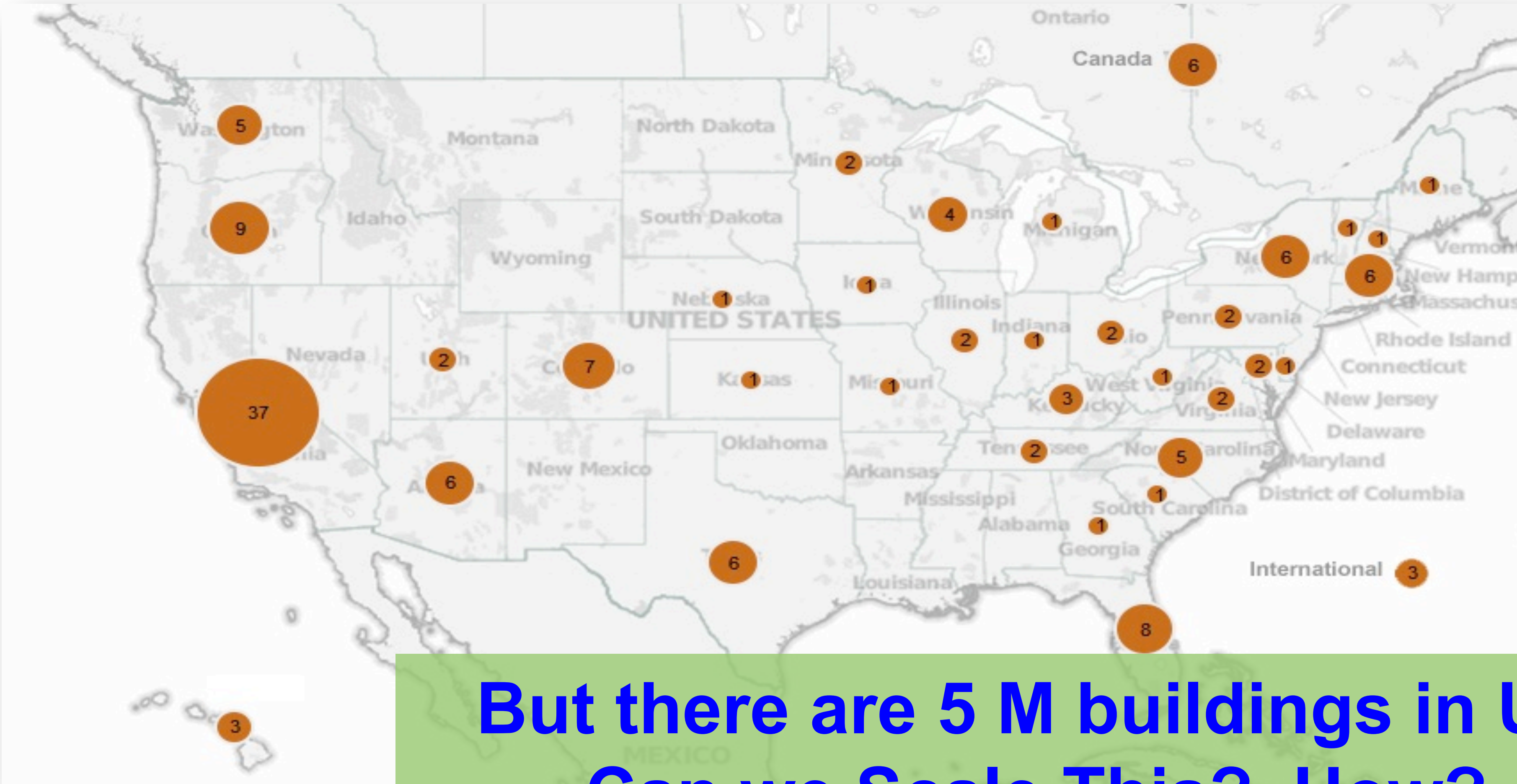
Net Zero Energy Buildings =

Energy Efficiency first reduces Use by 60-90%; Renewable, carbon-neutral source for remainder



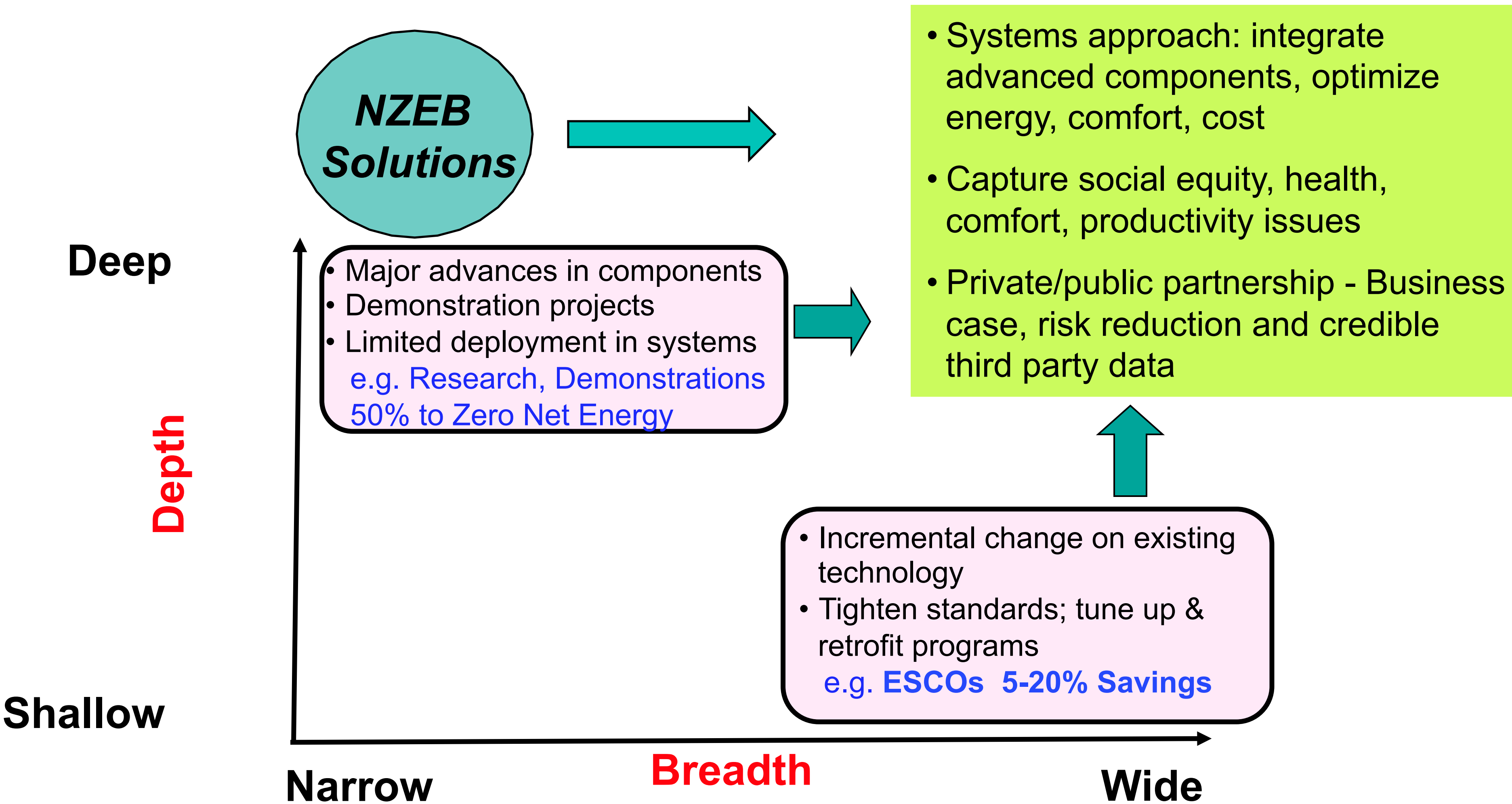
Zero Net Energy Buildings Status: 2014

~ 147 buildings in 37 states!



But there are 5 M buildings in US
Can we Scale This? How?

Scale and Impact:
We Need Both to Achieve Sector-wide Efficiency Goals



NZEB: Net (Nearly) Zero Energy Buildings

The Vision

- “Net Zero Energy Buildings” is the right goal
- NZEB = 60-80% savings + renewables

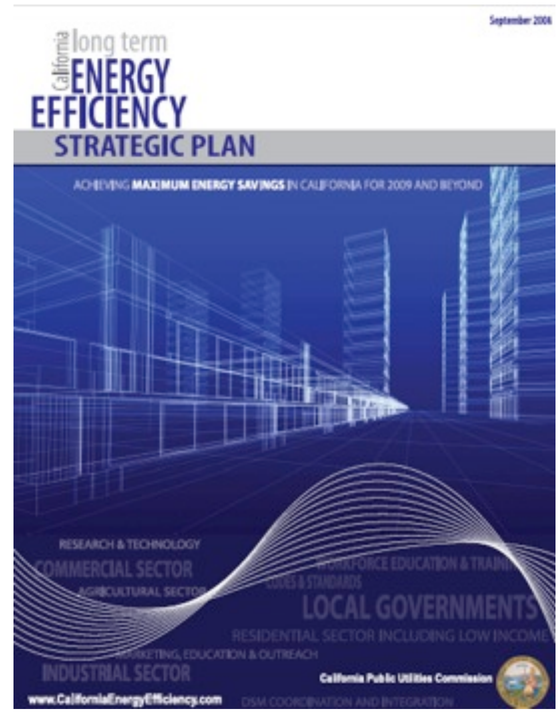
The Dream

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

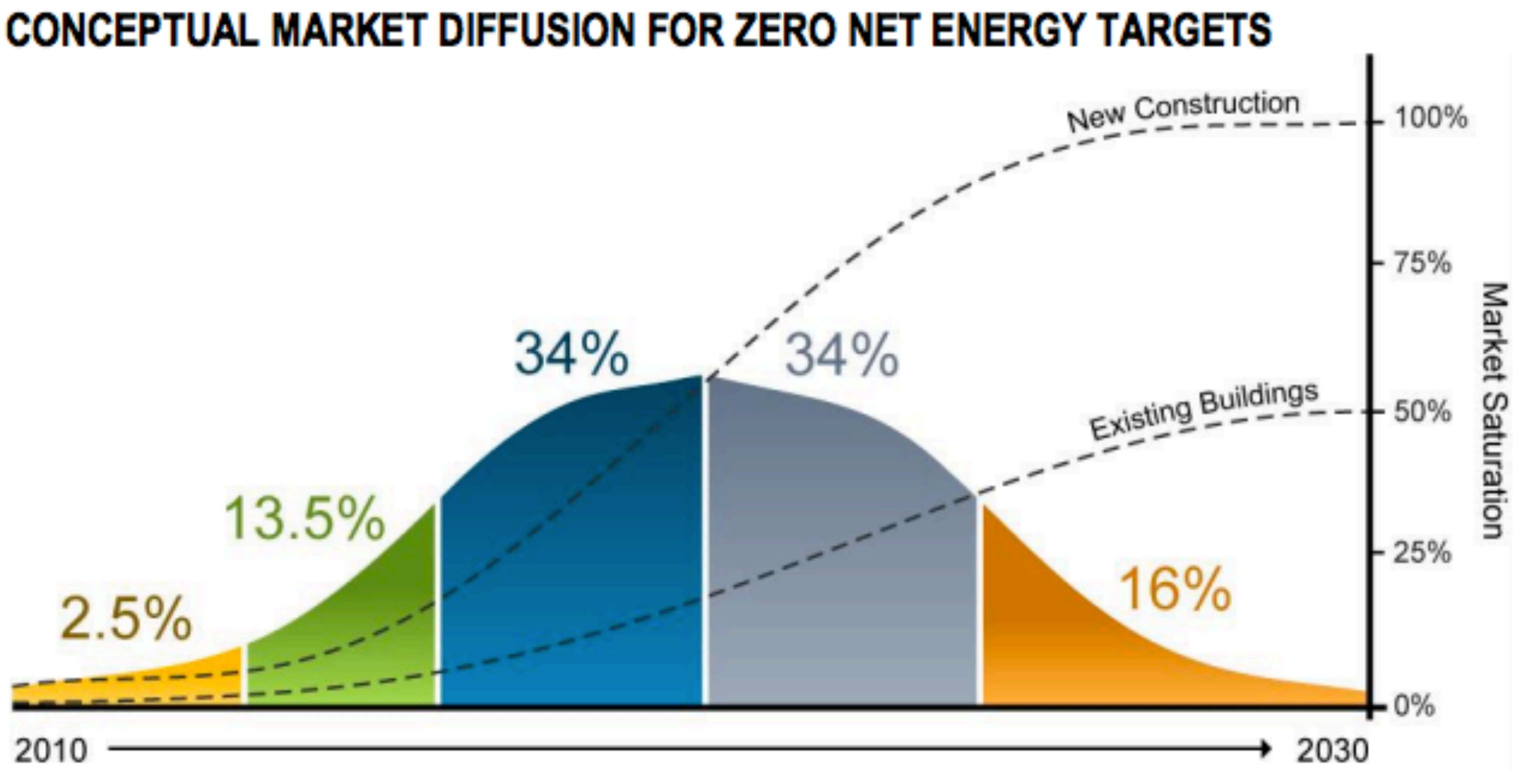
The Reality

- ***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*

California – Test Case



California Path to Net Zero by 2030



Innovators
1-4/1-5: Innovative Finance Tools & Incentives

Early Adopters
1-3: Path to Zero/ZNE Pilots
1-6: Integrated Design
2-6: Existing Building Finance Tools
2-8: Plug Loads

Early Majority
2-1: Lead by Example
2-4: Benchmarking
2-5: Business case
2-7: Integrated Energy Management

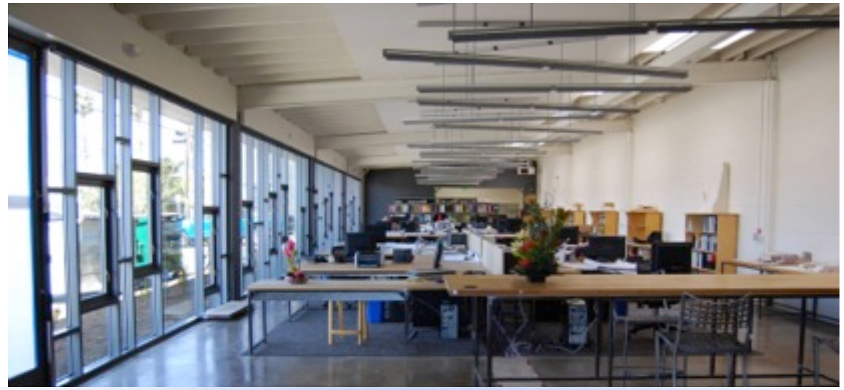
Late Majority
2-2: Codes for Existing Buildings

Laggards
1-1: ZNE Codes
1-2: T24 and T20
2-3: Code Compliance

Zero Net Energy Buildings in California: Commercial Buildings

60 ZNE commercial buildings since 2007*

DPR Construction San Diego Corporate Office , Chip Fox



Bacon St. Offices, SDG&E & Hanna Gabriel Wells Architects

SMUD East Campus Operations Center, Doug Norwood

- Building Size
- Building Type
- Design Team Skill
- COST

- Analysis performed by New Buildings Institute. Includes ZNE Ready and Near ZNE buildings. Not all verified.

Current Dialogue re: CA ZNE Building Goals

- Are the current ZNE goals the right goals?
- If not, how should they be changed?
  - Building type, timing,….
- What should be the various role of the state agencies and teams to address / advance ZNE Comm goals?
  - In utility programs? (~$1B/yr)
  - In CPUC Updated Strategic Plan?
- Role of Mandatory Standards?
- Role of Utility Incentive and Rebate programs?
- Role of Training and Education: Designers, Contractors,…?
- **Role of Innovation and R&D…**
  - **Efficiency but also Risk, Cost**

Building Innovation "Game Changers"

MATERIALS AND SYSTEMS

- **Smart Glass/Dynamic solar control**
- **High R Windows, Insulation**
- **Thermal Storage- Envelope, structural**

- **>200 lumen/watt lighting**
- **Daylight integration**
- **Dimmable, Addressable Lighting Controls**

- **Task Conditioning HVAC**
- **Climate Integrated HVAC**
- **HVAC vs comfort and IEQ**

- **Miscellaneous Electrical Loads**

- **Demand Response**
- **Controls infrastructure- sensors, networks**
- **Building- and Grid- Smart electronics**
- **Electrical Storage**

SYSTEMS: IT, 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/Behavior
- Facility Operations


N
San Gabriel Mountains
Santa Monica
Mountains
Hollywood
LAX
Chino Hills
Disneyland
Santa Ana
Mountains
Long Beach
Naval Shipyard
Los Angeles, CA

1/3 of the Planet Lives Off The Grid

Small Changes=> Big Impacts on Lives

Adequate light is a life changing innovation

Luminet.org

Lighting Challenge

Goals:

- **Comfortable, productive, and healthy environments for living and working**
- Economical, Affordable
- Save energy, carbon
- Manage Electric demand, load shape

Functionality:

- Deliver right amount of light, right quality of light, to the right place, at the right time.

Lighting Challenges

- **Lighting and People**
  - Performance
  - Health
  - Comfort
- **Lighting and Buildings**
  - Light Sources/Fixtures
  - Lighting controls
  - Daylight
  - Systems Integration
- **Lighting and the Electric Grid**
  - Load shape, Peak demand
  - Responsive loads
- **IMPLEMENTING ACTION:**
  - Change people, their "needs" and their "actions"
  - Change technology

~ 100+ years: Generation of Light
(Efficacy: lumens/watt)

- **Sunlight, Daylight** 80-150 l/w
- **Open flame:** candle, whale oil, kerosene, gas < 1 l/w
- **Filament lamp:** incandescent 5-15 l/w
- **Gas Discharge:** Mercury, Fluorescent, HID,
  Sulfur, Plasma 30 - 140 l/w
- **Solid State Electronic**: LED, OLED 60 – 200 l/w
- Filtered Sunlight/Daylight 120 - 200 l/w

Two Lighting Technology Pathways

- **Electric Light Sources - Solid State Lighting Technology**
  - Light Emitting Diodes, LED (point sources)
  - Organic Light Emitting Diodes, OLED (planar sources)
  - Features:
    - **Scalable Lumen packages**
    - **Directional control**
    - **Dimming control**
    - **Color control**

- **Electric Lighting Control: Any source; control for:**
  - **On-off**
    - Schedule
    - Occupancy
  - **Dimming**
    - Lumen maintenance
    - Tuning Light level
    - Daylight responsive
    - Demand response

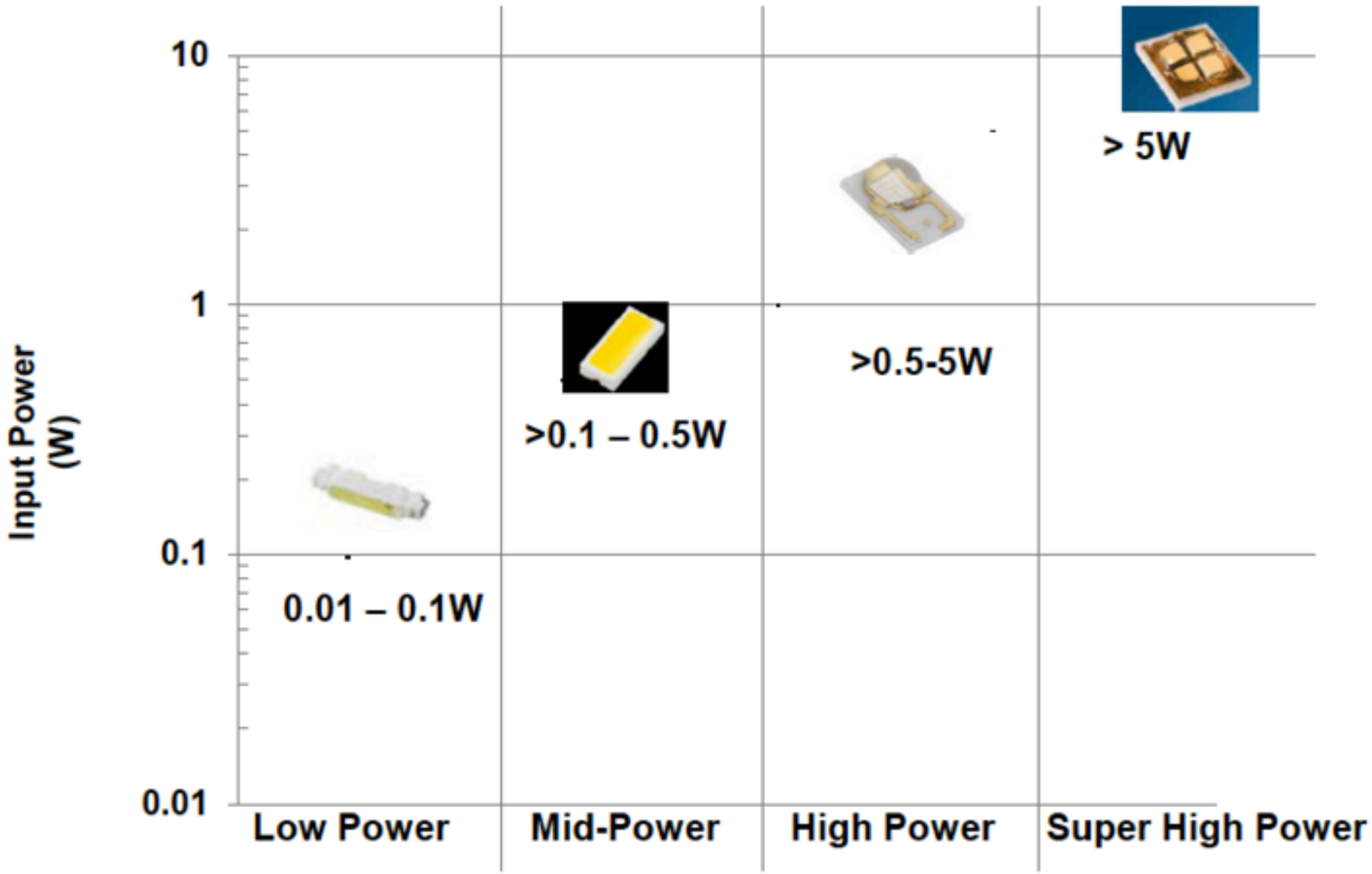
Two Lighting/Building "Systems" Pathways

- **Integrated Building Systems - Envelope and Lighting/Daylight**
  - **"Design for daylight" – façade design: glass, shading,…**
    - Energy
    - View
    - Spectrum
  - **Lighting vs Cooling; View vs Glare**

- **"Internet of Things" / "Internet of Everything" –**
  bringing reliable, low cost optimization to system performance
  - Low cost, distributed, ubiquitous devices
  - Sensors, Actuators
  - Communications (wireless)
  - Intelligence

LED Chip Evolution
Chip → Lighting System

Substrates → Die/Chip → Packaged LED → Module/ Engine → Lamp/ Luminaire → Lighting System



LED Costs are Dropping Rapidly
(faster than expected just a few years ago)

Retail Consumer Prices ($US)

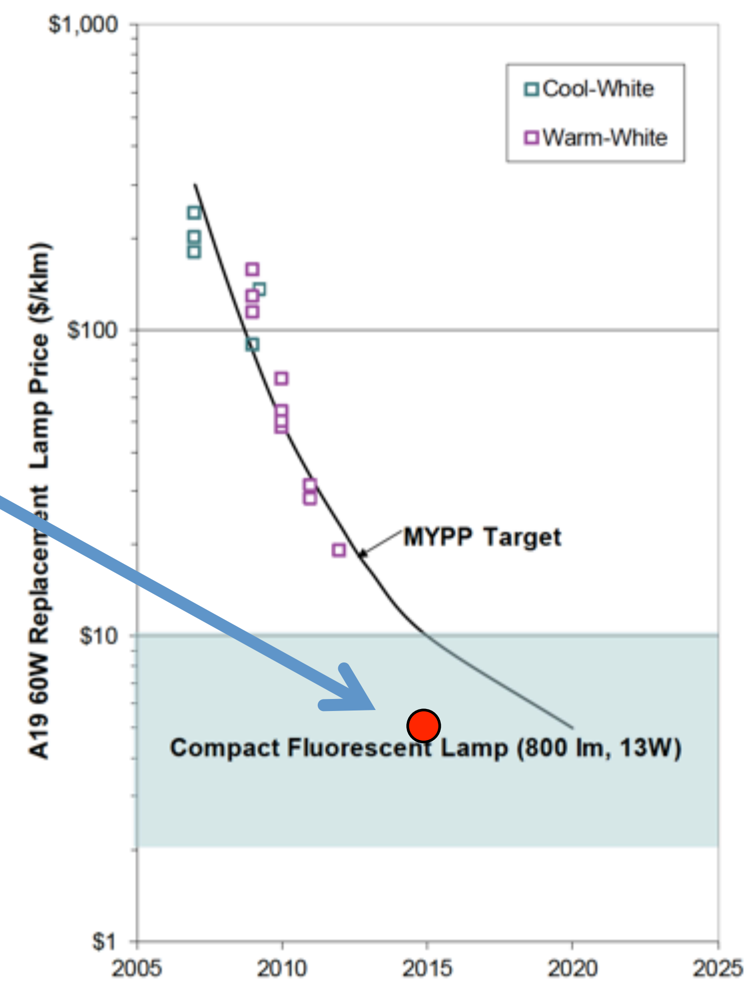


FIGURE 2.6 A19 REPLACEMENT LAMP PRICE PROJECTION (60W EQUIVALENT)
Note: The shaded region illustrates the price range for a typical equivalent performance CFL (13W self-ballaste
CFL, non-dimmable at bottom, and dimmable at top).

Law

Innovation Driven by Massive R&D Investment

Estimated Worldwide LED/SSL R&D Spending, 2012

LE 3.10 ESTIMATED WORLDWIDE LED-BASED SSL R&D SPENDING IN 2012 [32] [33]

Country	Total R&D Spend ($ million)	Government R&D Spend ($ million)	Government SSL R&D Spend ($ million)
USA	436,000	125,700	21
Europe	338,100	118,000	40
China	198,900	50,000	1,000
Taiwan	22,300	6,700	250
South Korea	56,400	15,000	N/A
Japan	157,600	25,000	N/A

U.S. DOE SSL MYPP

R&D on Inorganic LED: Pubs and Patents
Massive investment in R&D Pays Off

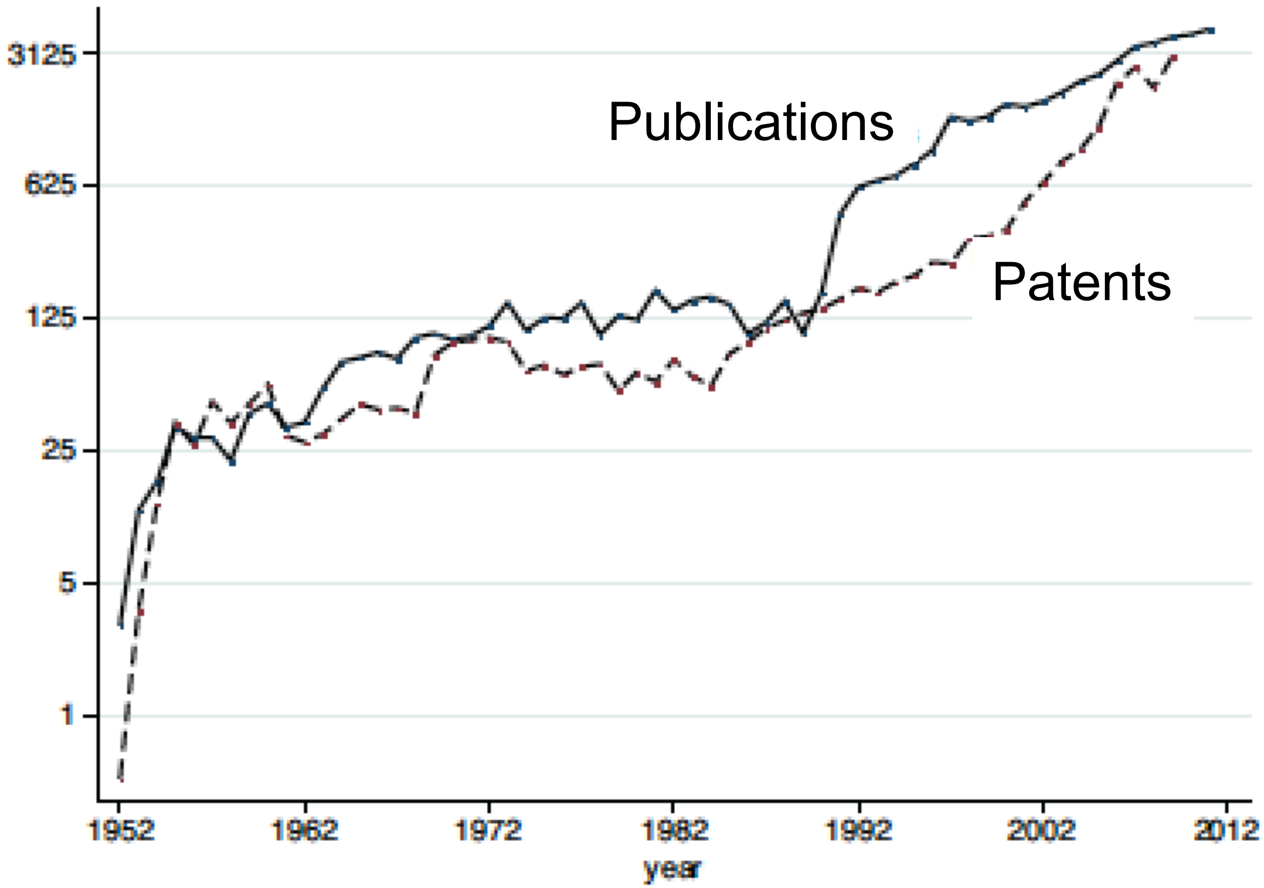


Fig. 2. Inorganic LED Publications and Patents by Year.

Sanderson et al 2014

LED Diffusion by Market Niche

Early markets are high value, niche applications
Building applications, more price sensitive, will follow

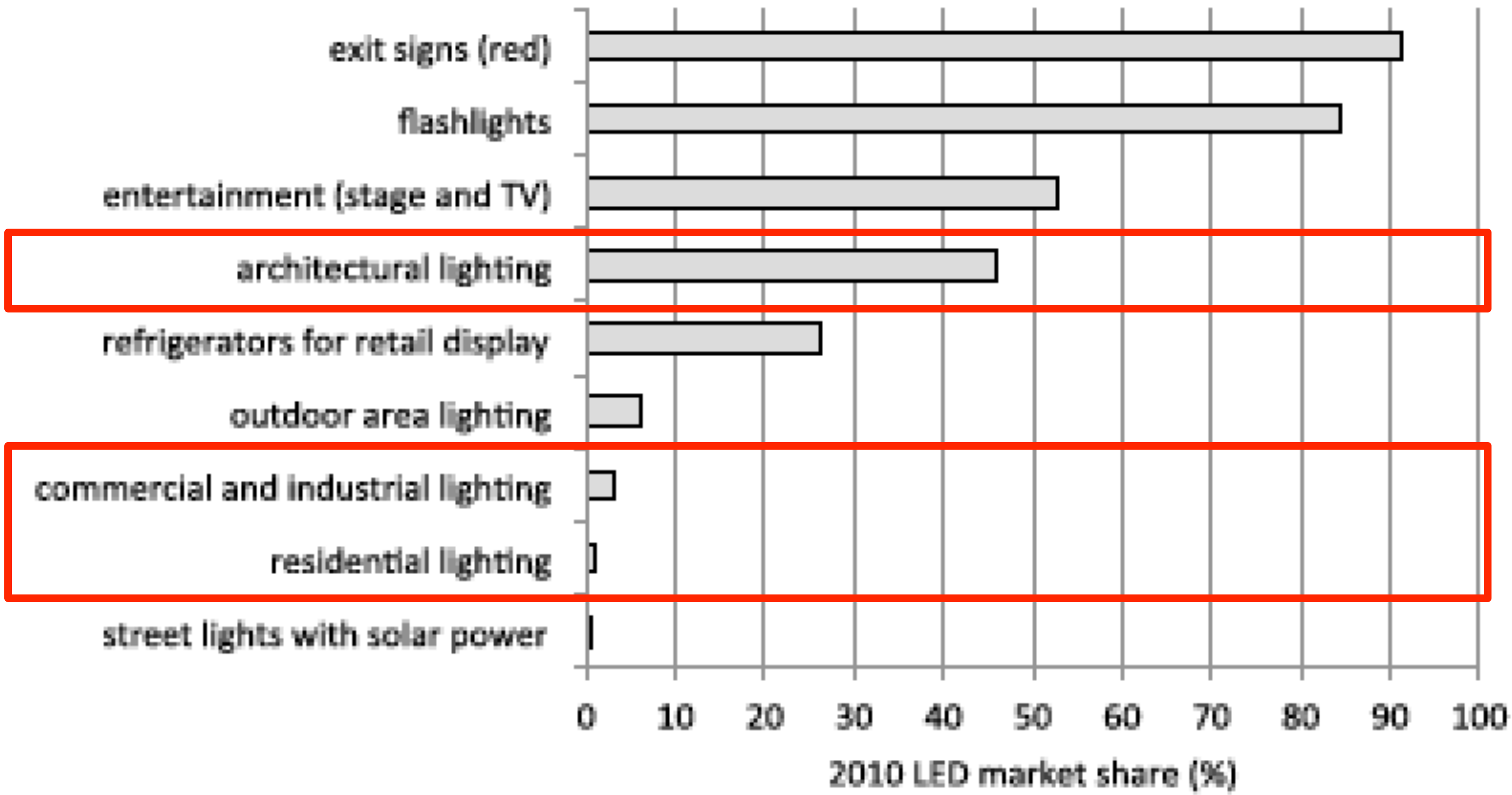
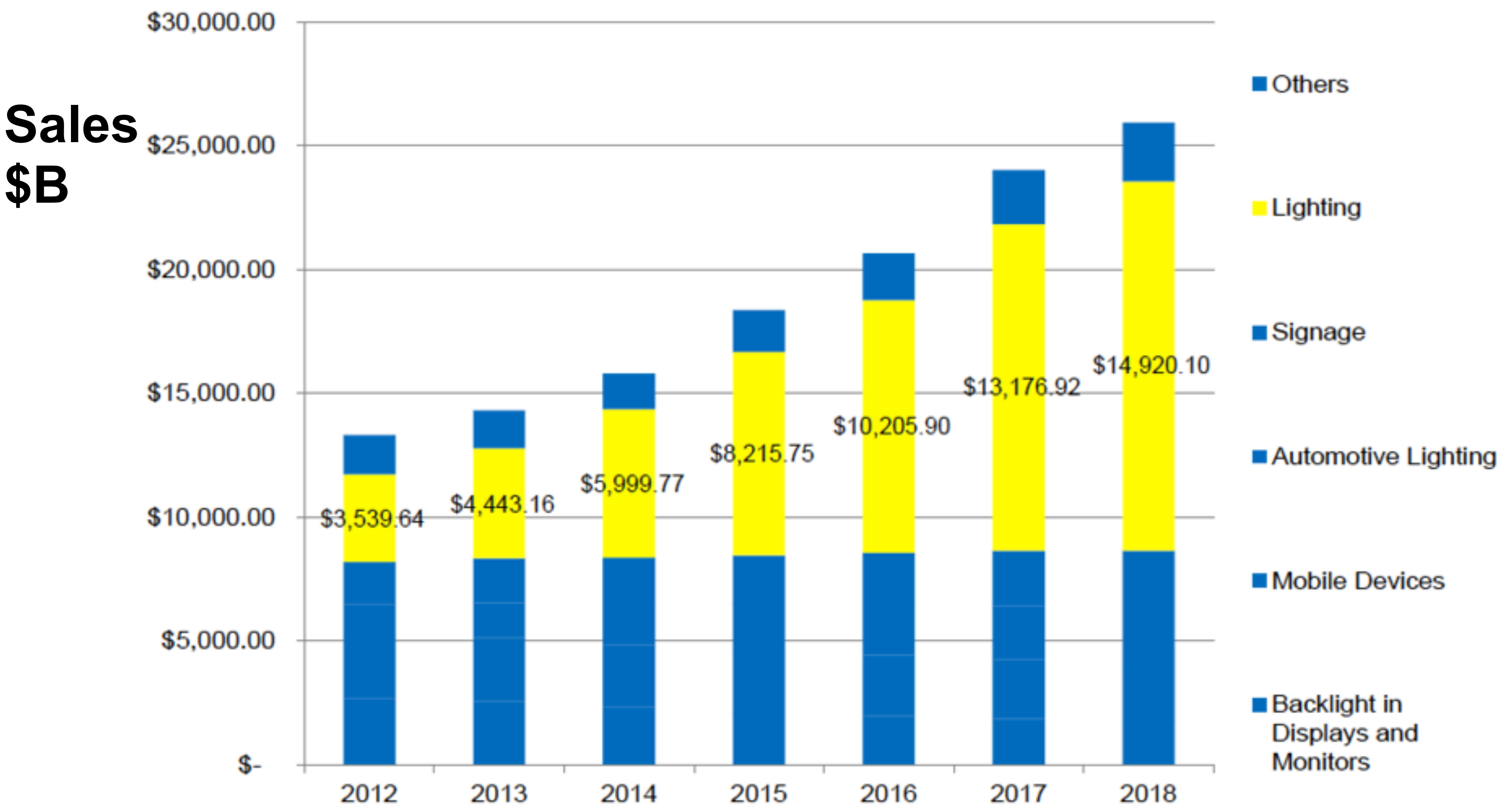


Fig. 1. Diffusion of LEDs by Market Niche, 2010 (estimates from Strategies Unlimited).

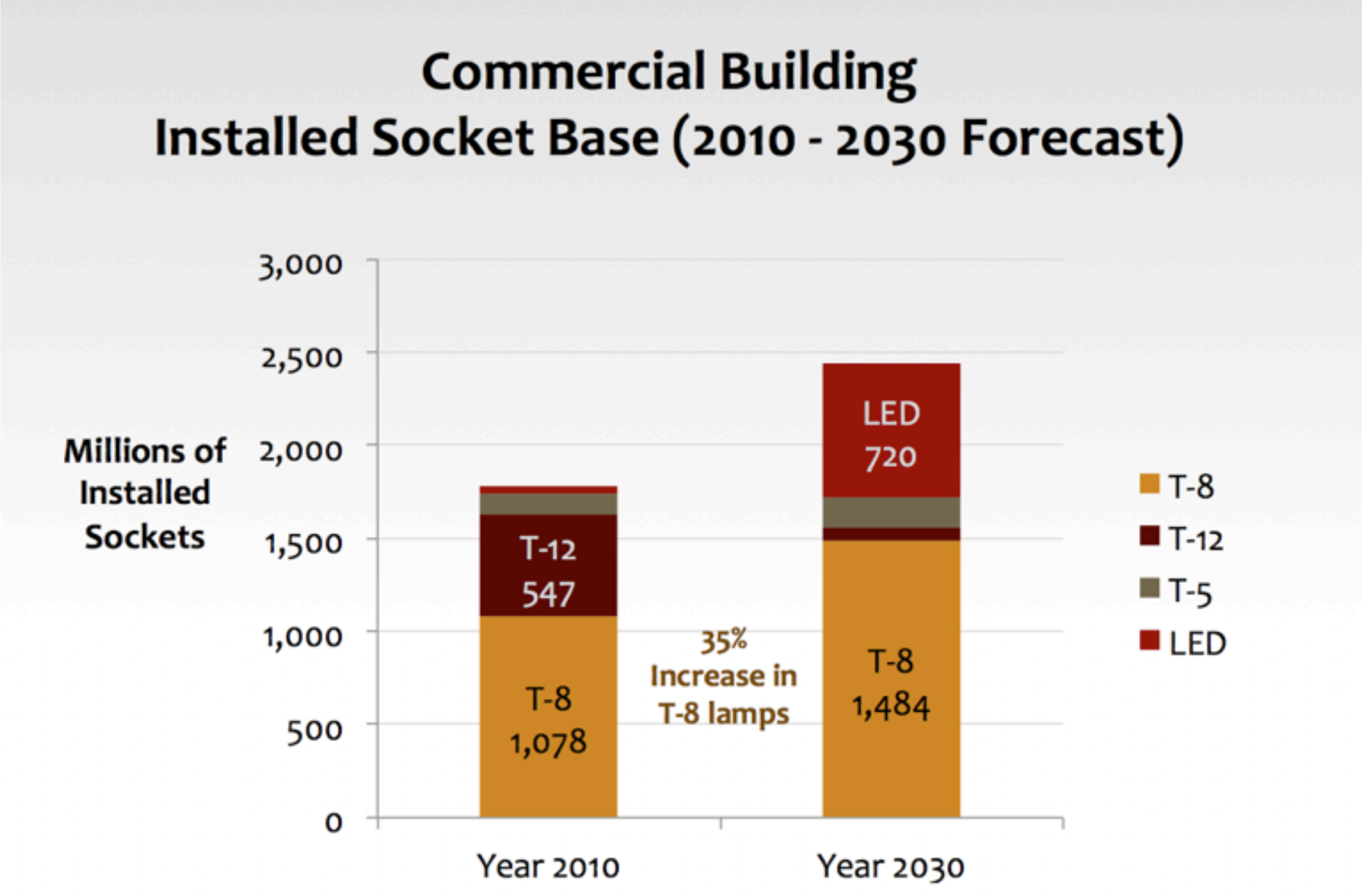
Sanderson et a 2014

LED Light Sales by Sector, Projected



K. Evstratyeva, PennWell

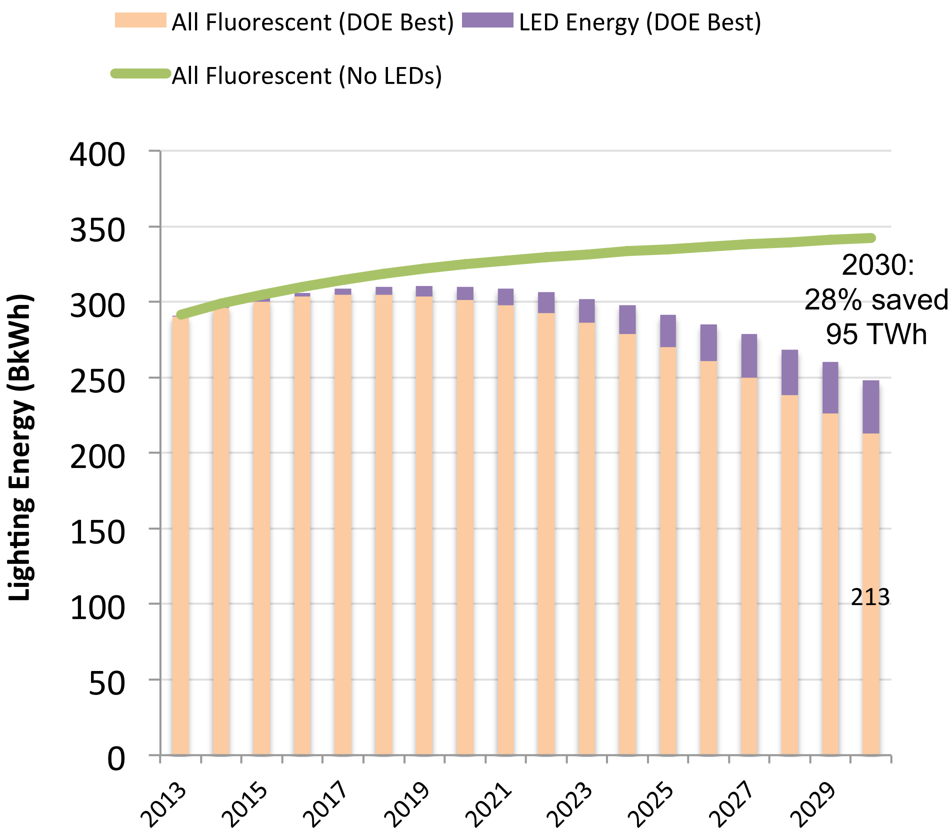
Building Stock Retrofit Challenges:
Moral: Buildings Change Slowly, Aggressive Control of Legacy T-8 Systems will Provide Large Savings



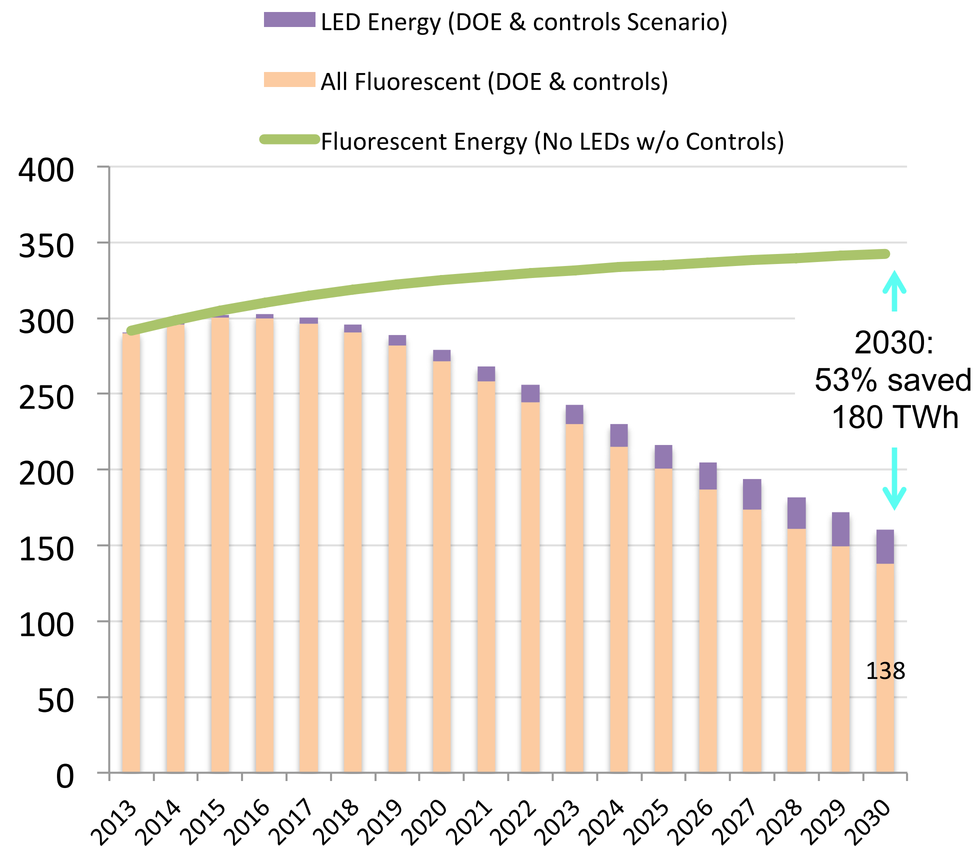
Sources:
1. Lamp projections calculated from DOE Solid-State Lighting Research Multi-Year Program Plan 2013, Figure 2.4.
2. Forecasted increase in commercial sector size 2010 – 2030 is extrapolated from 2003 – 2012 growth rate (1.5% annually)

Impact of Lighting Controls on Energy Use in Linear Fixture Market

No Lighting Controls



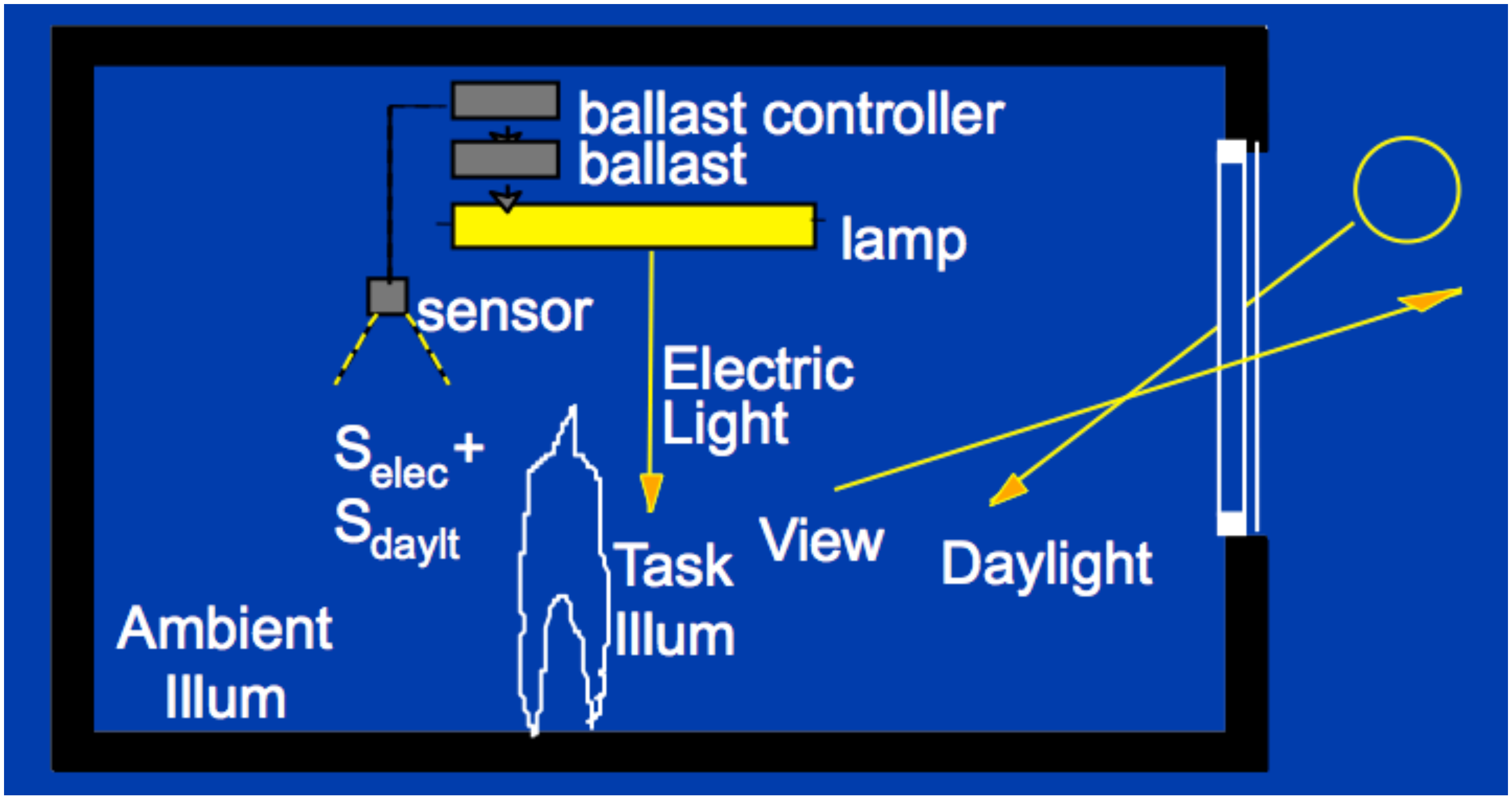
With Lighting Controls



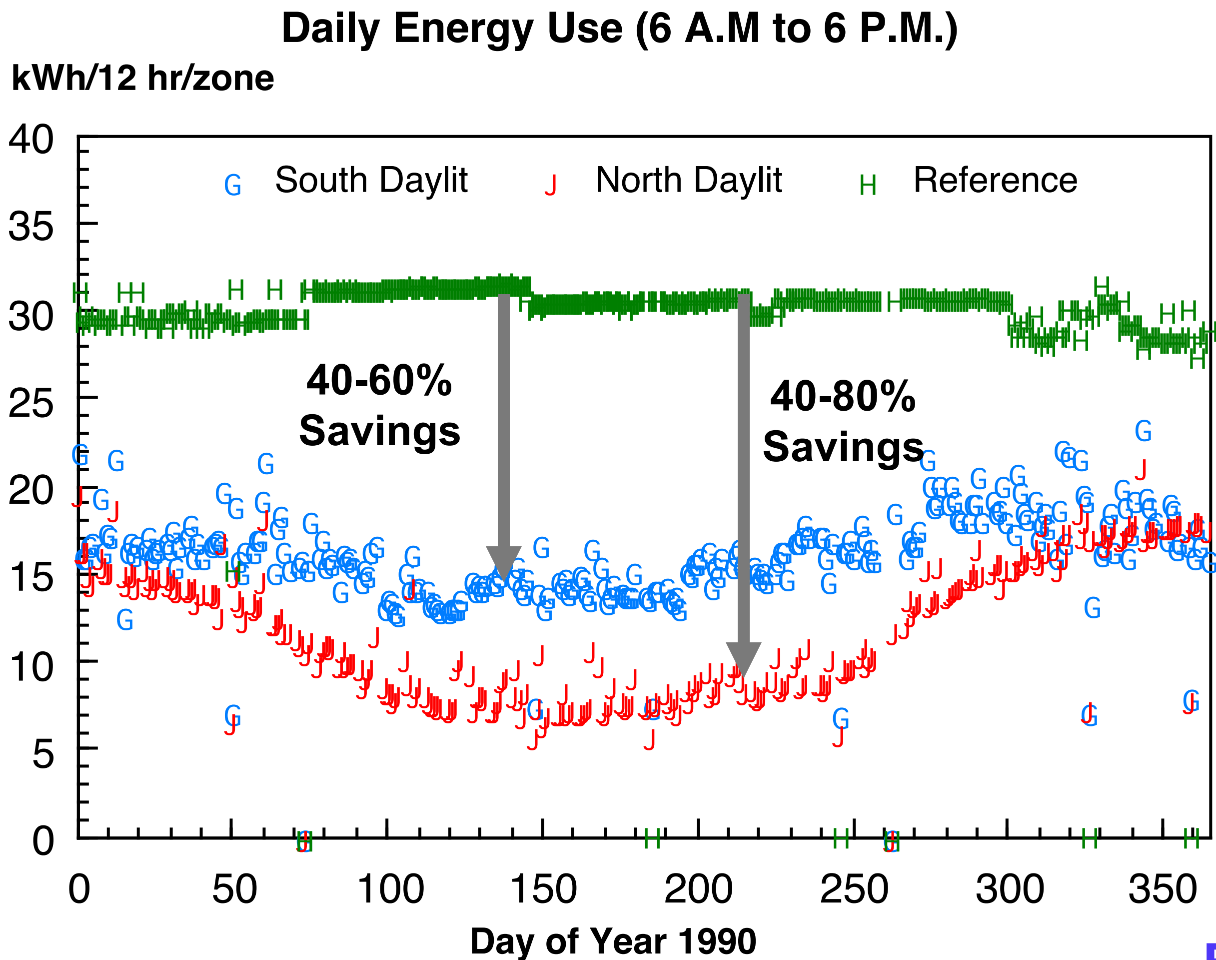
The Most Efficient Electric Lighting Source is the One that You Don't Need Because the Space is Fully Lit with Daylight

(Day)Lighting: 3 challenges

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



Good Lighting Controls (Daylight Dimming) Work



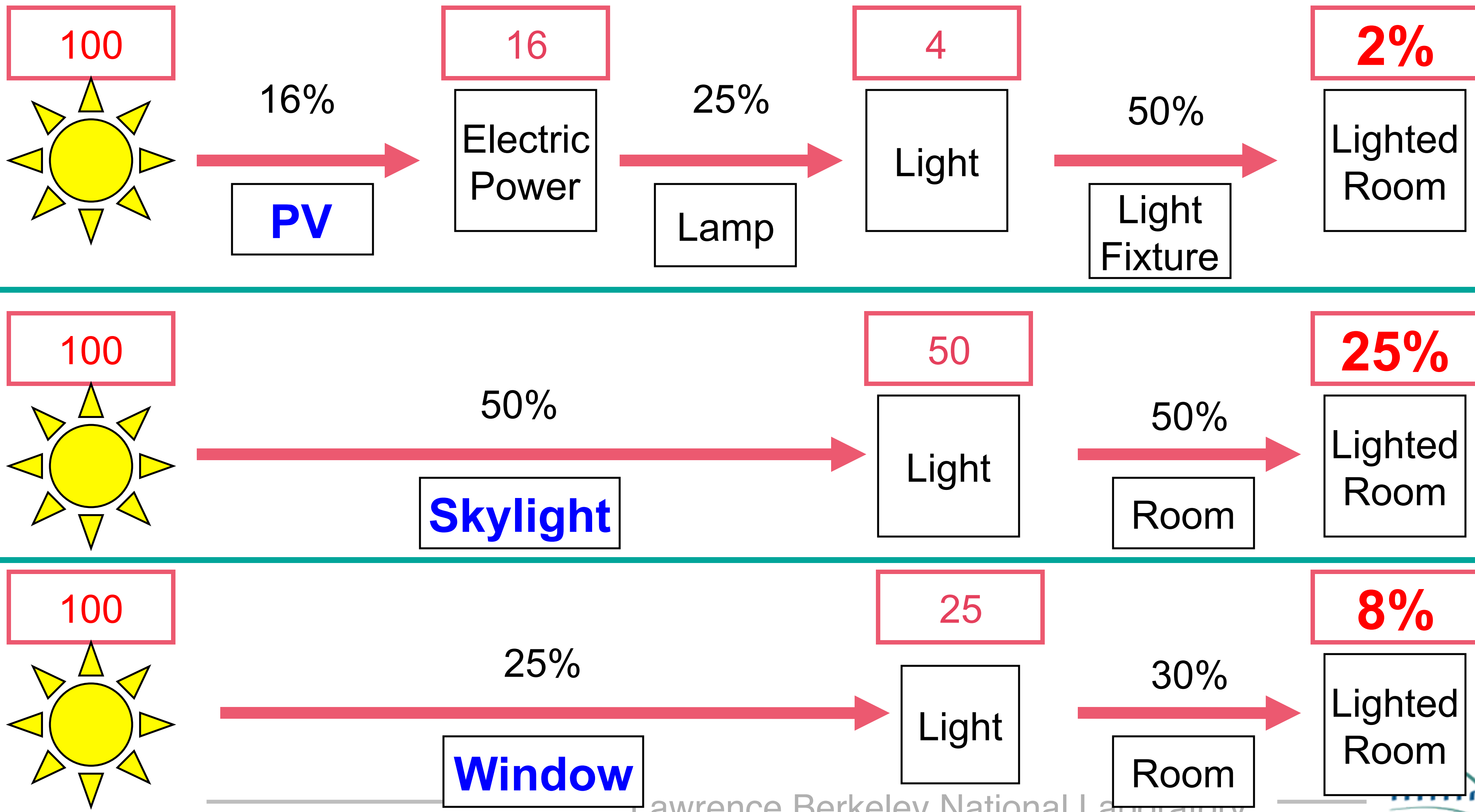
Data from advanced lighting controls demonstration in Emeryville, CA (1990) ← !!!

Energy Use before retrofit:

After retrofit:
South zone:
North zone:

But Dimming is only 3% of lighting sales!

Using Sunlight Effectively?
Electric conversion vs Direct Use



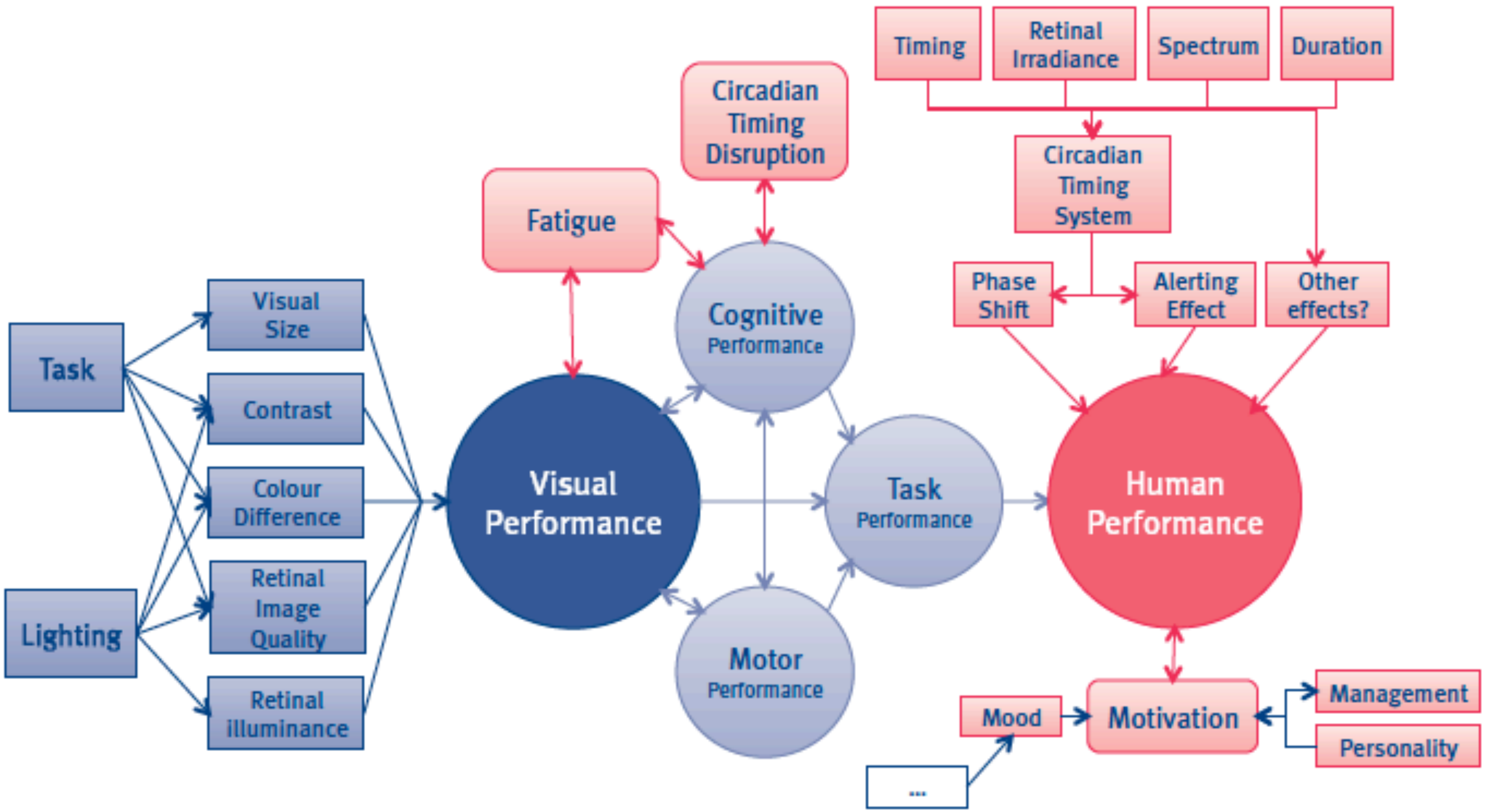
Non- Energy Benefits of Daylight

- **View**
- **Connection with outdoors**
- **Biophilia – connection with nature**
- **Color/Spectrum/Variability**

= Health, Well-being, Productivity,….(??)

- These are real effects, but:
- **Very difficult to attribute a measurable impact to a design variable**

Human Performance and Lighting: Important – but Complex



after Boyce

Annual Energy Costs in Perspective: Occupancy Costs >>> Energy Cost

Cost / Sq. M. Floor -Year

- Energy Cost: $50.00
- Rent/Lease: $500.00
- “Productivity” $5000.00+

Glazing, Windows and Facades: Two Contrasting Views of Energy Efficiency

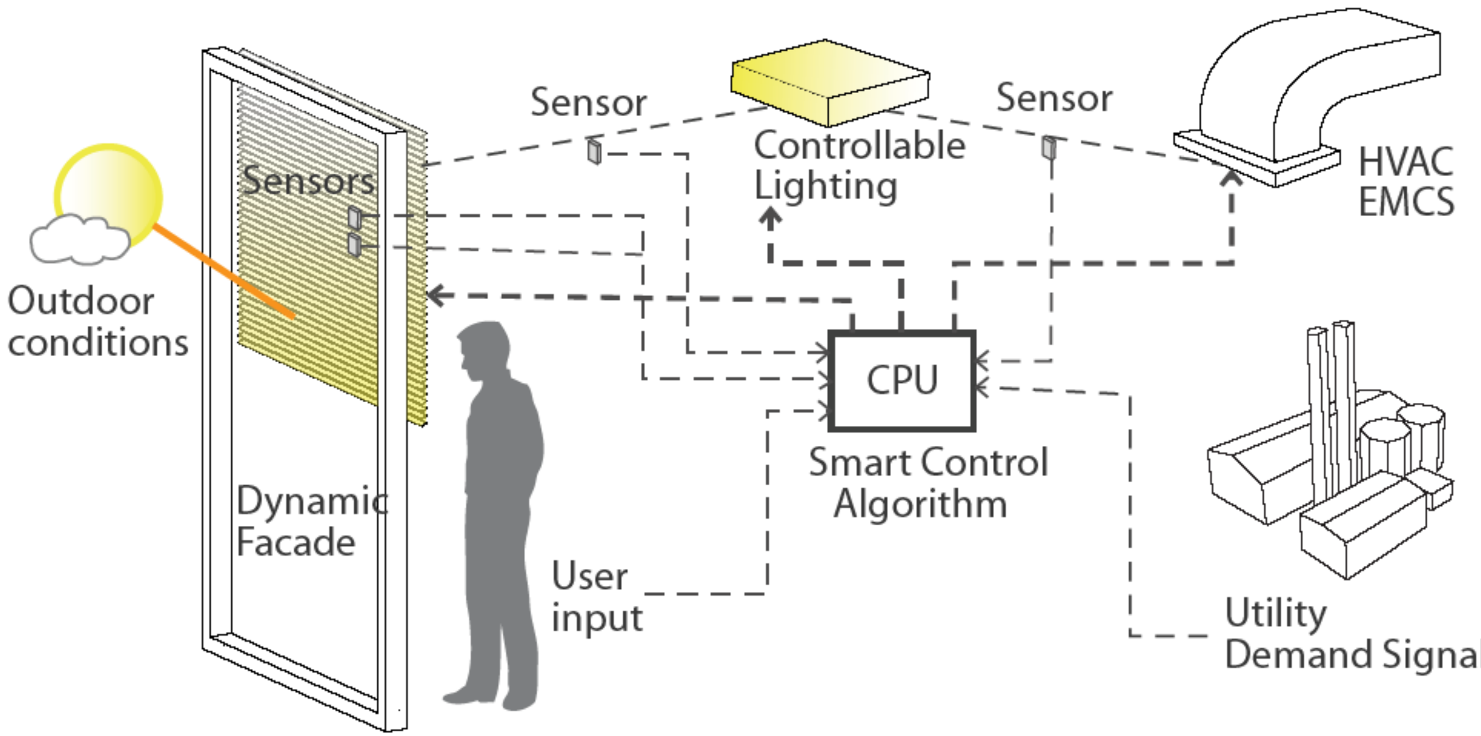
1976 Perspective:
Code Official's View of Ideal Window

2014 Perspective:
Architect's View of Ideal Window

BERKELEY LAB

An "Intelligent" Façade might…..

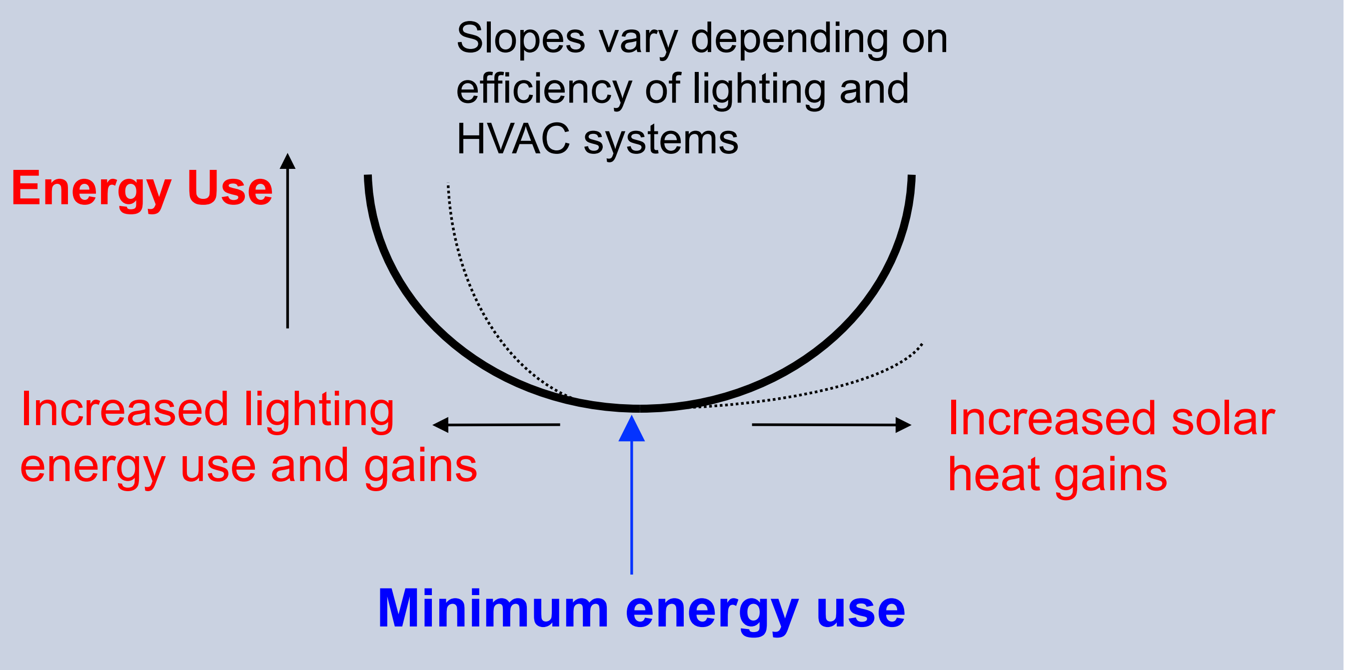
- Manage **thermal loss and gain**
- Provide dynamic **solar control:**
- Provide glare-free **daylight**
- Provide **fresh air** to interior, minimize noise
- **Enhance occupant health, comfort**
- **Reduce demand** on utility
- **Generate power** (photovoltaics)



Optimizing Energy in Integrated Facades

Key parameters

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



Balance Performance issues

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

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

… Its Complicated!!

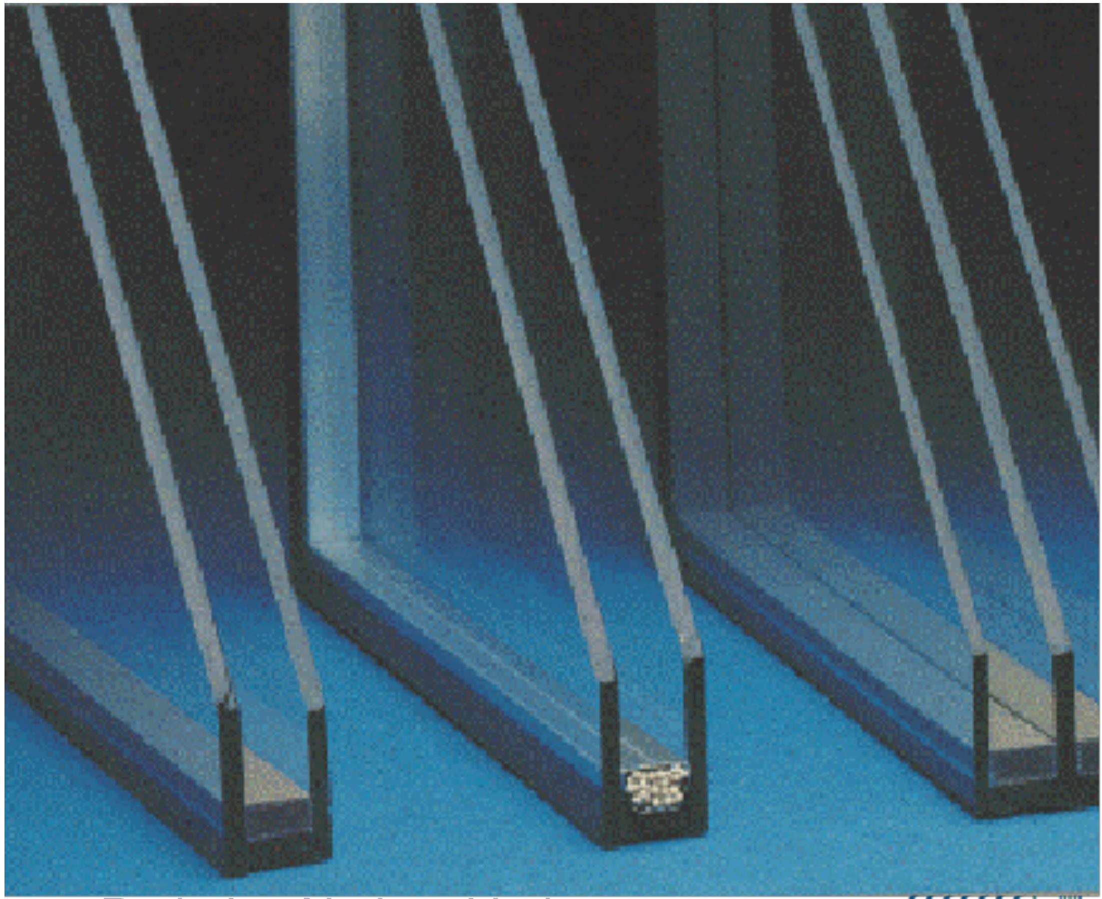
Zero-Energy Window Objectives

Nearer Term Objective: U-value < 0.8 W/m^2-K

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

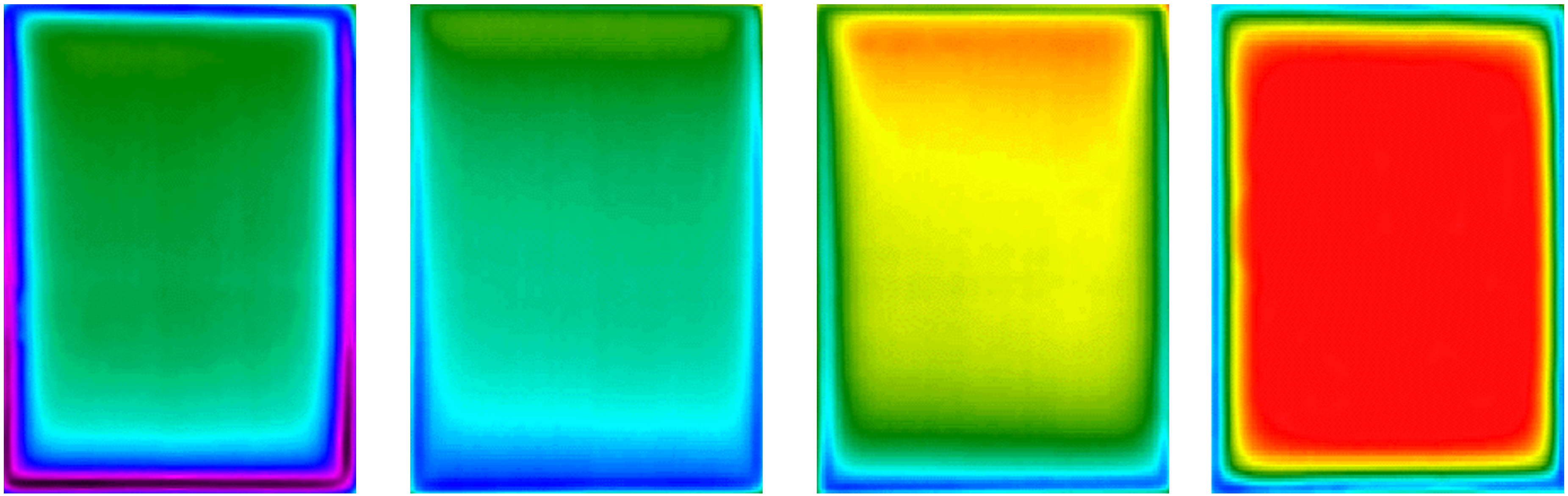
Approaches:

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



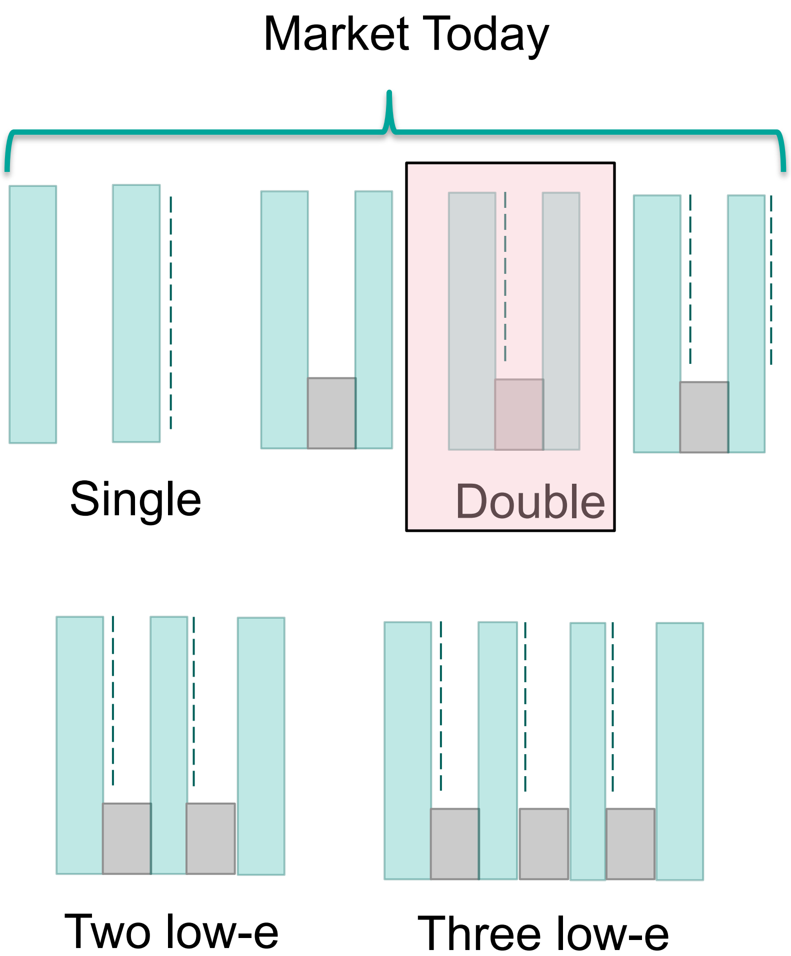
Technologies to Reduce Heat Loss

Dual, Clear, Alum. spacer | *Dual, Clear, Foam spacer* | *Dual, Low-e, Foam spacer* | *Superwindow, 4-lites, low-e, Kr*

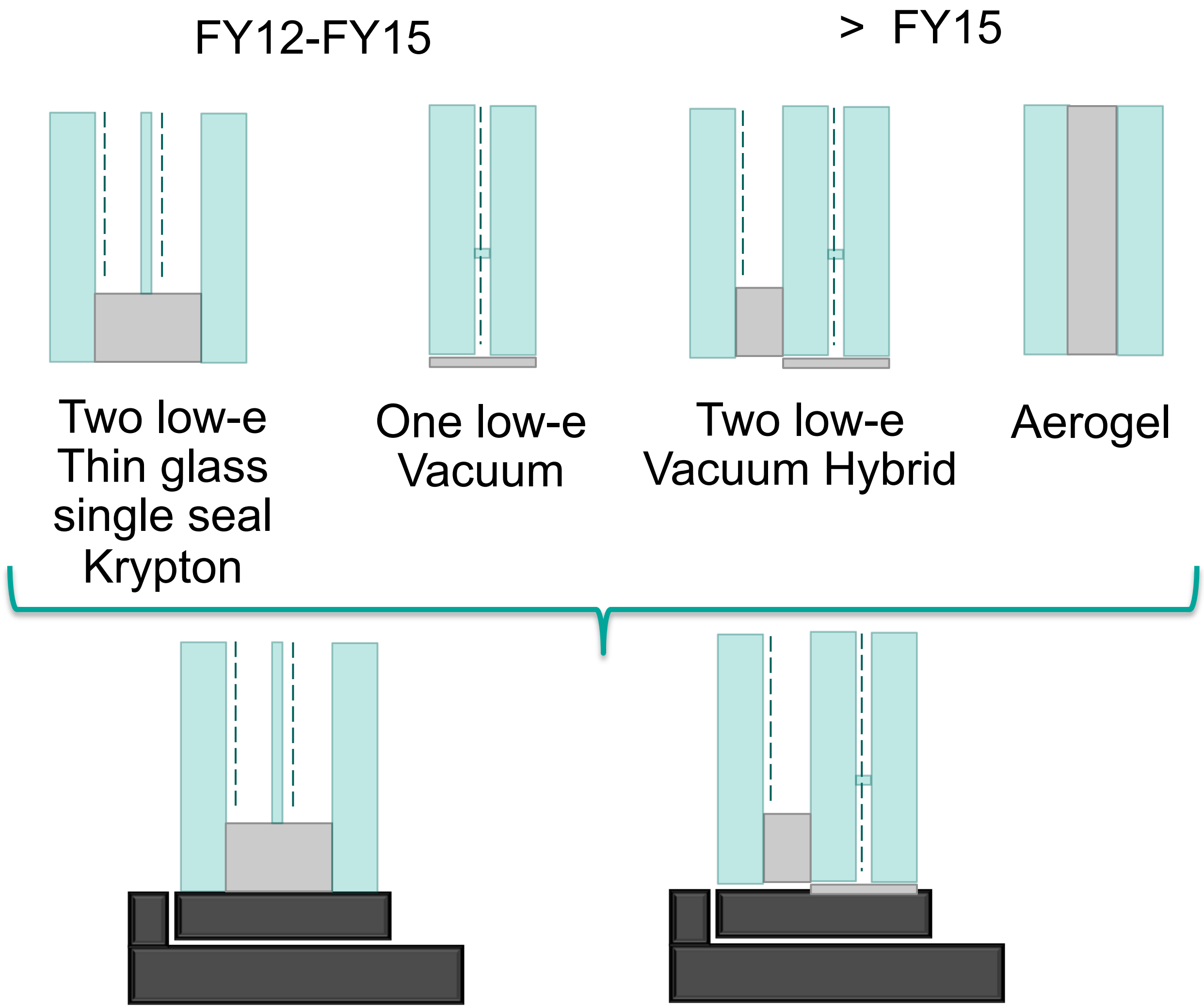


Images from LBNL Infrared Thermography Lab

GLAZING SOLUTIONS: U ~ .1BTU/h-ft²-F



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



Super-insulating frame with highly insulated glazing

Window Coatings as Oil Wells

from the Center for Building Science / Lawrence Berkeley Laboratory

New Energy Supply Technology for the 21st Century

High Tech Window Coatings "Supply" Energy Services

Buildings account for over one third of all U.S. energy consumption. Energy policy has emphasized the development of new secure energy supply options such as off-shore oil. But advanced building technology that effectively reduces the need for current consumption can also be viewed as a supply option.

Consider the following two choices for "supplying" $1 billion of energy services:

Low-E Window Technology

Heat loss from windows is responsible for about 4% of total U.S. energy consumption, or the equivalent of 1.4 million barrels of oil per day. Transparent low emissivity (low-E) coatings provide one third reductions in window heat loss.

This industrial low-E coater (See ***Recipe 1***) can coat over 20 million square feet of glass for windows each year. Savings accumulate rapidly since each window continues to save energy over its entire lifetime, at least 20 years.

Offshore Oil Wells

Oil under the continental shelf is a secure, but environmentally fragile, costly and depletable supply option. (See ***Recipe 2***).

Recipe #1

Low-E Window Technology

Step 1: Invest $8 million in a low-E coating system.
Step 2: Coat 20 million square feet of windows per year for the 10 year nominal life of the coating system.
Step 3: Accumulate energy savings over the 20 year life of the window.

Step 4: RESULT: Savings of 36 million barrels of oil equivalent!

Figure 1

Glass coaters such as this high-rate sputtering system can coat large sheets of glass with sophisticated multilayer coatings for control of heat and light in buildings.
Photo courtesy of Airco Solar Products, Concord, CA.

Recipe #2

Offshore Oil Wells

Step 1: Invest $300 million in a 10 well offshore oil platform, producing 10,000 barrels per day.
Step 2: Pump oil for the 10 year nominal life of the oil field (don't spill a drop).

Step 3: RESULT: Supply of 36 million barrels of oil!

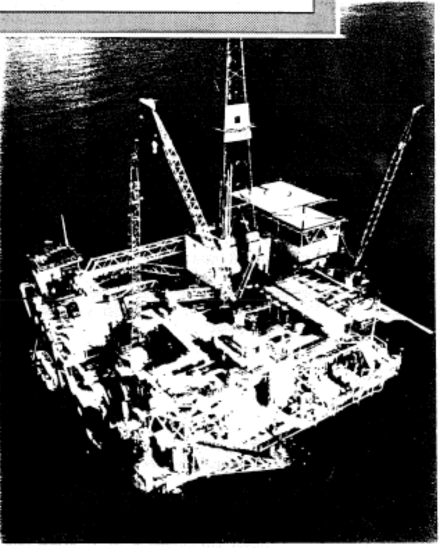


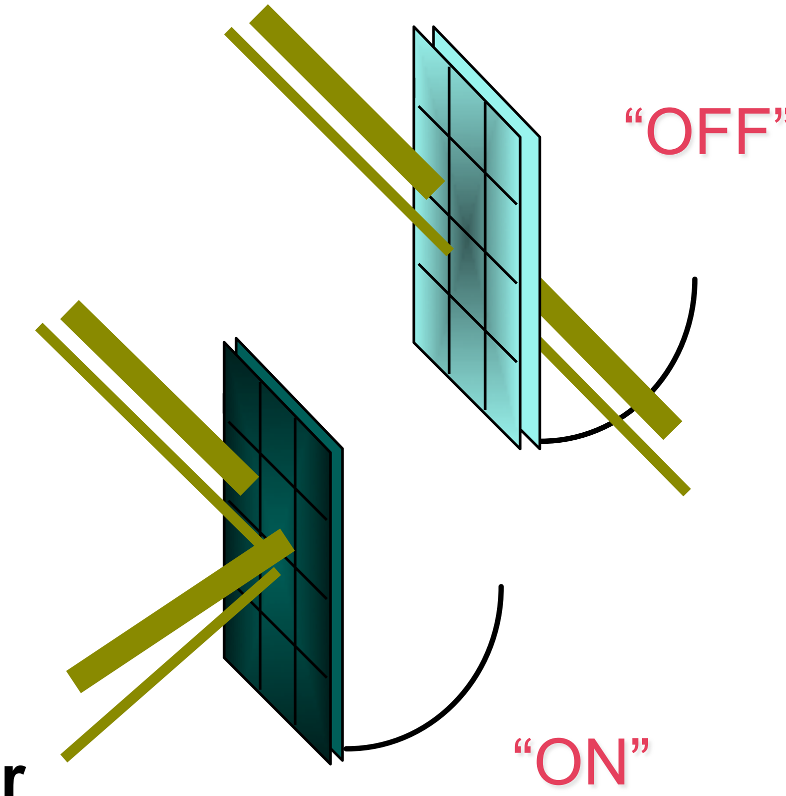
Figure 2

An oil company's 10,000 barrel/day, 700 foot-high, $ 300-million platform off the Santa Barbara, California coast.

Smart Coatings for Dynamic Control of Windows

Balancing Cooling and Daylighting, View and Glare

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



Electrochromic "Smart" Windows:

Progress Towards the Marketplace

Technology, Design, Integration Challenges

Exploring Performance of Integrated Shading/Lighting Control Systems in LBNL Facade Testbed Facility

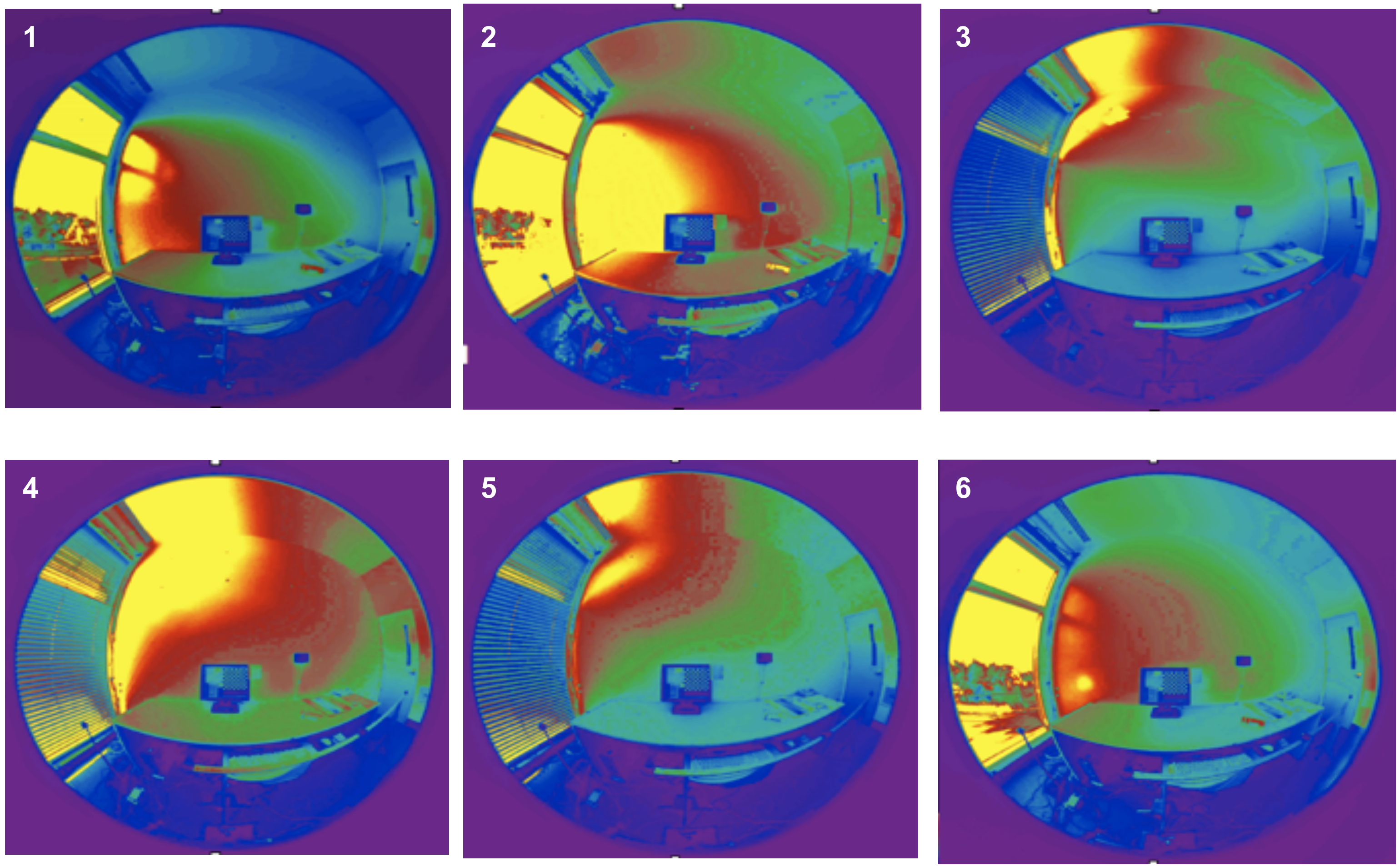
External Dynamic Shading

Daylight Redirecting Glass

Electrochromic Glass

Automated Shading Controls Glare Throughout the Day

Time Lapse from Tests in LBNL Façade Test Facility:
Interior Daylight Luminance Patterns with Dynamic Shading



Getting Integrated Systems Solution That Works at Scale

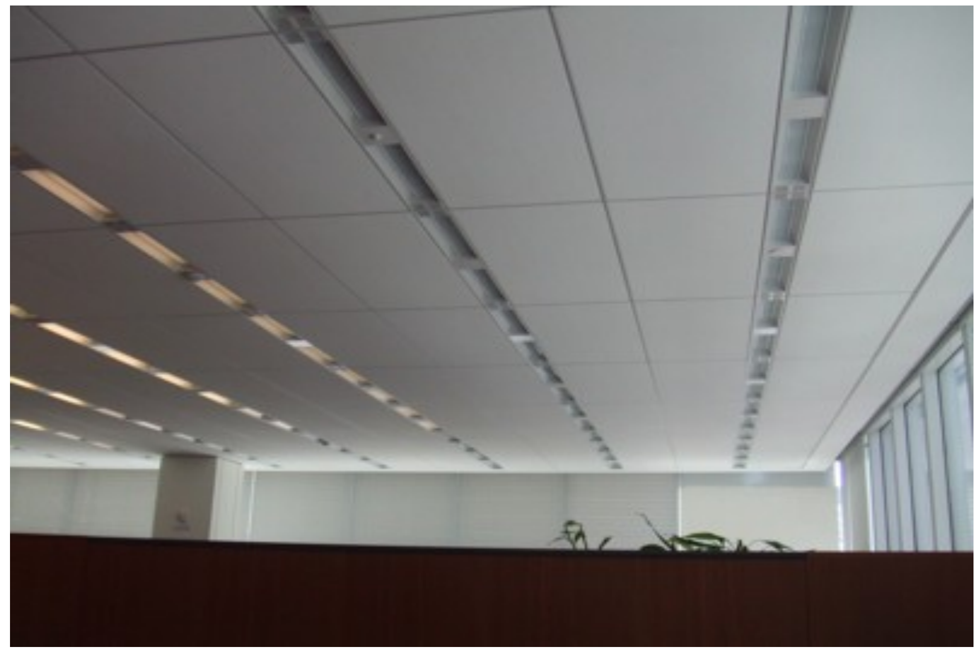
NY Times: Intelligent Lighting, Shade Control, UFAD

Design: 2003;   Field Energy Measurement 2013

- Automated Shaded

Occupied 2007

- Dimmable lighting
  - Addressable
  - Tunable



New York Times office with dimmable lights and automated shading

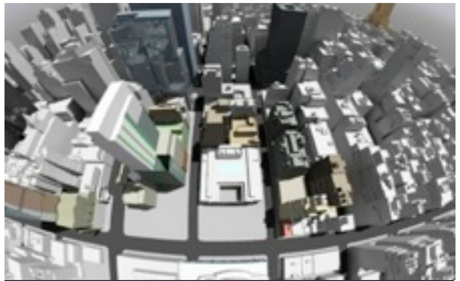
NY Times Testbed: Optimize: Physical & Virtual

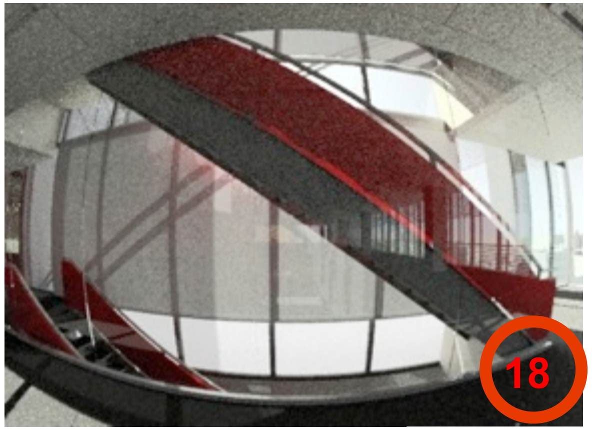
Phase 1: Physical Testbed, 18 month field study

- Evaluate Shading, daylighting, employee feedback and constructability in a ~5000 sf testbed
- Fully instrumented; 1 year testing

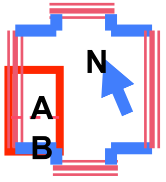
Phase 2: Virtual Model, extend measured data

- Extend Test Data: more Orientations and Floor Levels
- Shade Control Algorithms for Motorized Shades Developed using Simulation
- Built a virtual model of the building in its urban context using hourly weather data to simulate performance





Simulated Views from 3 of 22 view positions



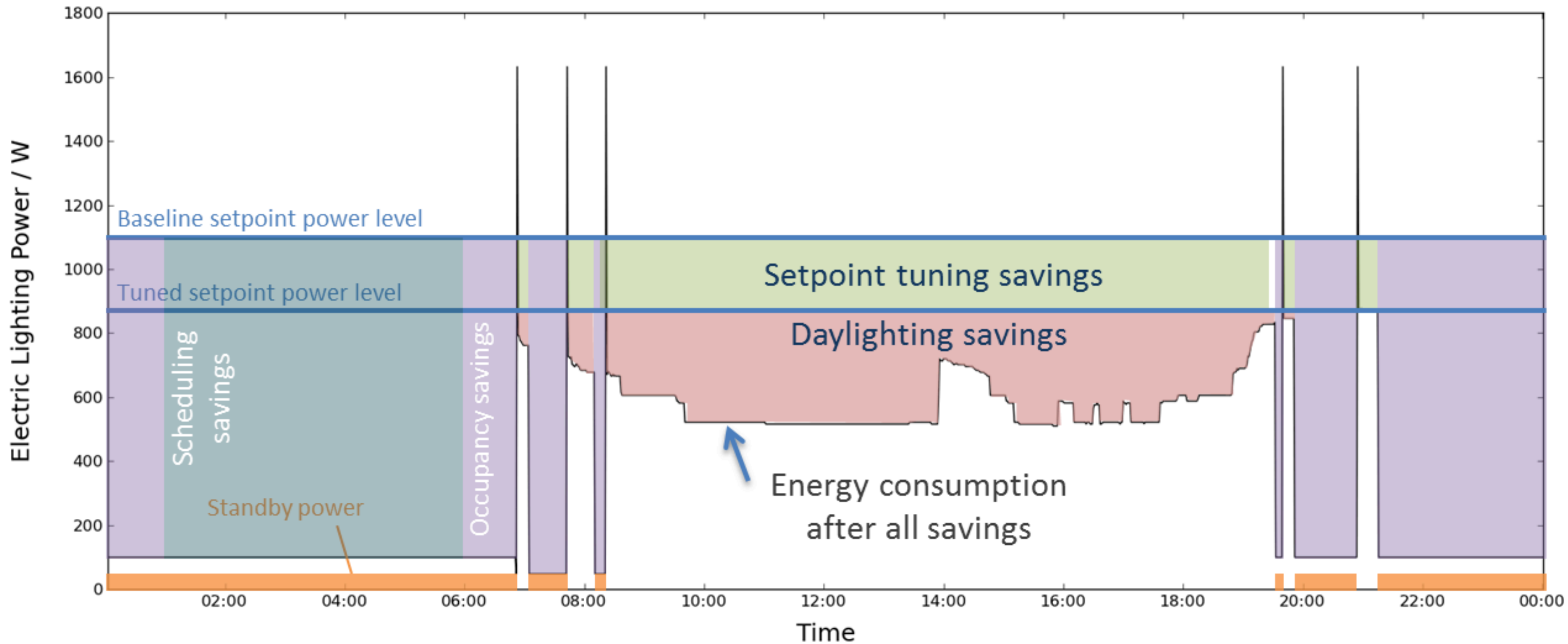
New York Times Building
Energy Monitoring and Post Occupancy Evaluation

Lighting Control Systems:

On/off: Scheduling, Occupancy

Dimming: Setpoint Tuning, Daylight, Demand Response

56% savings vs previous slide



Gadgets and Widgets → Integrated System Design = *Bigger Savings at Lower Cost*

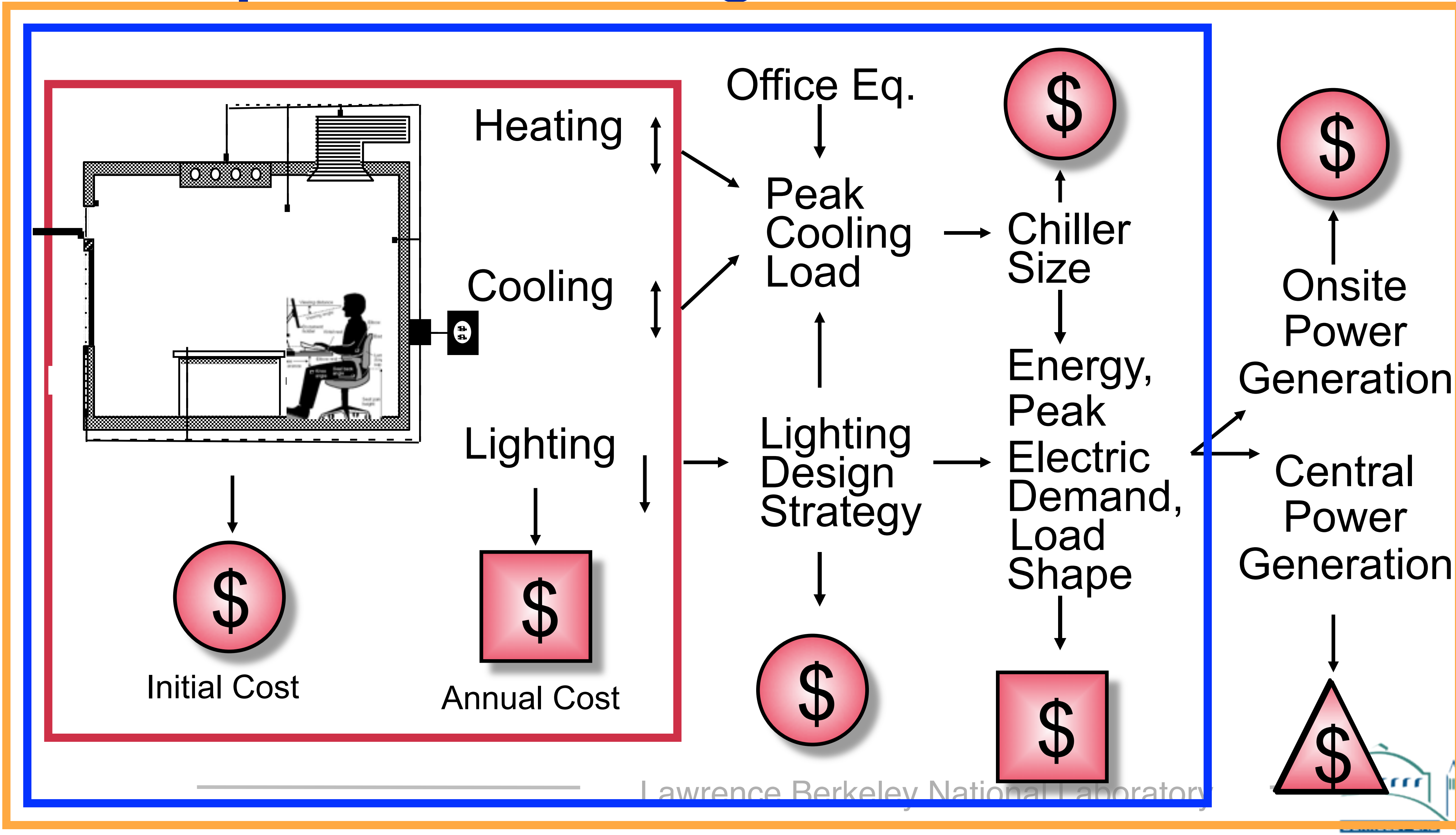
Current Design and Research Paradigm – Silo Approach

Single component or isolated system EEM → 5-20% Energy Savings for the isolated component or system

Integrated Building Systems Approach

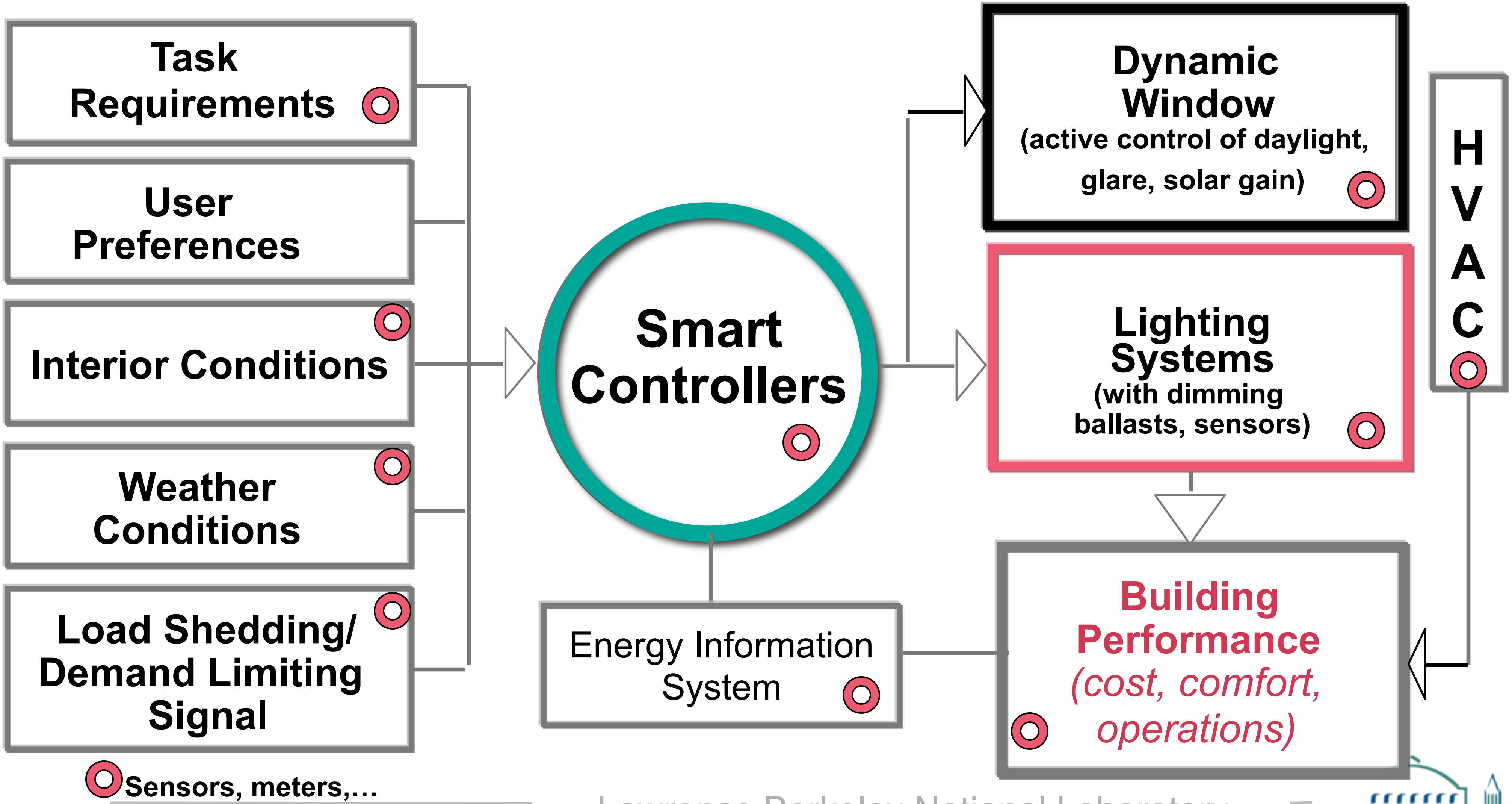
Multi-system integrated EEMs → 30-50%+ Whole Building Energy Savings

System integration → Cost/Risk tradeoffs
People ←→ Buildings ←→ "Smart Grid"

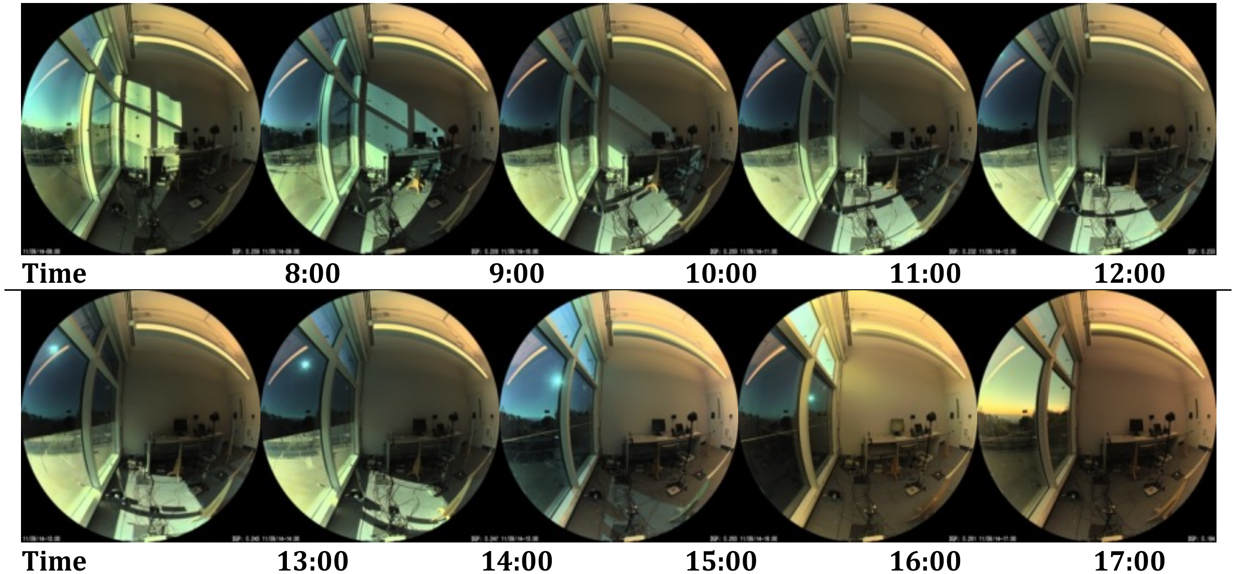


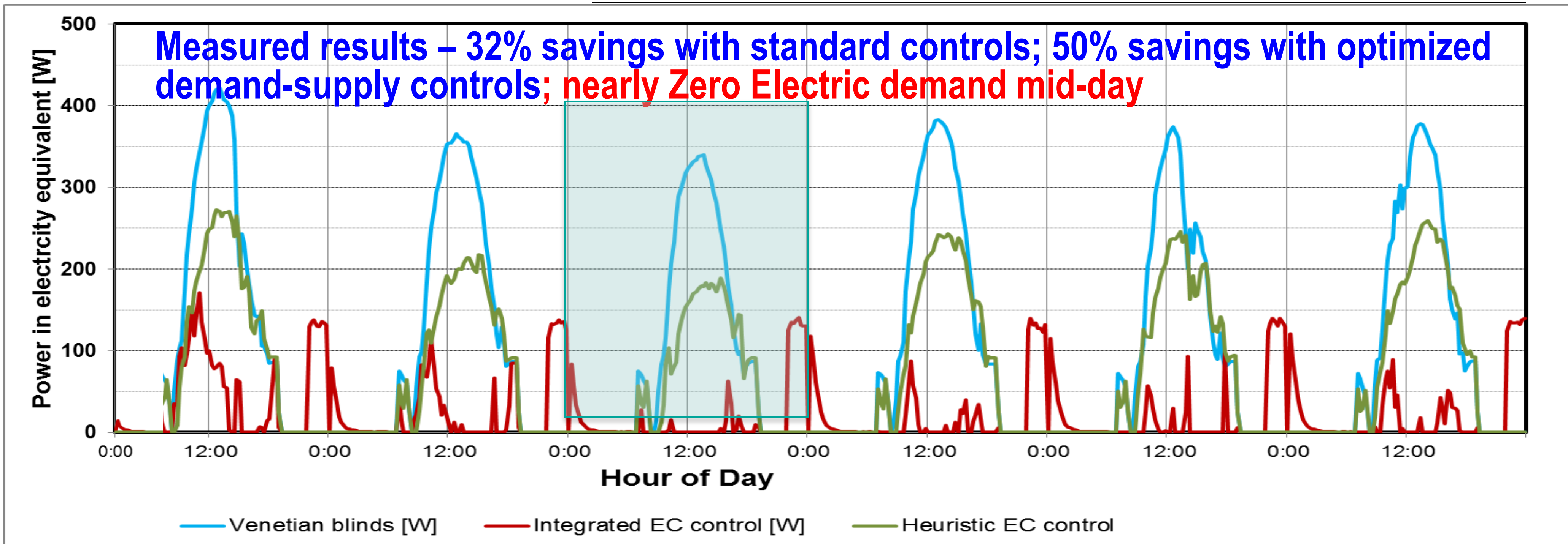
Exploring Intelligent Building Control Systems:

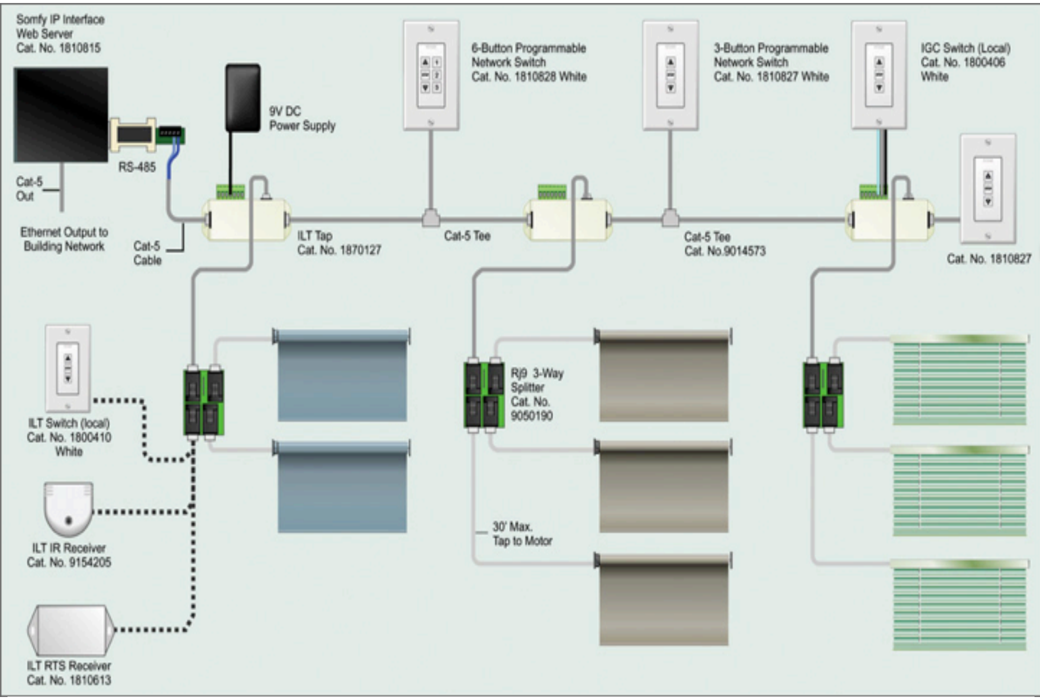
The "Internet of Things" Collides with the Building Industry…

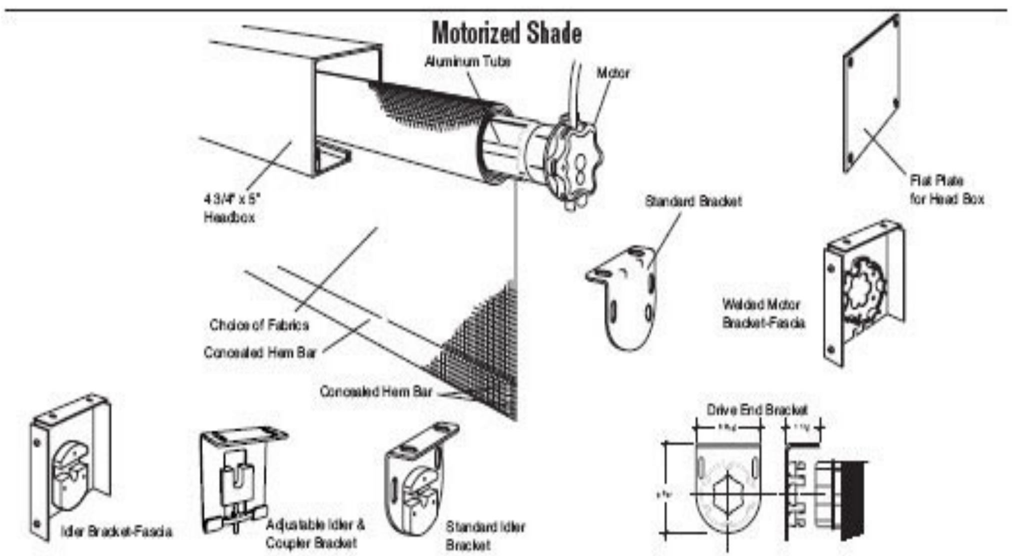


"DC Microgrid":
Electrochromic windows, dimmable LED lighting, 200 W PV, Electric storage









LUTRON

MechoShade The Architect's Choice.™

somfy

perfecta® Retractable Fabric Awnings

sunbrella

LEVOLOR

PHIFER

EST 1973 CASTEC

Qmotion

Electronic Solutions, Inc. A Hunter Douglas Company

NYSAN SOLAR CONTROL

LOUVOLITE

RollEase ENGINEERED TO BE ESSENTIAL

WorldScreen

DRAPER

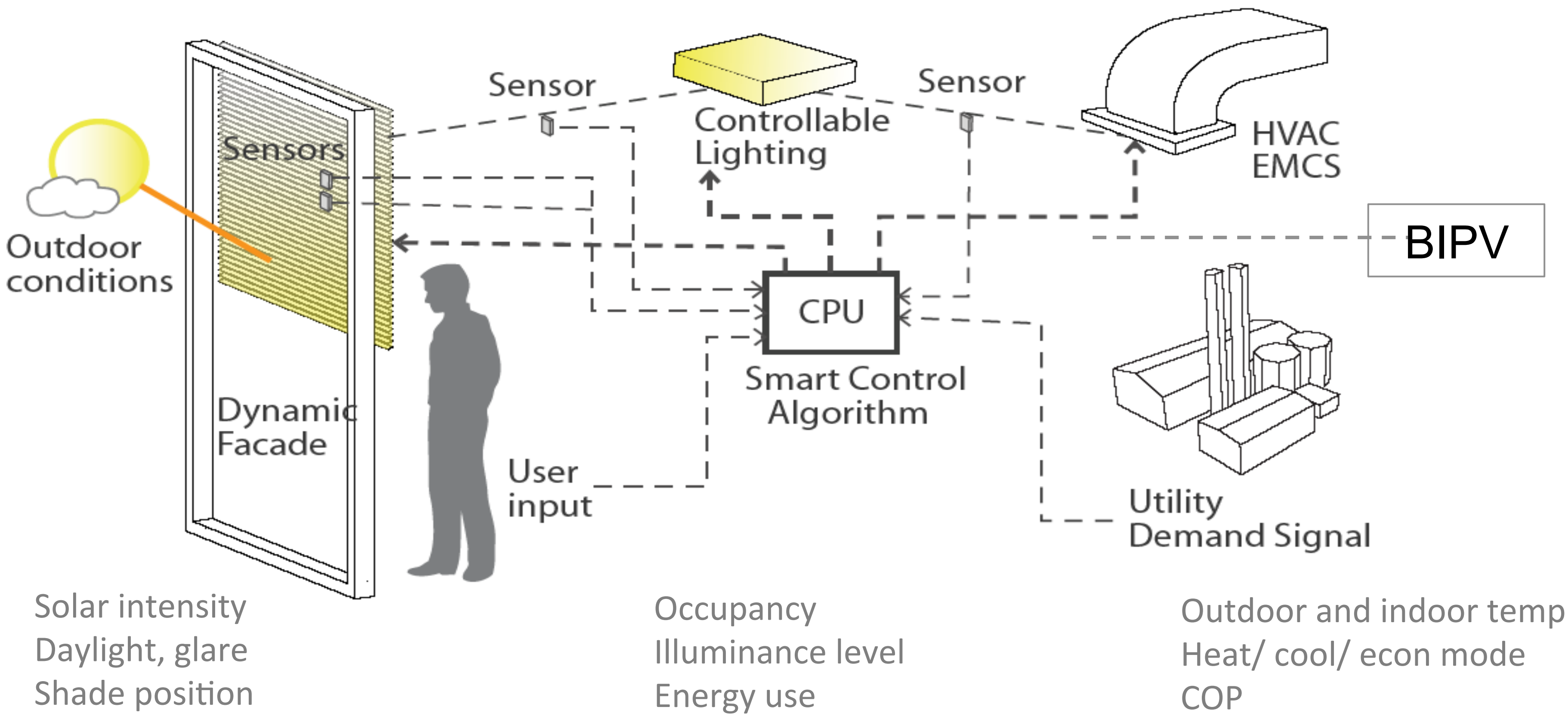
Eastern Awning Systems, Inc. The Best Awnings Under the Sun

HunterDouglas

The Integrated Façade/Lighting System "Challenge"

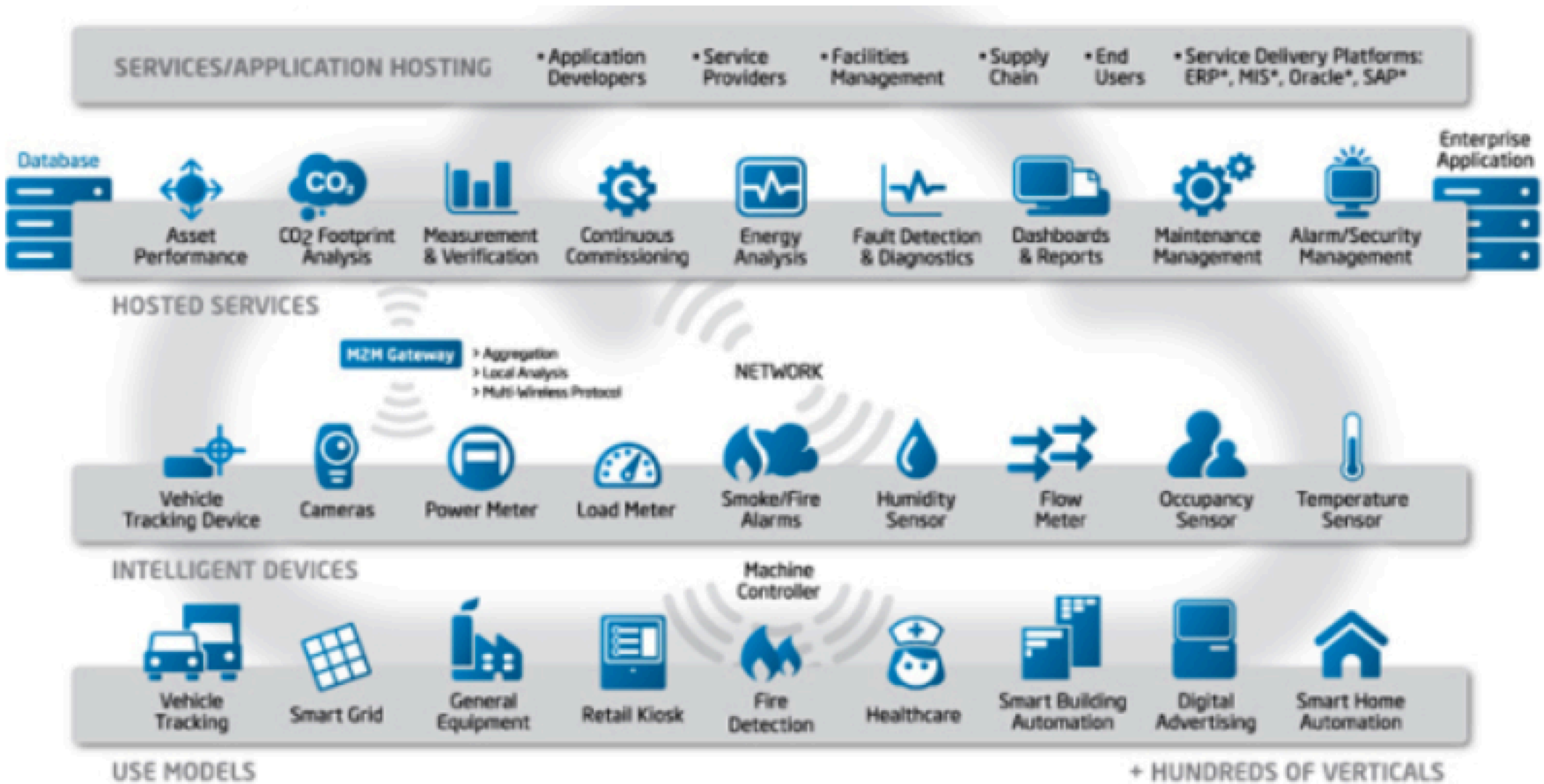
- **20 Glazing/Curtain Wall Suppliers**
- **5 Smart Glass Suppliers**
- **30 Shading Suppliers**
- **50 Lighting Fixture/Control Suppliers**
- (HVAC – ignore for now)

150,000 possible combinations, each with different protocols, connection requirements, etc



“Internet of Things” IoT

- “The Internet of Things IoT is the interconnection of uniquely identifiable embedded computing devices within the existing internet structure. IoT offers advanced connectivity of devices, systems and services and covers a variety of protocols, domains and applications.”   *Wikipedia*



Intel

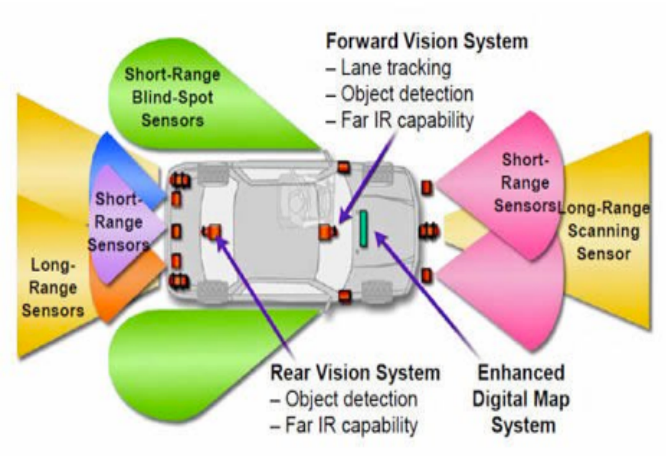
Very, Very Low Cost Base

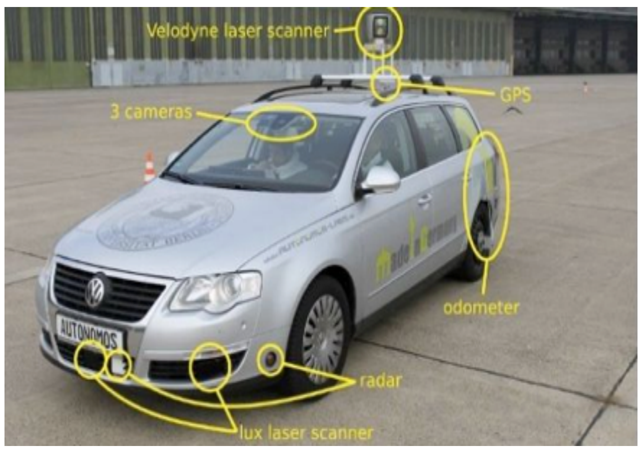
(because we are "stealing" useful technology from other high volume industrial uses)

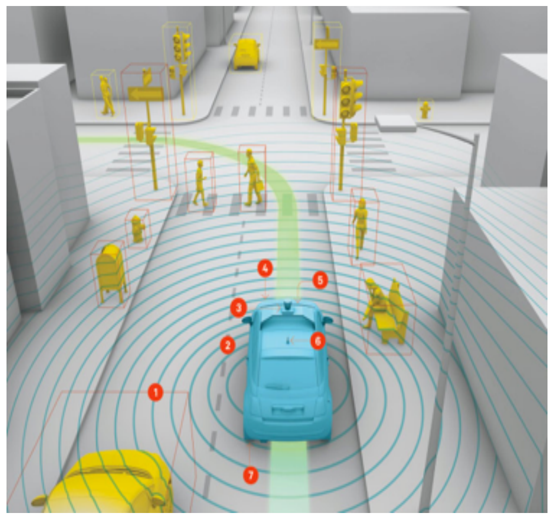
	2012	2016
▪ **ARM® Cortex-M0 microcontroller**	**$0.49**	**<$0.30**
▪ Wi-Fi	$1.30	$0.80
▪ Bluetooth	$0.75	$0.35
▪ MEMS Sensor (vibration/accelerometer)	$1.30	$0.95
▪ Camera (1.8 MP CMOS image sensor)	$1.70	$1.10
▪ GPS	$1.15	$0.65

Source: Gartner, ARM Estimate

Relative Cost and Complexity?







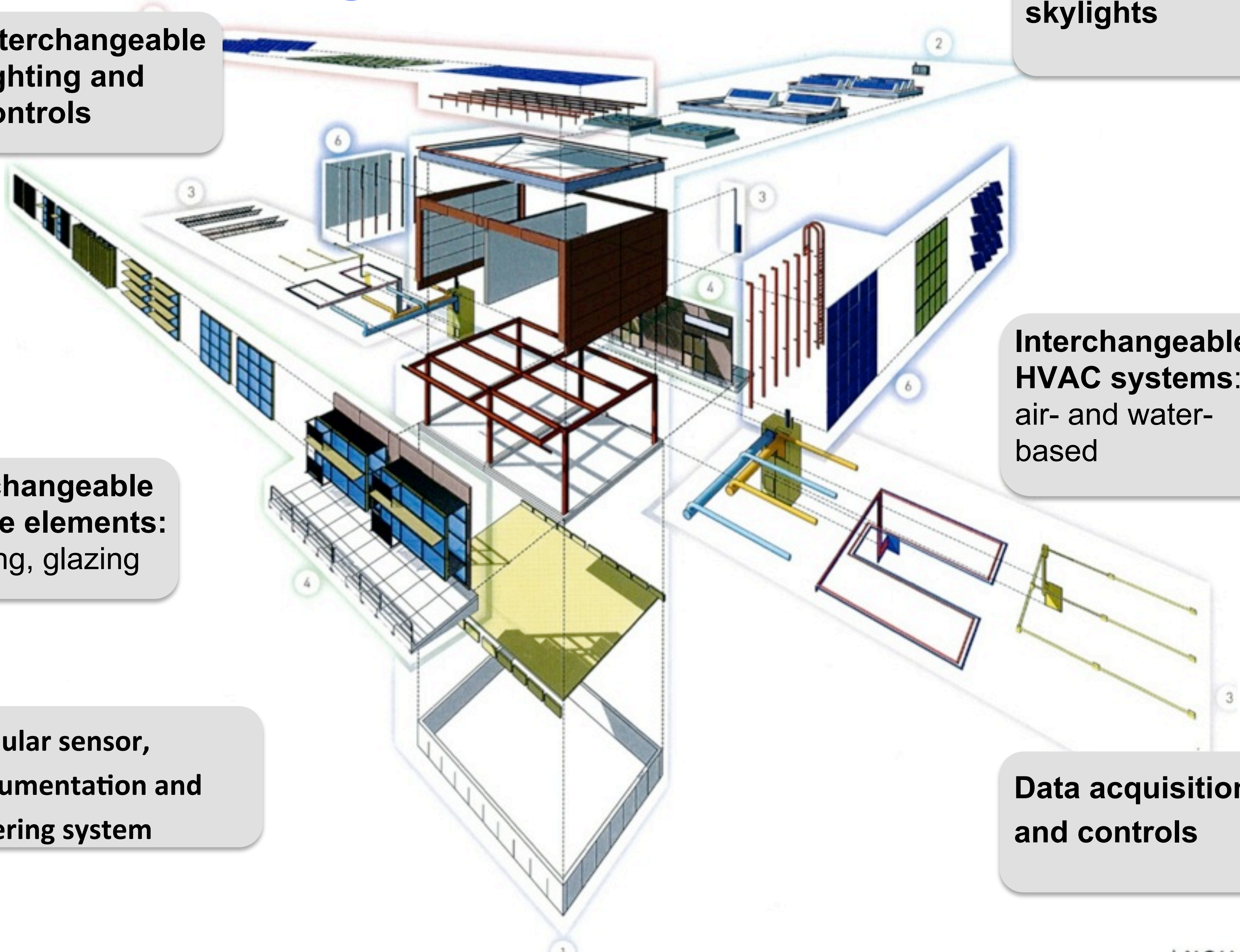
VS

Sensor Driven Automated Shade

Autonomous Car w/ Sensors

FLEXLAB
Facility for Low Energy eXperiments in Buildings

Reconfigurable, "Kit-of-Parts"



Interchangeable lighting and controls

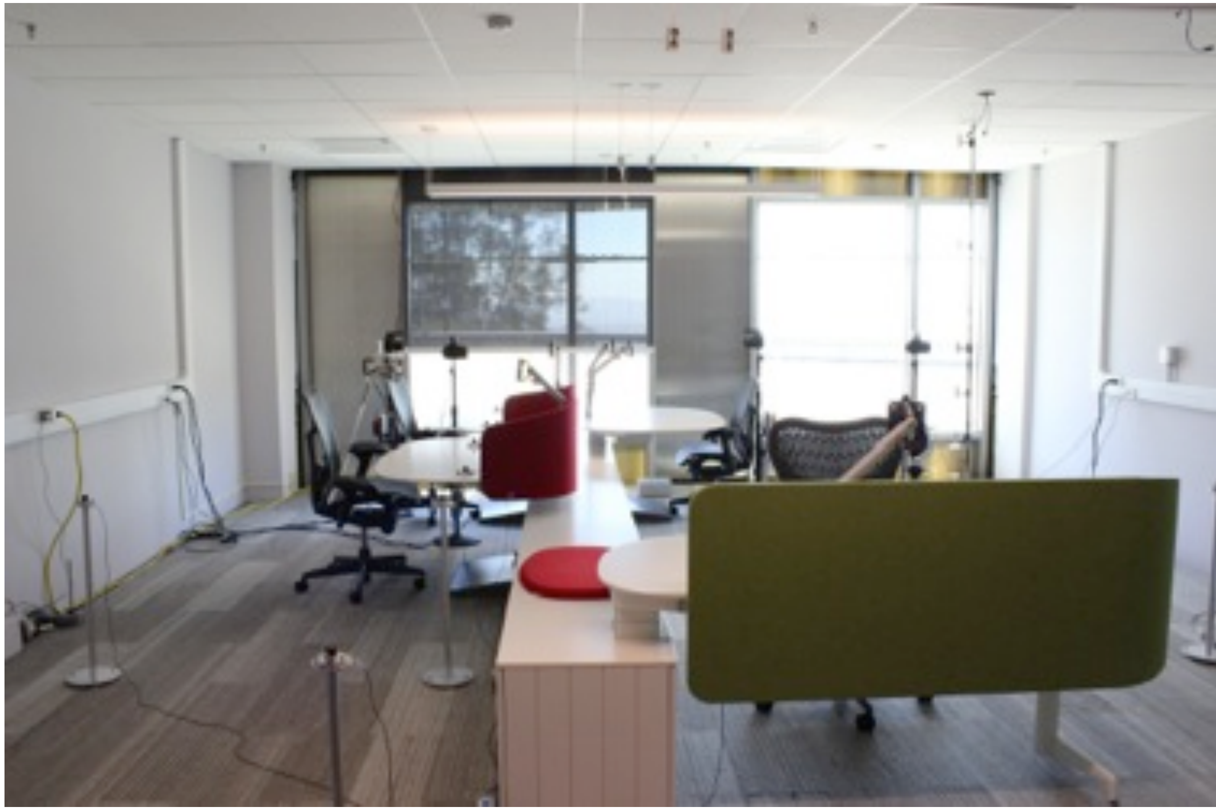
Interchangeable skylights

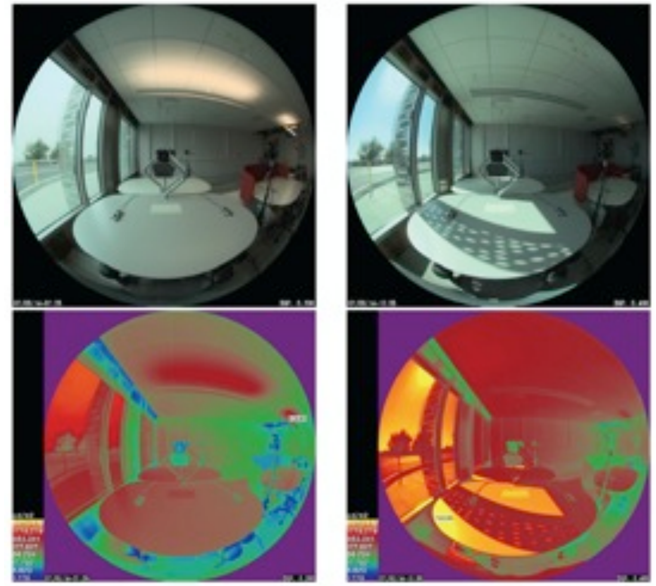
Interchangeable HVAC systems: air- and water-based

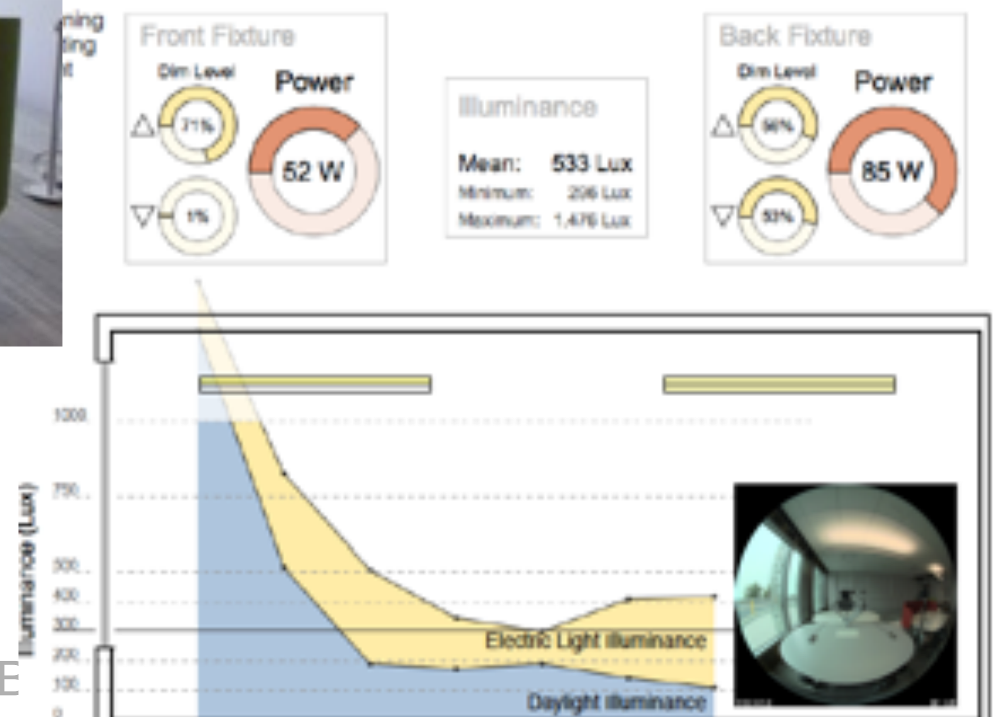
Interchangeable façade elements: shading, glazing

Granular sensor, instrumentation and metering system

Data acquisition and controls






Front Fixture
Dim Level
Power
71%
1%
52 W
Illuminance
Mean: 533 Lux
Back Fixture
Dim Level
Power
85 W
Illuminance (Lux)
Electric Light illuminance
Daylight illuminance

Build Mutual Interest for Challenge and Opportunities w/ Net Zero Energy/Green Buildings

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

Defining an Innovation Pathway to the Future

We must aggressively accelerate and sustain….

1. The learning curve
2. The adoption curve
3. Creation of new partnerships, business models
4. Establishment of new expectations
5. Delivery on performance promises

Challenge the Status Quo !
Take Action !

"If I had asked people what they wanted, they would have said faster horses."

Henry Ford

Ask the Right Questions;

Listen Carefully to the Answers

Make Data-Informed Decisions and Act with the Future in Mind

How Do We Move Forward?

"Think Big, Start Small, Act Now"

Benefits of High Performance, Green Buildings

Add Value,
Reduce Operating Costs

Reduce Energy,
Greenhouse Gas
Emissions

Improve
Occupant Comfort,
Satisfaction and
Performance

Occupant

Building Owner

Planet