ARPA-E
Advanced Building Energy Technologies Workshop
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Buildings as Testbeds?
Testbeds as Buildings?
Needs, Opportunities, Challenges

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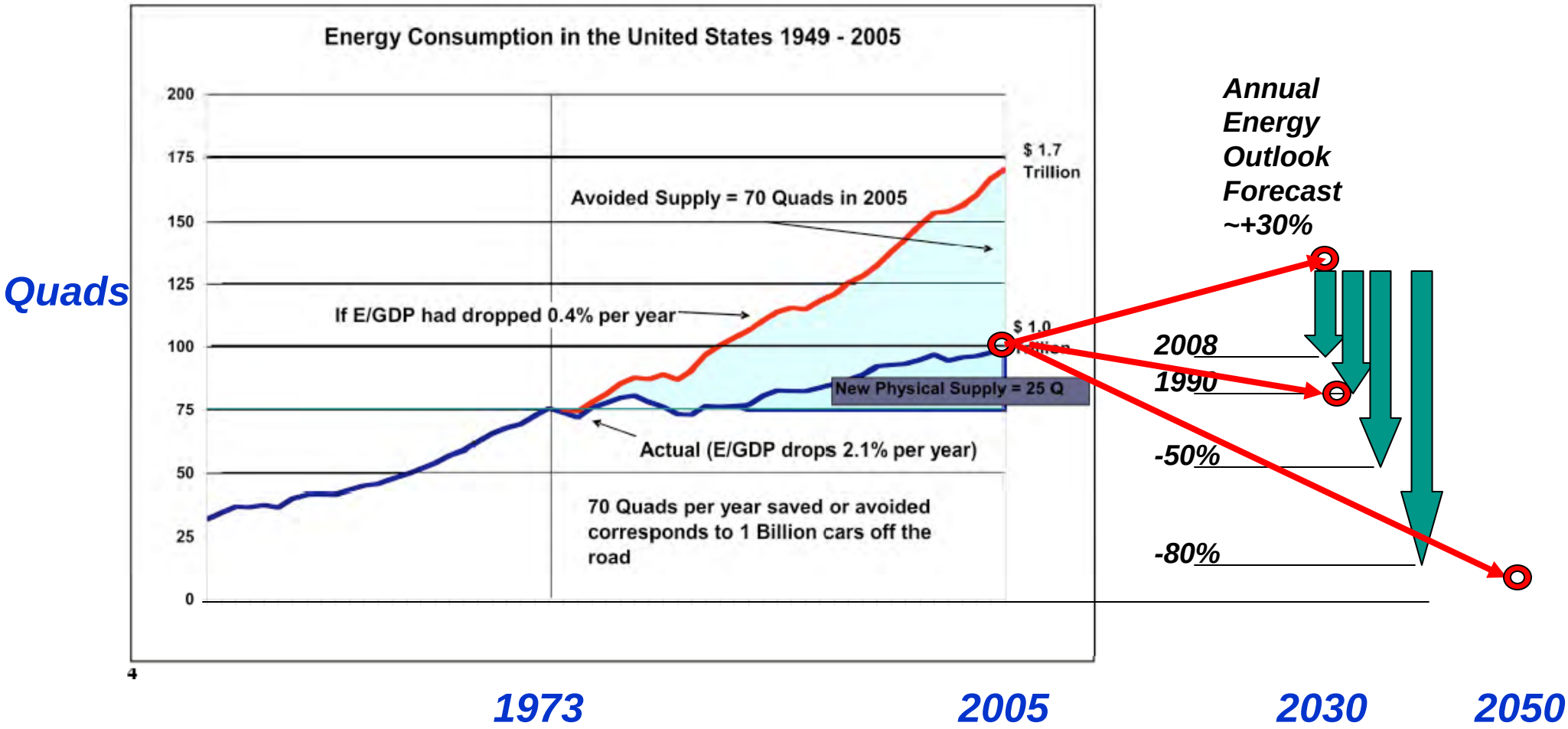
Outline

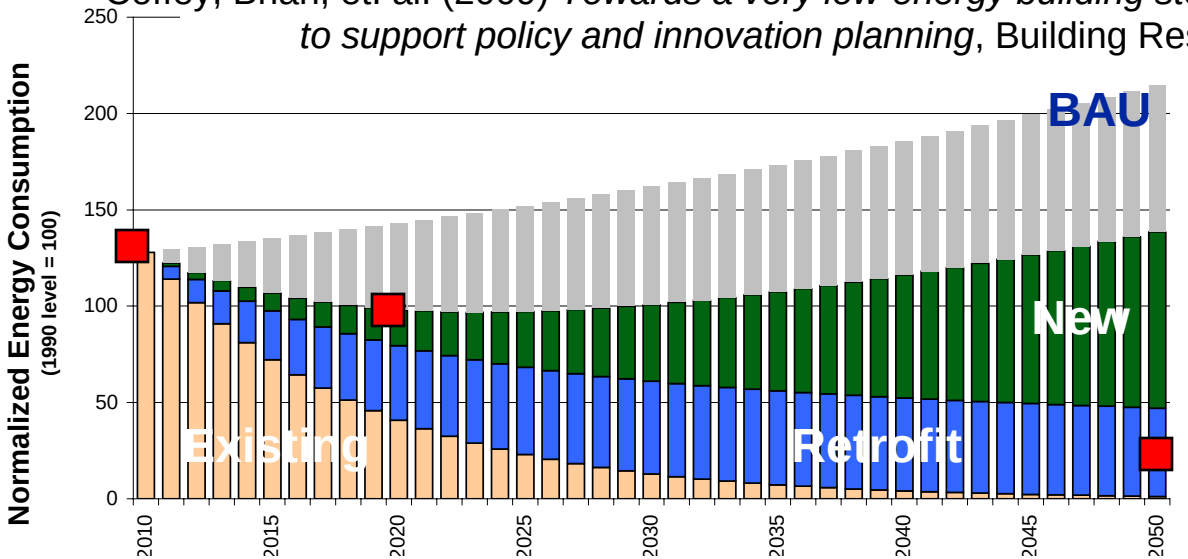
- Building Energy Performance Context and Background
- Integration Issues
- Demonstrations, Testbeds, User Facilities
  - Roles for each
  - Examples of existing facilities, testbeds, building demonstrations
- LBNL Building Systems User Facility - Initial Plans

Trends and Projections: Good News/Bad News

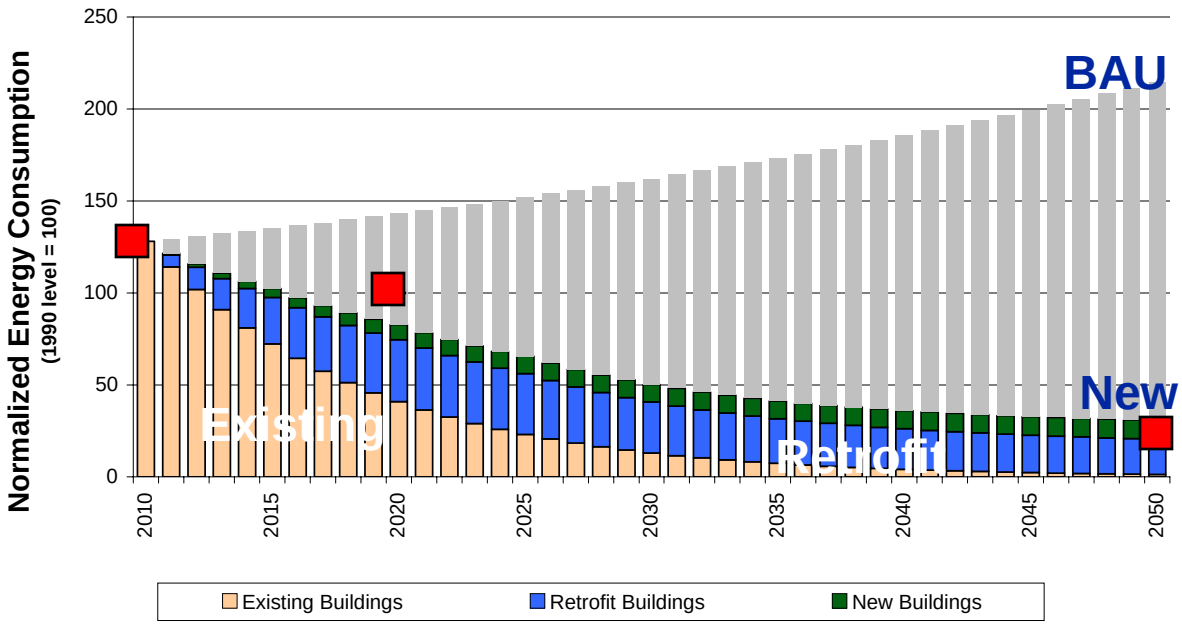


Commercial Sector: Inventing the Future

Coffey, Brian, et. al. (2009) *Towards a very low-energy building stock: modeling the US commercial building sector to support policy and innovation planning*, Building Research & Information,37:5,610 — 624



"Aggressive"
New construction savings: 50% saves 50%;
Retrofit savings: 10%/yr w/ 50% savings

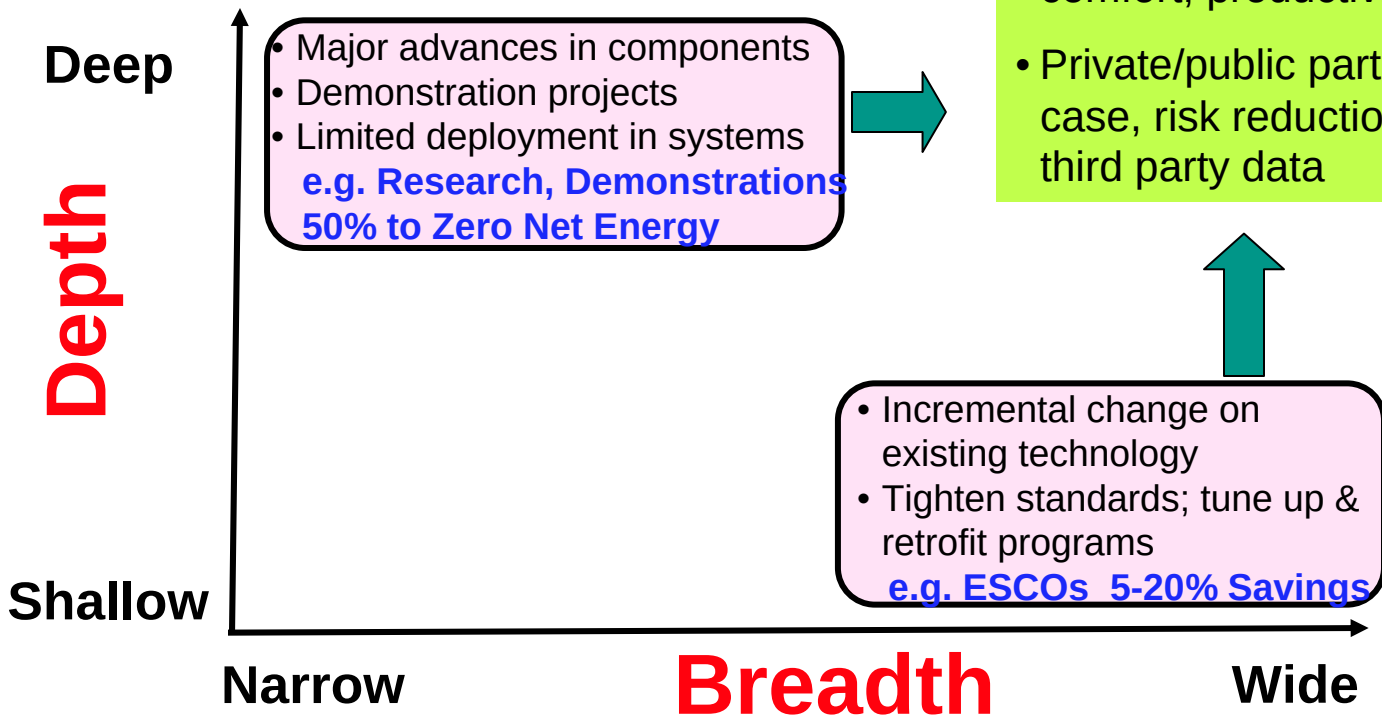


"Ultra Aggressive"
New construction savings: 60% --> 90% in 2030
Retrofit savings: (10% stock/yr); 50%--> 80% in 2030

Achieving Aggressive Sector-wide Energy/Carbon Goals

Requires Both **Breadth of Scale** and **Depth of Impact**

- 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



Building Innovation "Game Changers":
Many of Key Opportunities are "Systems solutions"

MATERIALS AND SYSTEMS

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

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

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

- Miscellaneous Electrical Loads
- Building Service Loads

- Building System Controls, Diagnostics
- Demand Responsive - sensors/controls
- Building <-> Grid: Communications
- 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/Behavior
- Facility Operations

Building Science R&D Objectives

Provide basis for development and deployment of advanced technology, systems, tools and practices that lead to substantial and sustained reduction in energy use in buildings, with improved health, comfort and productivity.

Impacts: Potential savings relative to current practice

Reduce energy use by 50% in standard practice
Reduce energy use by 70% in best practice (top 20%)
Reduce energy use by 90% - state-of-the-art

Potential impacts: $150B/yr in energy/demand savings

Role of R&D:

Create enabling knowledge bases, technologies, systems, tools

Incremental advances, and
"Leapfrog," "disruptive" technologies

Demonstrate and quantify impacts

Reduces costs and risk
Accurate performance Information to guide investment decisions

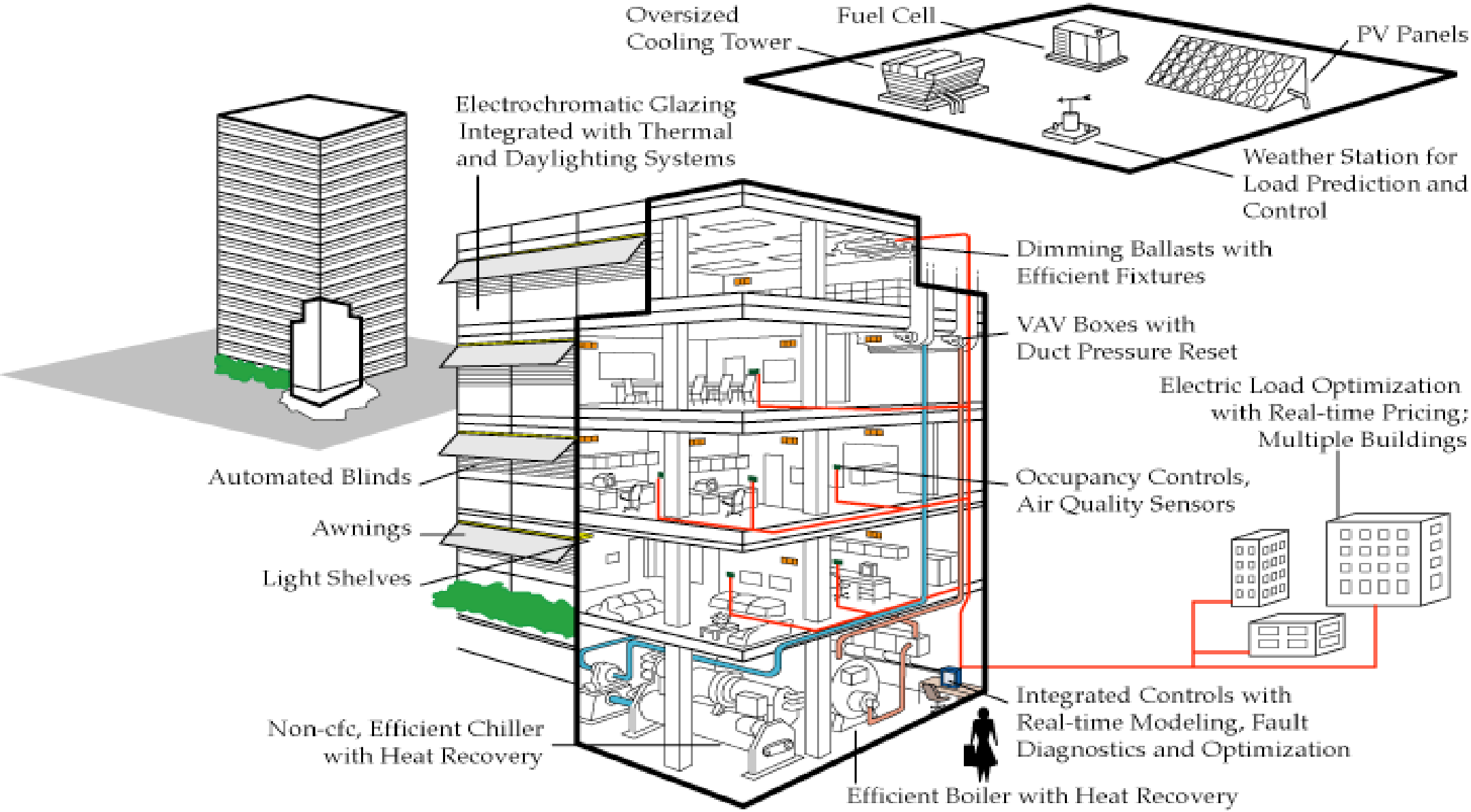
Goal: R&D that facilitates change in building design and operations

3 Types of Building Systems Integration Needed

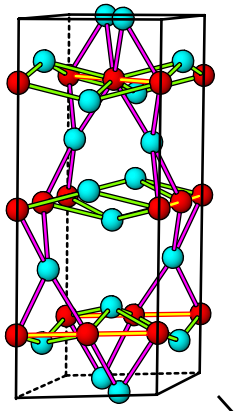
1. Hardware and physical building systems
   - Individual Components --> Integrated Building Systems
2. Integrated R&D Strategies
   - From basic materials science to occupant impacts
3. Economic perspective on Systems Integration
   - Expand Boundaries for assessing costs and benefits

3 examples follow

Commercial Building Systems Integration Opportunities

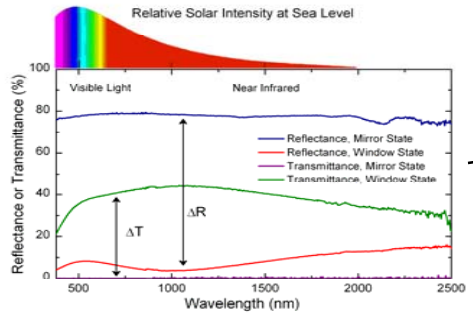


Integrated R&D Strategy: Electrochromic Devices

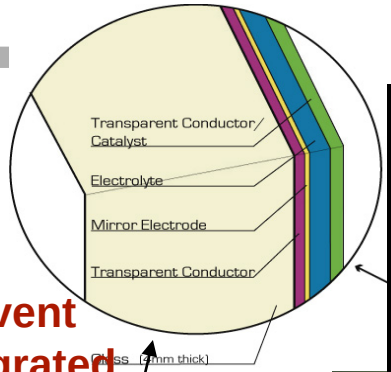


Mg_2Ni

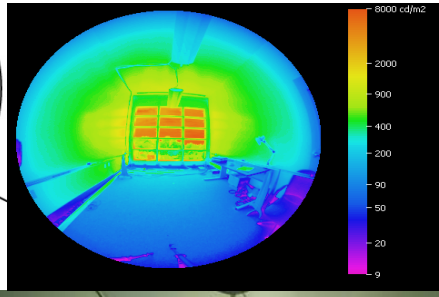
Invent New Materials

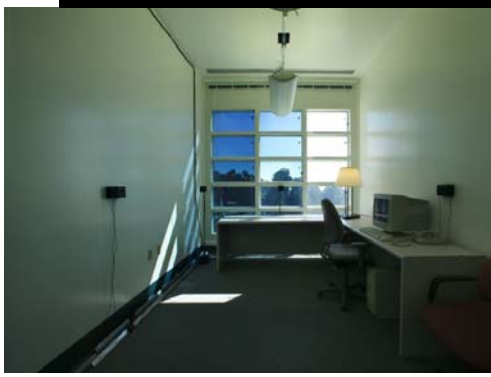


Characterize Coating Performance



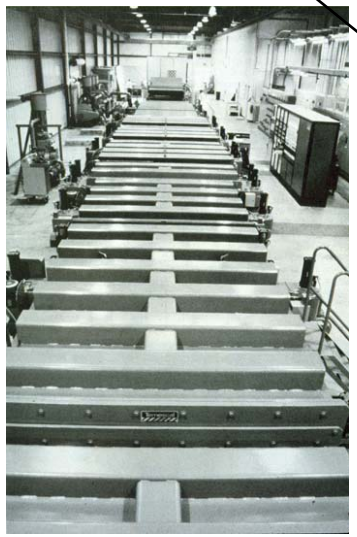
Invent Integrated Window



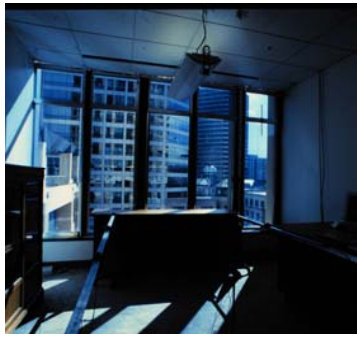


Assess Human Factors

Assess Savings

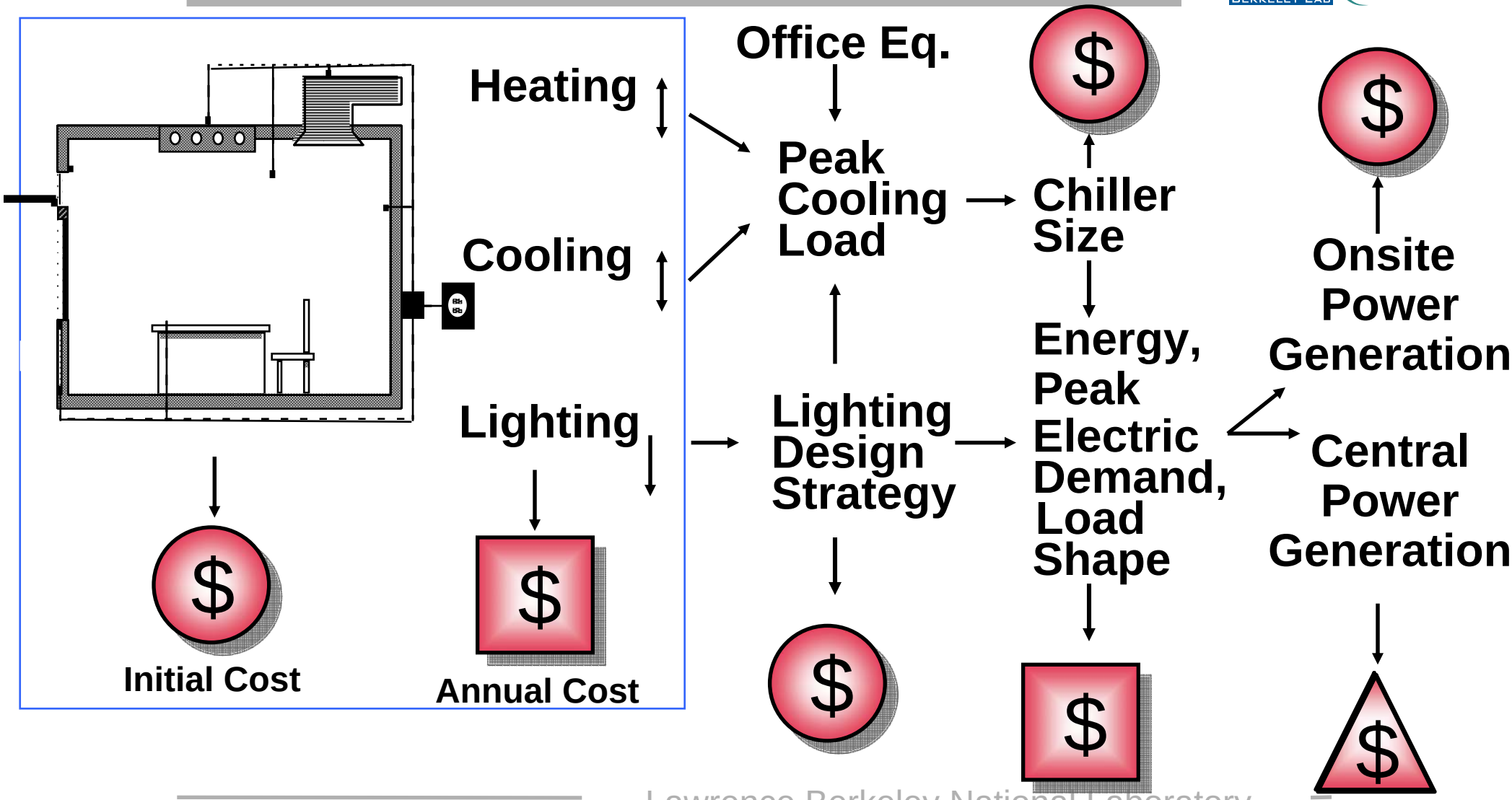


Invent Innovative Manufacturing Process



Invent/Test Integrated Systems

System integration: Cost tradeoffs



Buildings as Testbeds, Prototypes

vs

Heavily-Instrumented National User Facilities

- **Almost every building constructed is a one-off prototype with some (modest) R&D investment**
- The problem is there is no process, feedback loop in place to capture, assess and enhance lessons learned….
- Challenge: "Learn from Every Building"
  - Make Every Building a Testbed, Living Lab, User Facility,….??
  - Collect and utilize data; feedback to next design…
- But we also need **Heavily-Instrumented Integrated Building Systems Testbeds, (National User Facilities)** with trained scientific staff, rigorous experimental design, etc. to validate simulation models, prove-out new technologies, etc.

Testbeds <--> Building Performance

A high level perspective

Public Buildings
GSA, FEMP, DOD, State and Local, Schools, Campuses

Building as "Living Laboratory"

Component Test Labs:
Testing
Rating
Certification

Simulation Tools:
Design <--> Operations

Integrated Building Systems Testbeds:
National User Facilities

Private Buildings
Corporate, Non-Profit Campuses

Tools: Ratings, Labels, Certification

Utility Billing Data

National Building Performance Data Base
CBECS, CEUS, USGBC, Public, Private…..

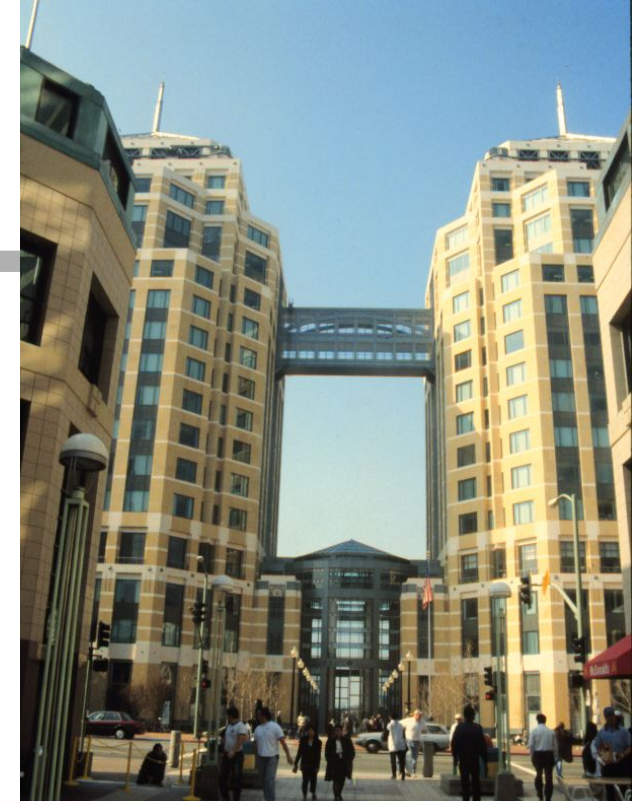
Examples from 30 years of Field Testing of Building Technologies, Systems, Strategies in Testbeds and Buildings

Pilot Demonstration: Emerging Integrated System

- Site: conference room in DOE building; retrofit

- Electrochromic Windows:
  - Automated control
  - Manual override
- Lighting controls:
  - DALI dimmable ballasts
  - Architectural scenes, occupancy, daylight controls
- Monitoring underway

Full-scale Testbed in Oakland GSA Federal Building, 1990s



- Retrofit: Side-by-side test offices with south-east orientation
- Stage 1
  - 4 month winter test comparing static vs dynamic, unshaded large-area EC windows
  - Laminated-polymer electrochromic IGU installed inboard of existing glazing (no cooling load measurement)
- Stage 2
  - Automated interior blinds with “optimal” controls
- **Integrated control between window and lighting system**
- **Demonstrated energy and demand savings; and occupant satisfaction**

The New York Times HQ Building

Owners program:

- **Highly glazed façade gives workers views and allows the city to see "news" at work**
- **But glare, cooling, visibility etc**
- **(52 stories; 1.6M sf)**

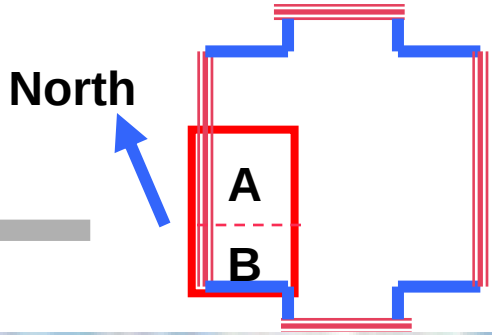
Need/Goal:

- **Develop integrated , automated shading and dimmable lighting system**
  - **Affordable, reliable and robust**

Challenge:

- **How to develop a workable, integrated hardware/software solution**
- **How to "guarantee" it will work in practice**
- **How to Scale- Transform the market- push/pull these solutions toward widespread use**

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



- **Evaluate Shading, daylighting, employee feedback and constructability in a ~4500 sf custom built testbed**
- **Fully instrumented; 1 year testing, constructed 5 mi. from bldg site**

- 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

- Support:
  NYSERDA, DOE, CEC, NY Times

Outcomes: Intelligent Lighting and Shade Control

New Products now Commercially Available

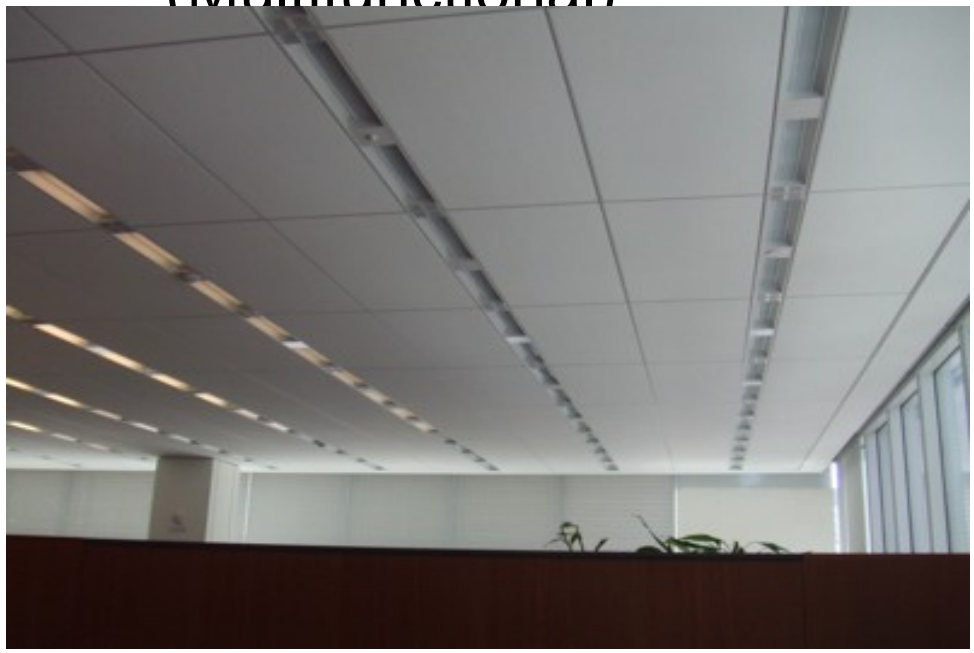
- Automated Shaded
- (Multifunctional)

Occupied 2007

- Dimmable lighting
- Addressable
- (Affordable)

(1/3 original cost estimate)

- (Multifunctional)



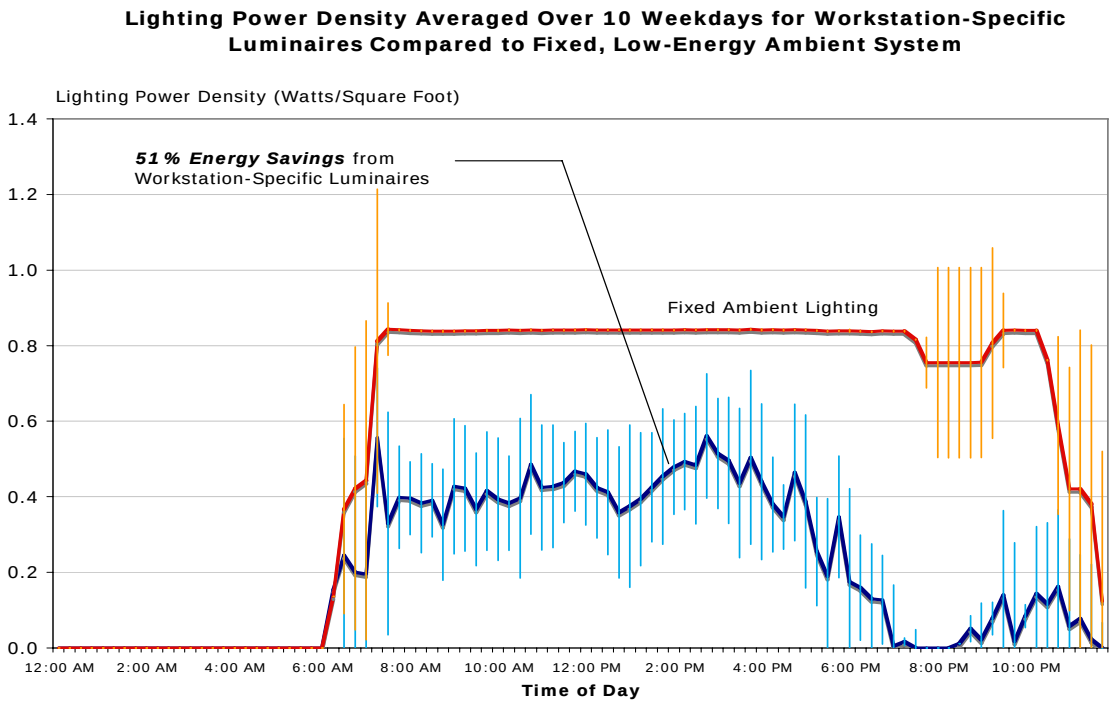
New York Times office with dimmable lights and automated shading

FEMP and Emerging Technologies (FEMP- Federal Energy Management Program)

- FEMP as Innovation Testbed for Federal Agencies

- Provides a list of emerging technologies for use in federal ESPCs
- Funds Field Tests/Demonstrations to Validate Technology Performance; examples:
  - Demonstration of duct sealing at the US House of Representatives
    - Enabled inclusion of technology into House ESPC
  - Funded demonstration of spectrally-enhanced lighting with GSA
    - Since included in several ESPCs

GSA Office Building Smart Lighting Retrofit: 8,000 sf
(40-60% measured reduction in lighting energy use)



Exploiting Cubicle Vacancies to Reduce Lighting Demand:

Sensor-driven dimmable lighting

GSA SF Federal Building
"Night Natural Ventilation Cooling System with Thermal Mass"- No Mechanical Cooling In Open Office Space

Morphosis/Arup design/GSA Owner

Outcome: **"Class A" office building;**

- **Comfortable work environment**
- **First cost savings, operating savings**
- **Key: quantify performance and risk**

Status: **Occupied 2007**

Extensive Energy design assessment

- **Extensive climate, energy modeling**
- **Comfort analysis under peak conditions**
- **CFD modeling for air flow details**

— ***Orientation, section, plan optimized***

— ***Automated operable windows and night vent cooling***

— ***Exposed concrete ceiling stores "coolth"***

— ***No mechanical cooling for perimeter offices in tower***

Extensive Control Systems Optimization prior to Occupancy w/ Virtual Controls Testbed

—Control system development, testing

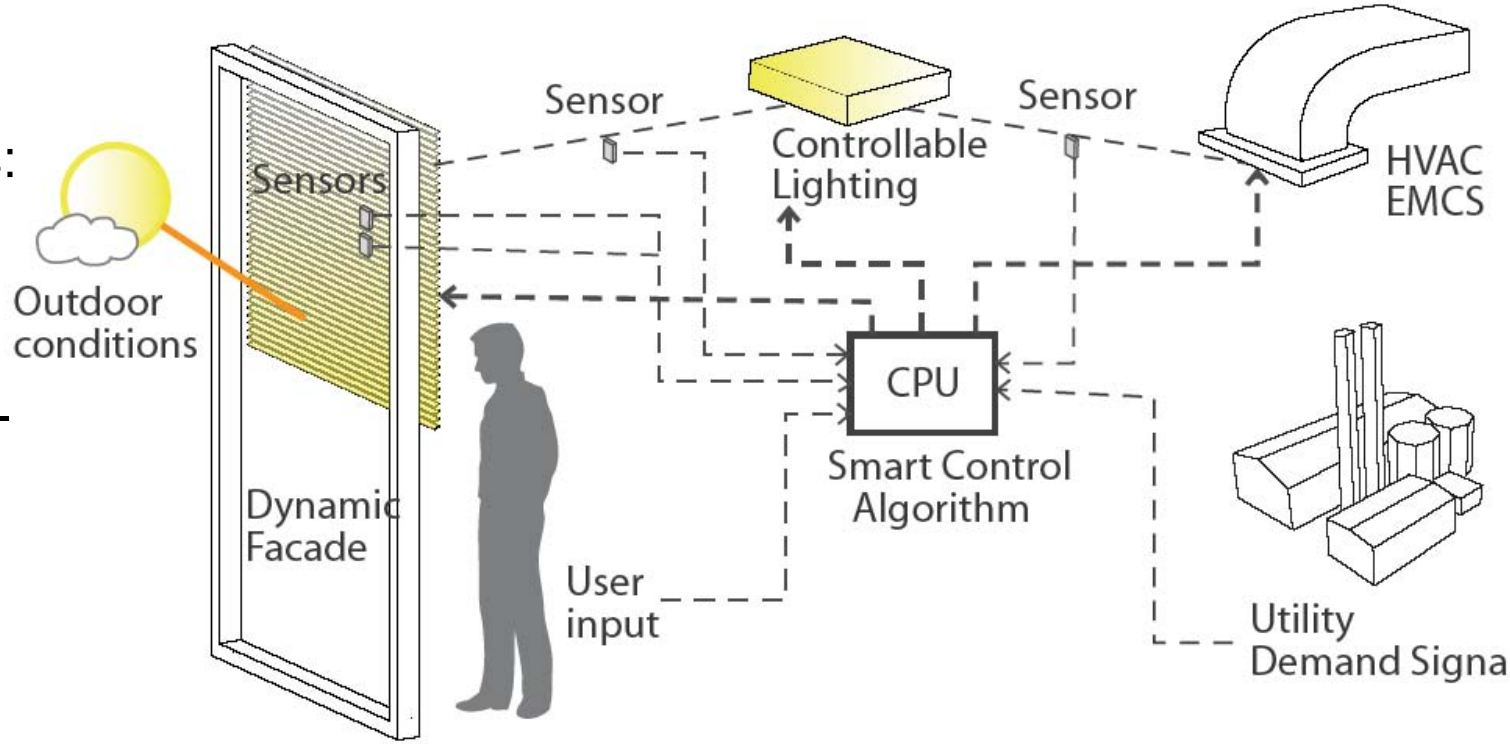
—Commissioning process

—Post-occupancy evaluations planned

Exploring Performance of "Smart Building Skin"

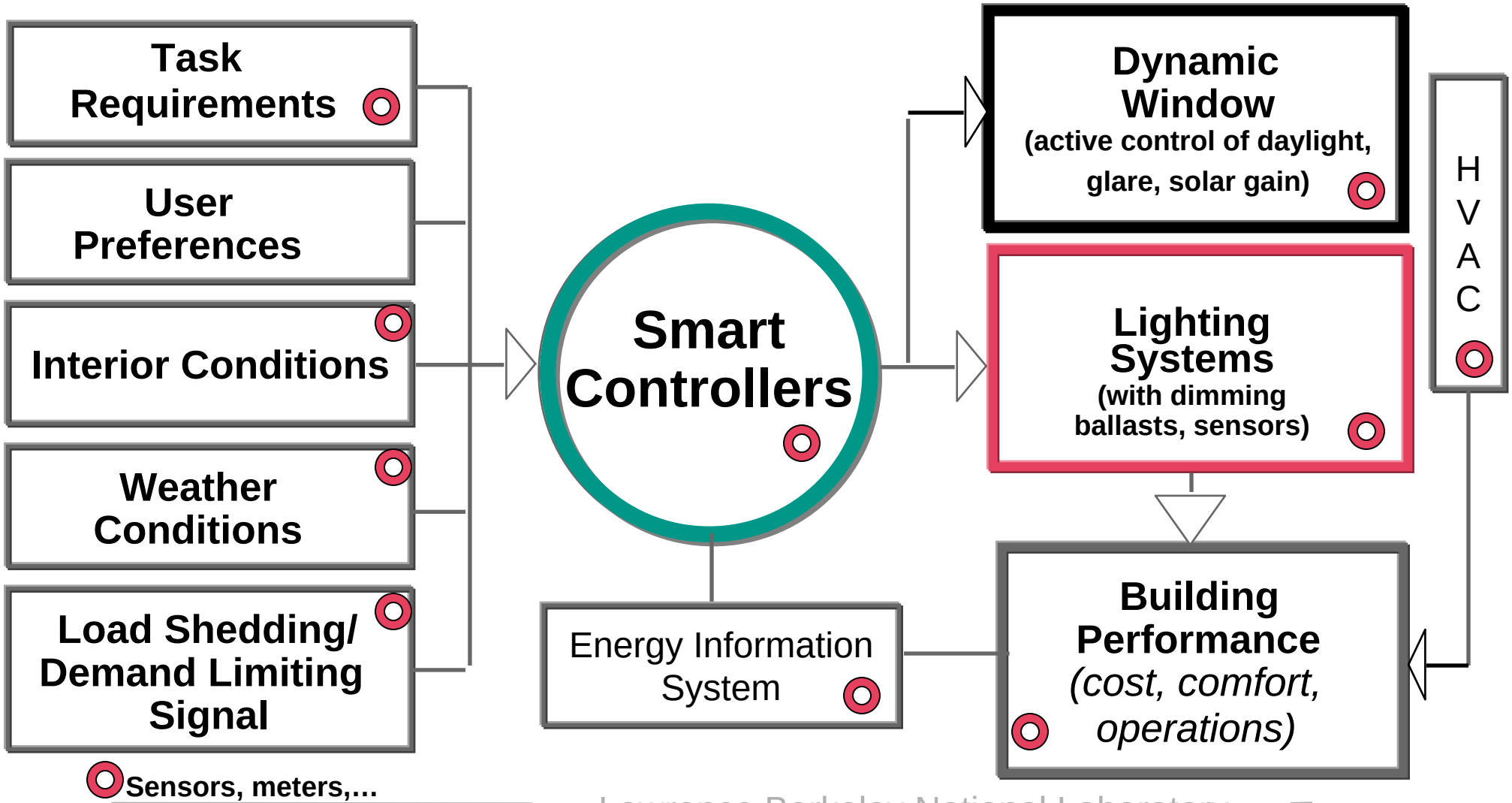
Interior or exterior **sensors** that measure relevant quantities that are used by the controller

Operable façade components: Motors or actuators for shading devices, light-redirecting elements, operable windows, or switchable glass coatings



Control algorithms: Accepts input from sensors or computations then determines how to position the operable façade components

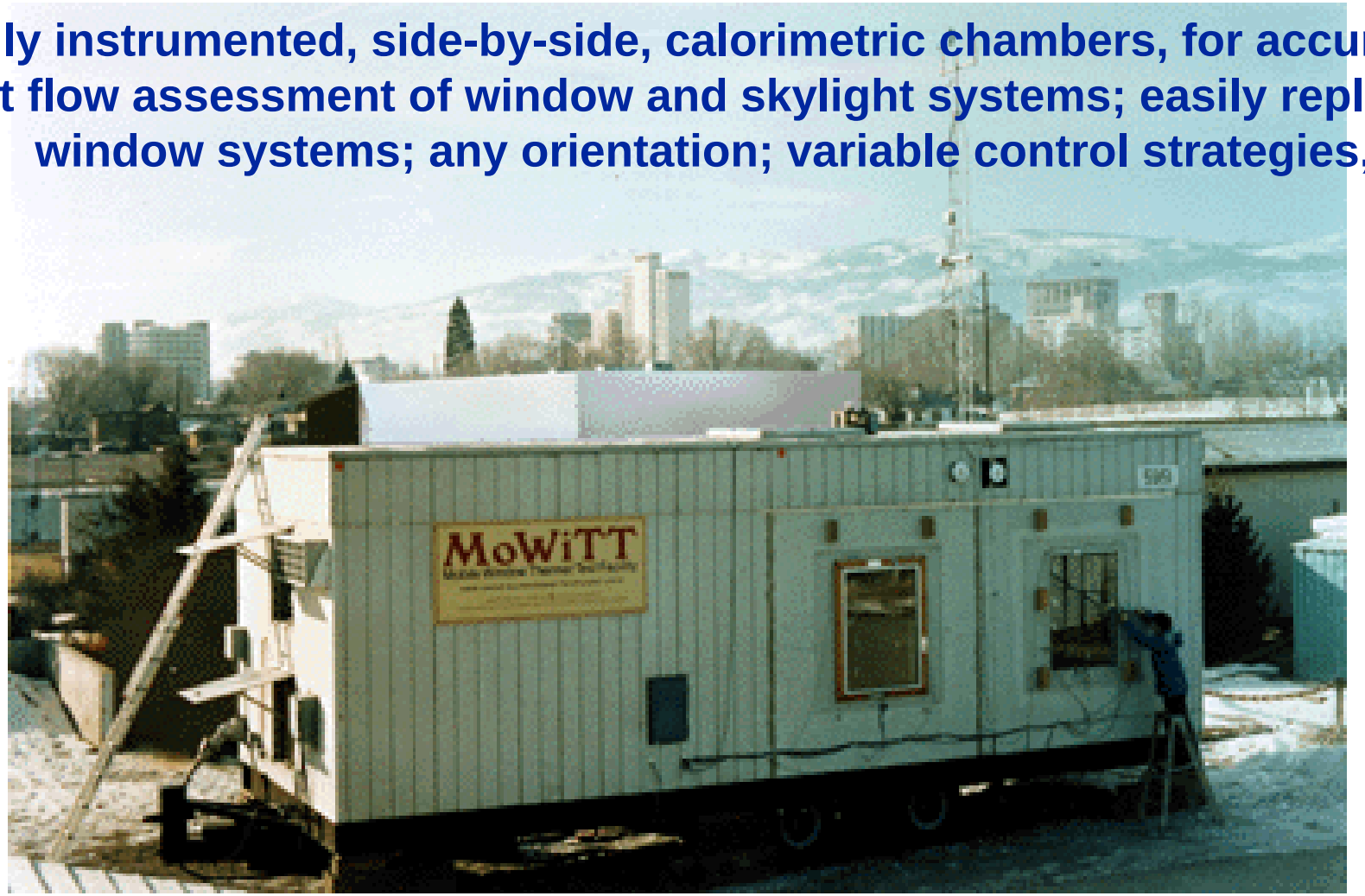
Exploring Intelligent Control Systems



MoWiTT: Mobile Window Thermal Test Facility

Reno, NV, 1985-2000

Heavily instrumented, side-by-side, calorimetric chambers, for accurate "net" heat flow assessment of window and skylight systems; easily replaceable window systems; any orientation; variable control strategies,…



LBNL Façade Testbed Facility

Highly instrumented, assess occupant response as well as energy balance

2003-2006
Electrochromic windows w/ daylighting

Industry Advisory Group:

Manufacturers
Glazing, Shading
Framing, Lighting
Controls

Designers
Architects, Engineers
Specifiers

Owner/Operators
Public, Private

Utilities

2007-2009
Automated Shades w/ daylighting

Interior Setup for Occupant Response Studies with Switchable Electrochromic Windows

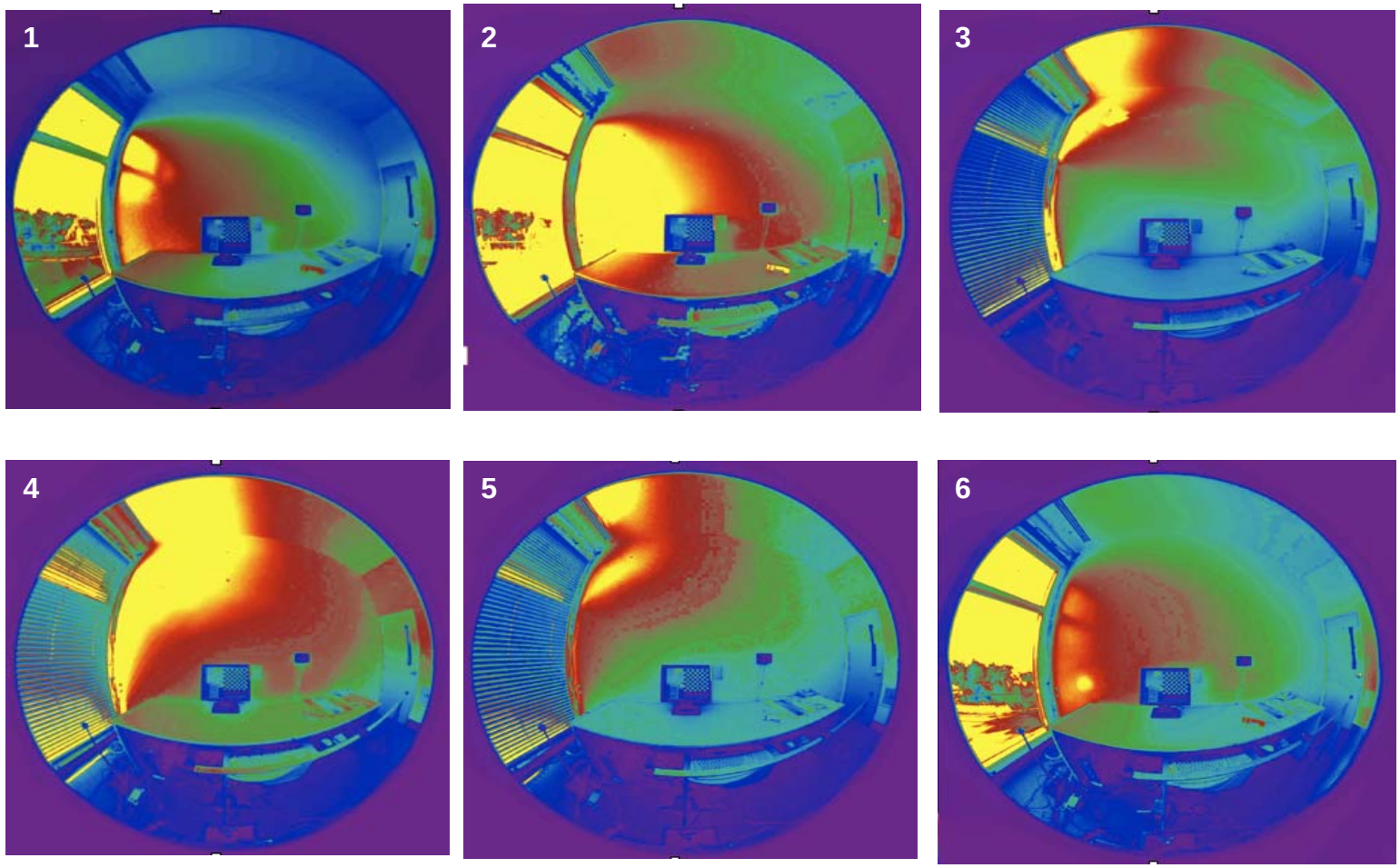
R&D Goals: 1) will users accept smart, sensor-based, automated controls?; 2) how do savings from Manual control compare to Automated Controls?

Time Lapse from Tests in LBNL Façade Test Facility:

Interior Daylight Luminance Patterns with Dynamic Shading

Automated Shading Controls Glare Throughout the Day

R&D Goal: Optimize control and operation of interior/exterior blinds to maximize energy savings and minimize glare.



Next Steps:
National User Facility for "Integrated Building Systems"

Response to DOE Call for a National User Facility was shaped by 20+ years of experience in lab and field testing of building systems; as illustrated in examples in prior slides:

Approach:

1. **Components -> Systems**: A new generation of innovative high-performance building materials and components that will be integrated into five key integrated building systems: Envelope, Lighting/daylighting, HVAC, Process loads and On-site power.
2. **Systems -> Integrated Building Solutions**: The integration of these five building systems into NZE "whole building solutions" will demonstrate energy, demand, carbon and operating cost savings, as well as improved occupant comfort and health.
3. **Process -> Performance:** The business process linkages and IT systems that integrate NZE building design, construction, and operations will reliably achieve optimized performance under field conditions.

Key Features of New LBNL User Facility

- **Focus on the Key Enabling Science for Net Zero Buildings**
  - Integrated Systems focus
  - Integrated Whole buildings focus
  - Integration of technology, people, process
  - Extend measurement impacts with advanced simulation
- **Build Pathways to Market with Aggressive Industry Engagement, Partnership**
  - Manufacturers, Designers/Engineers, Owners, Public interest with an extra focus on California partnerships (2030 program goals)
  - 8 testbeds allow broader industry engagement
- **Rapid Response**
  - Award announced 11/2009
  - Call requires completion in mid 2013
  - Initial facilities- Dec 2010
  - Complete: Mid- 2012

User Facility = 8 Testbeds

A. Comprehensive Whole Building Systems

#1 - Building Systems Integration Testbed

B. Specific End Use Integration

#2 – Façade, Building-Integrated Photovoltaics, Daylighting, and Lighting Systems Integration Testbed

#3 – Roof Systems, Skylights and Photovoltaic Integration Testbed

#4 – Low Energy and Low Demand HVAC Systems Integration Testbed

#5 – Intelligent Building Controls Testbed

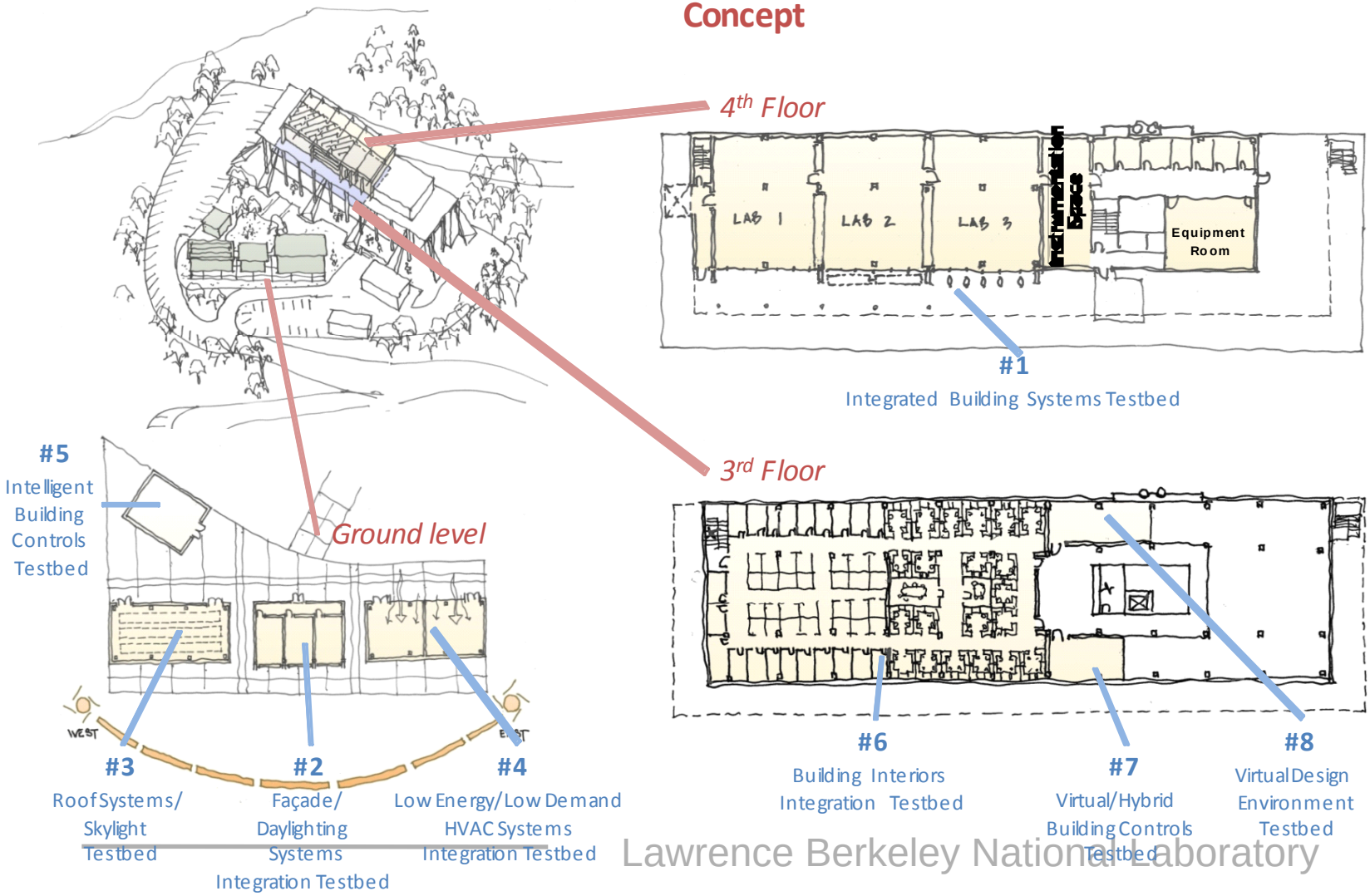
#6 – Building Interiors Integration Testbed

C. Simulation

#7 – Virtual Hybrid Building Controls Testbed

#8 – Virtual Design Environment Testbed

LBNL User Facility Elements

LBNL Net-Zero Energy Buildings User Facility

Concept