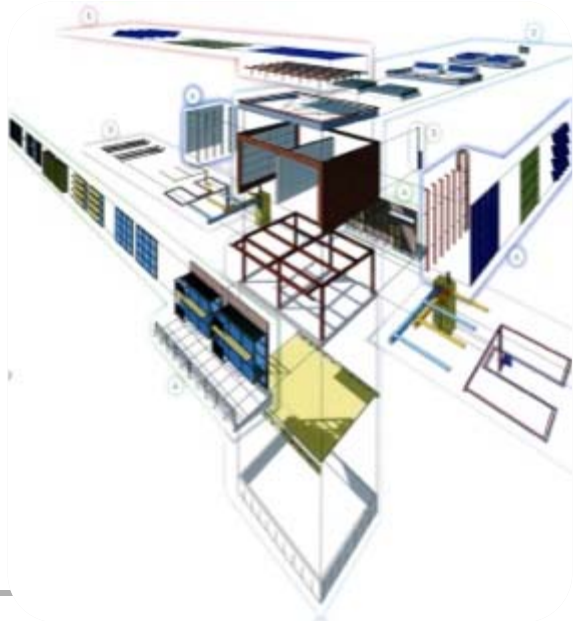
2012 Emerging Technologies Summit
Efficient Building Track 10/16/12

FLEXLAB:
Facility for Low Energy eXperiments in Buildings:

Supporting Progress Toward NZEB



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Building Technology and Urban Systems Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
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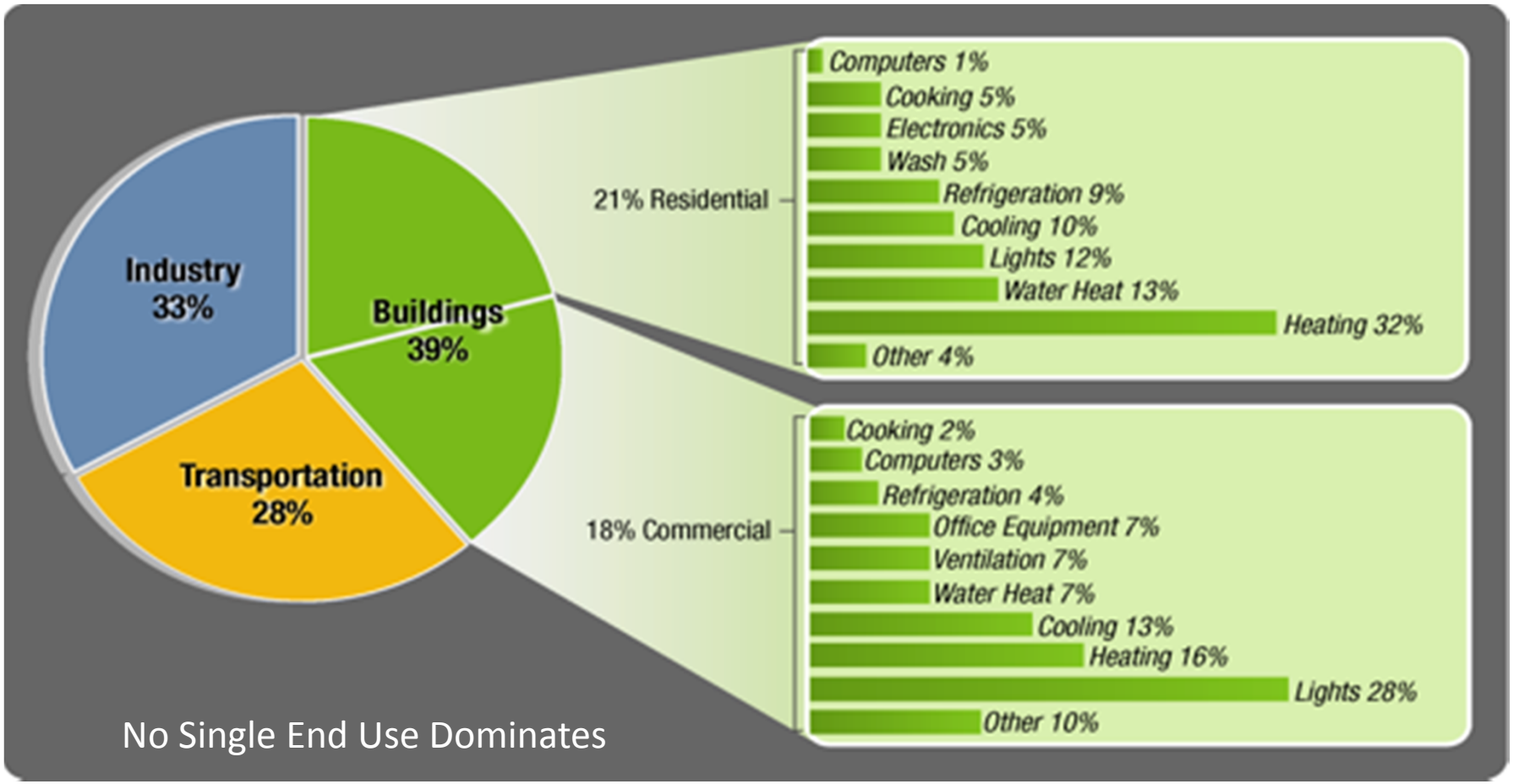
Outline

- Background and Emerging Tech Context
- Facility Concept and Description
- Users and Partnerships

U.S. Building End Use Energy Consumption

Buildings consume 40% of total U.S. energy

- 40% $C0_2$ emissions
- 71% of electricity
- 54% of natural gas
- 5.8 terawatts (TW) of peak power



No Single End Use Dominates

FLEXLAB Will Support Broad DOE Goals for Building Innovation "Game Changers" in Commercial Sector

ADVANCED MATERIALS AND INTEGRATED 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 and ENERGY USE

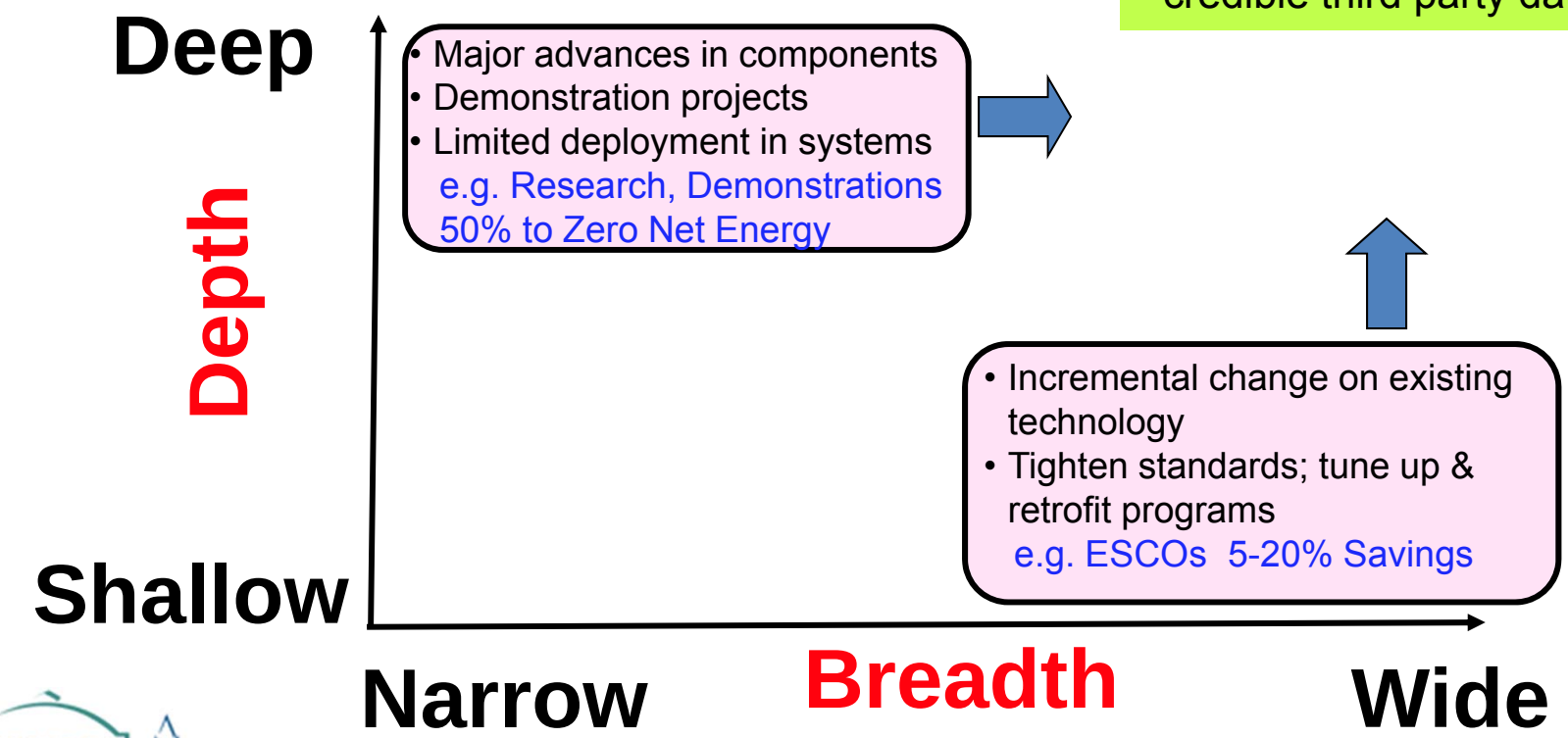
- Building Life Cycle Perspective
- Benchmarks and Metrics
- Building Information Models (BIM)
- Integrated Design Process and Tools
- Building Operating Controls/Platform
- Building Performance Dashboards

- Understanding Occupants/Behavior
- Facility Operations

Scale and Impact:

Approaches to Achieve Sector-wide Efficiency Goals?

- Systems approach: integrate advanced components, optimize energy, comfort, cost
- Business case: risk reduction and credible third party data



DOE Goals:**Achieving 50%+ Savings at Affordable Cost**

Current Paradigm – "Silo" Approach

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

Integrated Building Systems Approach

Multi-system integrated EEMs → **50%+ Energy Savings**

CA Goals: **All Buildings Net Zero Energy By 2030**

Net (Nearly) Zero Energy Buildings: Can We Get There?

The Vision

- "Net Zero Energy Buildings" is the right long term goal
- NZEB = 60-80% savings + renewables

The Dream

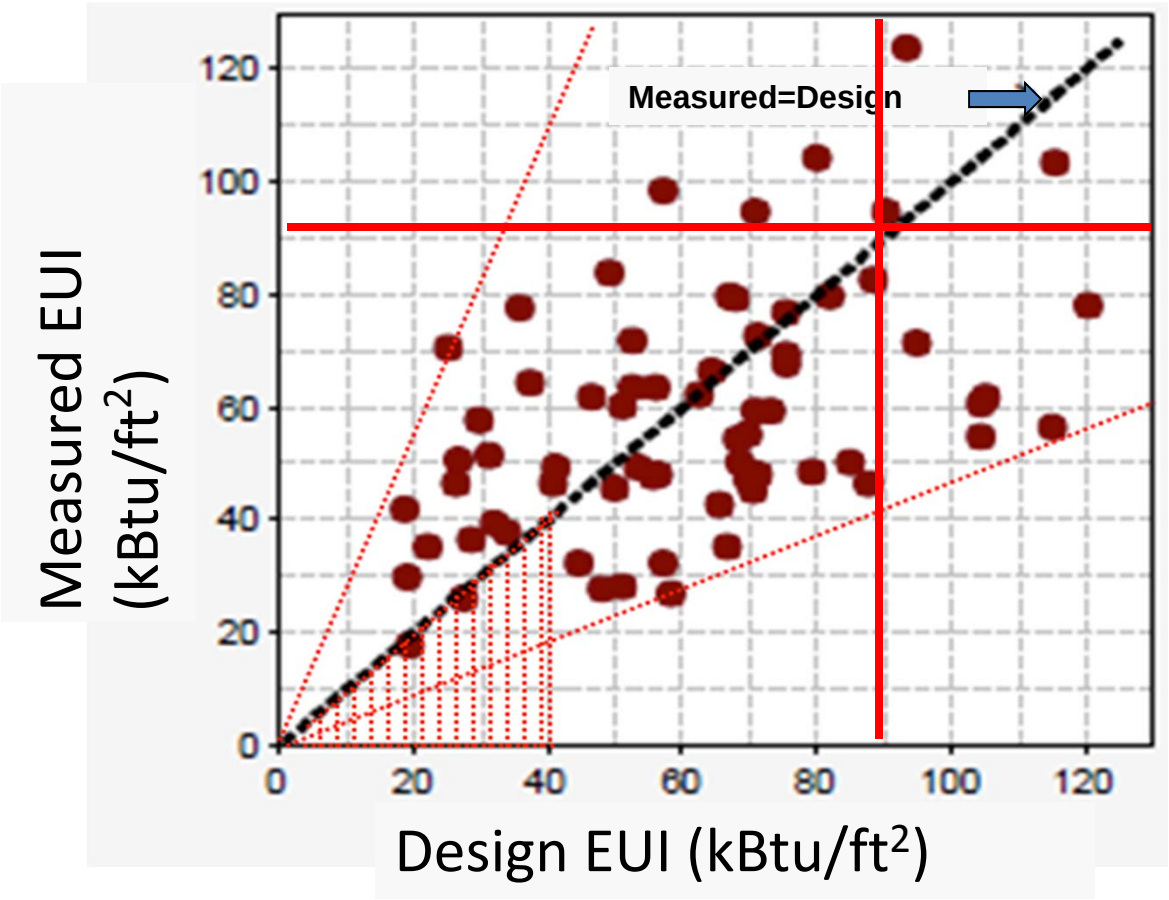
- *Just Do It*
  - Set a goal - march toward it
  - Its easy, if we commit and apply ourselves
  - We have the technology and know-how

The Reality

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

Can We Predict Building Performance Outcomes??

How Do Buildings Really Perform?:
Design Simulation vs Measured Performance



Observations:

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

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

Buildings "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

CA Utility Emerging Tech Program Needs

- Advance Technology to Market Acceptance
- Explore Performance of Integrated Solutions
- Measurable and Reliable Savings
- Extensible Solutions- via Simulation Tools

- Energy, Demand, Load Shape, Time-of-use,
- DR and Smart Grid
- EEM Integration with On-Site Power

Designing New Utility Incentive Programs

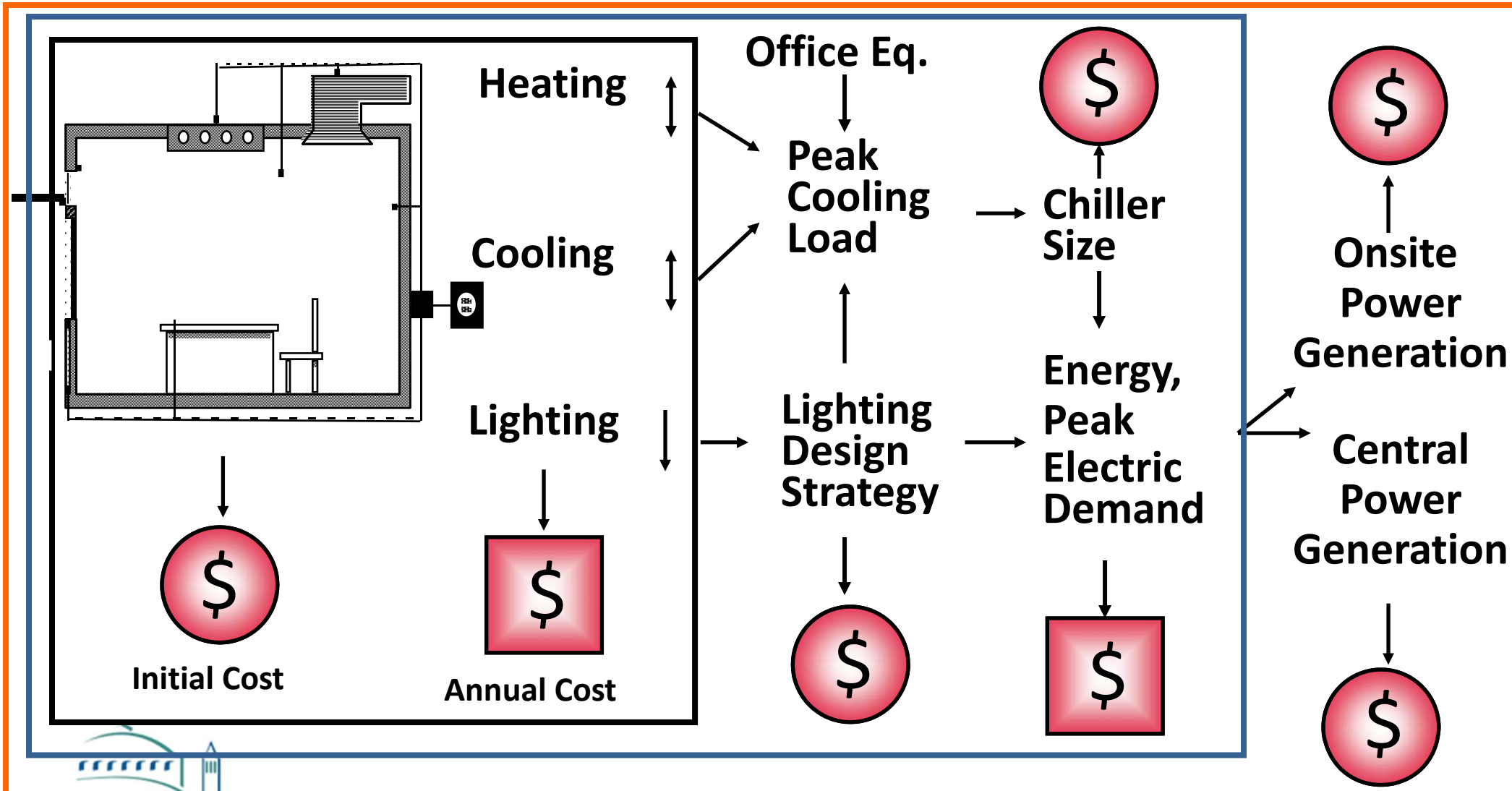
Wouldn't you like to know:

- Can aggressive shading and lighting controls reduce AC size?
- Can perimeter heating be eliminated?
- Can radiant cooling provide comfort in highly glazed buildings?
- Do Daylighting Lighting Savings Offset Façade Cooling Loads?
- Can Deep Daylighting Solutions Provide Savings to 30-40' zone depth?
- Does Plug Load Management translate into Cooling Reductions?
  - Is there a heating penalty?
- Do Retrofit Façade and Lighting really work?
- How effective are HVAC retrofits?
- Do Low-Energy Strategies Reduce Comfort?
- Can a Deep Retrofit Package Achieve 50% savings?
- How Cost-effective is BIPV?
- How much credit should codes give to "smart controls"?
- **How well can simulation tools predict all these effects?**

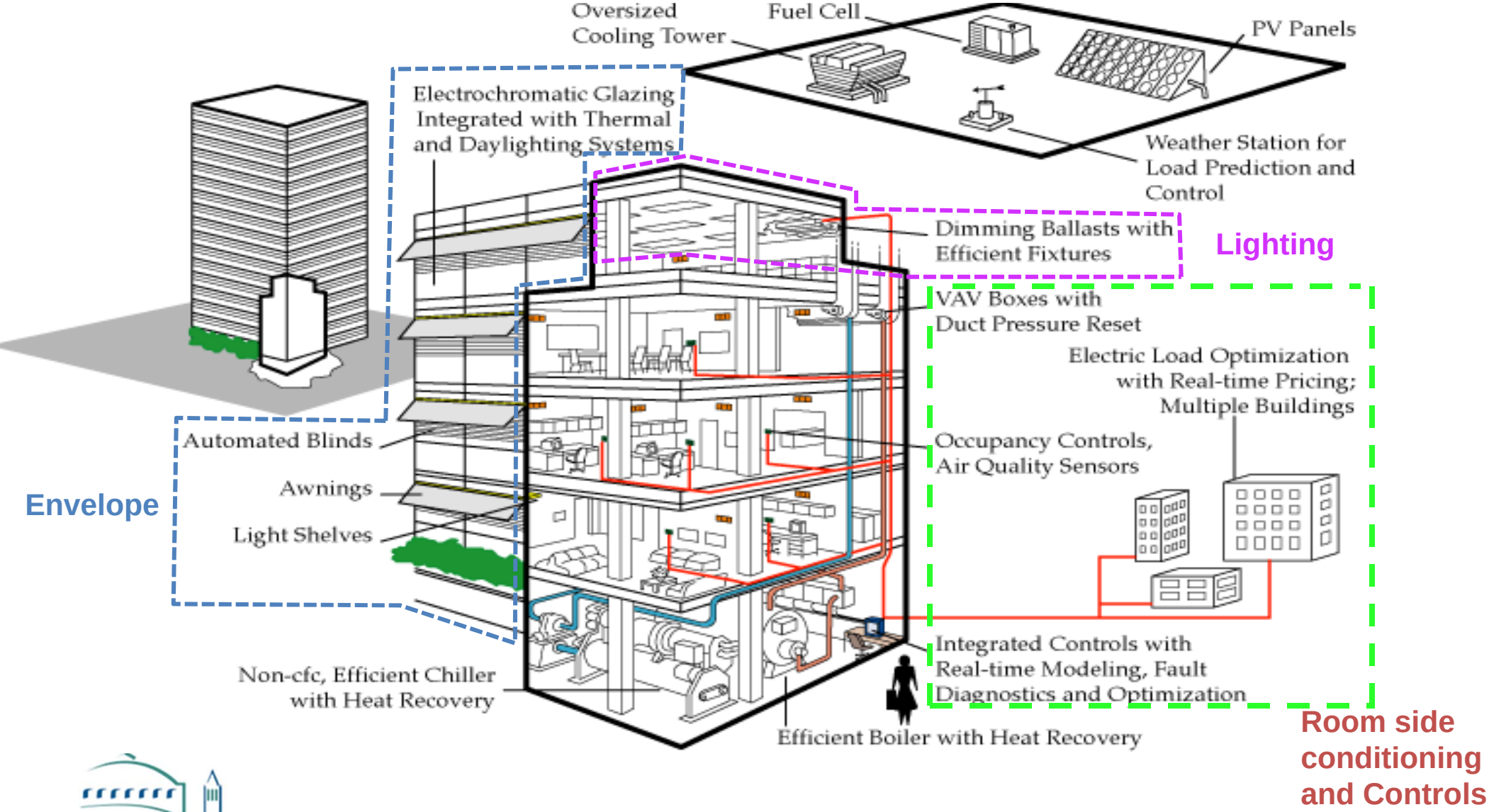
Integrated Systems Performance:

Need Models/Data to Quantify Investment Tradeoffs

Loads -> Systems -> Supply



Overall Commercial Building Systems Integration Opportunities: How Do We Measure and Validate Savings Across Systems?



Challenge: Extract "Useful" Performance Data from Field Performance of Buildings

- **Buildings as Test Beds?**
  - Almost every building is a "one-off prototype" with some R&D investment
  - No scientific process, feedback loop to capture and enhance lessons learned….

- Challenge: Make every building a test bed, living lab?
  - Useful….. but Messy, Complex, Costly, Constrained….

or

- **Create flexible "testbed facility" with data collection, analysis, synthesis →**
  - Accurate, detailed measurements, optimize performance,
  - Validate tools to extend impact of measured data
  - Guide building industry R&D investments
  - Guide government and utility "deployment"
  - Convince A/E and owners that solutions "work"

- Will this approach Work??

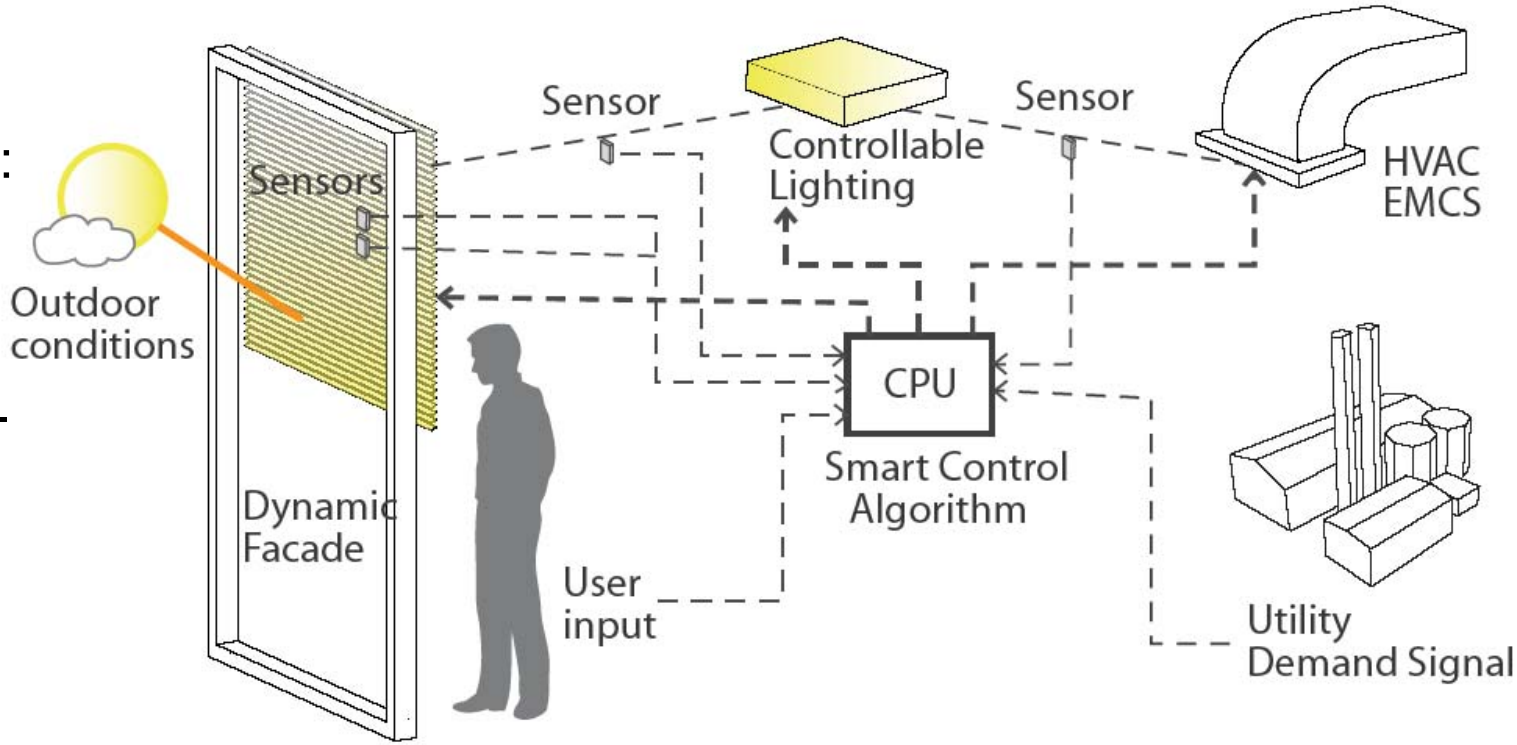
History of LBNL Collaboration with CA Utility Field Testing Programs

- **Electronic Ballast Field Tests** – 77 Beale St, 1979
  - First field demonstration of electronic ballast savings
- **ACTT Program** 1990s
  - 50% measured savings in new/retrofit energy use
- **Smart Glazing Project** – GSA Oakland Federal Bldg., 1990
  - First US demo of electrochromic glass, automated blinds
  - Partner in CEC-funded Advanced Façade Program
  - Led to largest daylight/auto shading project in US; NY Times
- **Advanced Façade/Daylighting Project**– CEC PIER, Phase 1, 2
  - SCE: Façade Workshop based on testing, evaluation
  - LBNL Advanced Façade Test Facility

LBNL Test Bed Experience/Basis for Design
Past R&D on Performance of "Smart Building Skin"

Interior and exterior **sensors** provide data

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



Control algorithms: input from sensors -> how to position the operable façade components

MoWiTT: Mobile Window Thermal Test Facility

Reno, NV, 1985-2000; 2012+

Side-by-side test rooms:
- Heavily instrumented
- Changeable Facades
- Changeable skylights
- Variable operating condition
- Variable orientation
- High Accuracy
- No Occupants
- Small Rooms

Explored:
- Net Energy Balance
- Technology impacts
- System tradeoffs
- Climate effects
- Control impacts

Full-Scale Test Bed Built into Oakland GSA Federal Building, 1990- 1992

- Side-by-side test offices; occupancy effects (interior changes only)
- Owner engagement
- Stage 1: Unshaded large-area electrochromic windows
- Stage 2: Automated interior blinds with “optimal” controls
- **Integrated controls optimize energy and demand for window and lighting system**

Outcomes: Integrated Intelligent Lighting, Shade Control, HVAC
In Progress: Field Verification of Savings in Occupied Building

Automated Shaded

- Multifunctional

Occupied 2007

Dimmable lighting

- Addressable
- Affordable (1/3 original cost estimate)
- Multifunctional

Interior: *New York Times* office with dimmable lights and automated shading

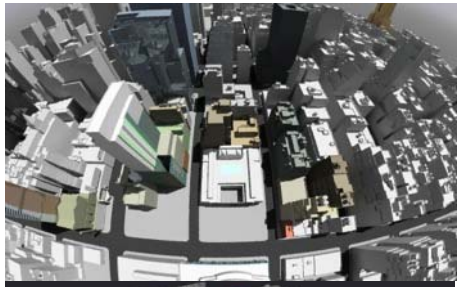
Test/Optimize: Physical & Virtual

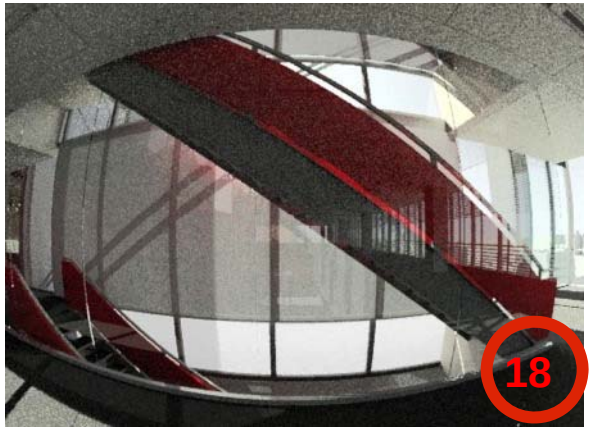
Phase 1: Physical

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

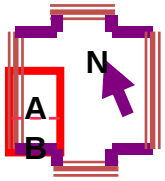
Phase 2: Virtual

- Extend Data by Orientation and Floor Level
- 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



Lessons Learned: Flexibility, **Side-by-side Comparison** -> LBNL Façade Test Bed Facility

2003-2006
Electrochromic windows

Industry Advisory Groups:

Manufacturers
Glazing, Shading, Framing, Lighting Controls

Designers
Architects, Engineers Specifiers

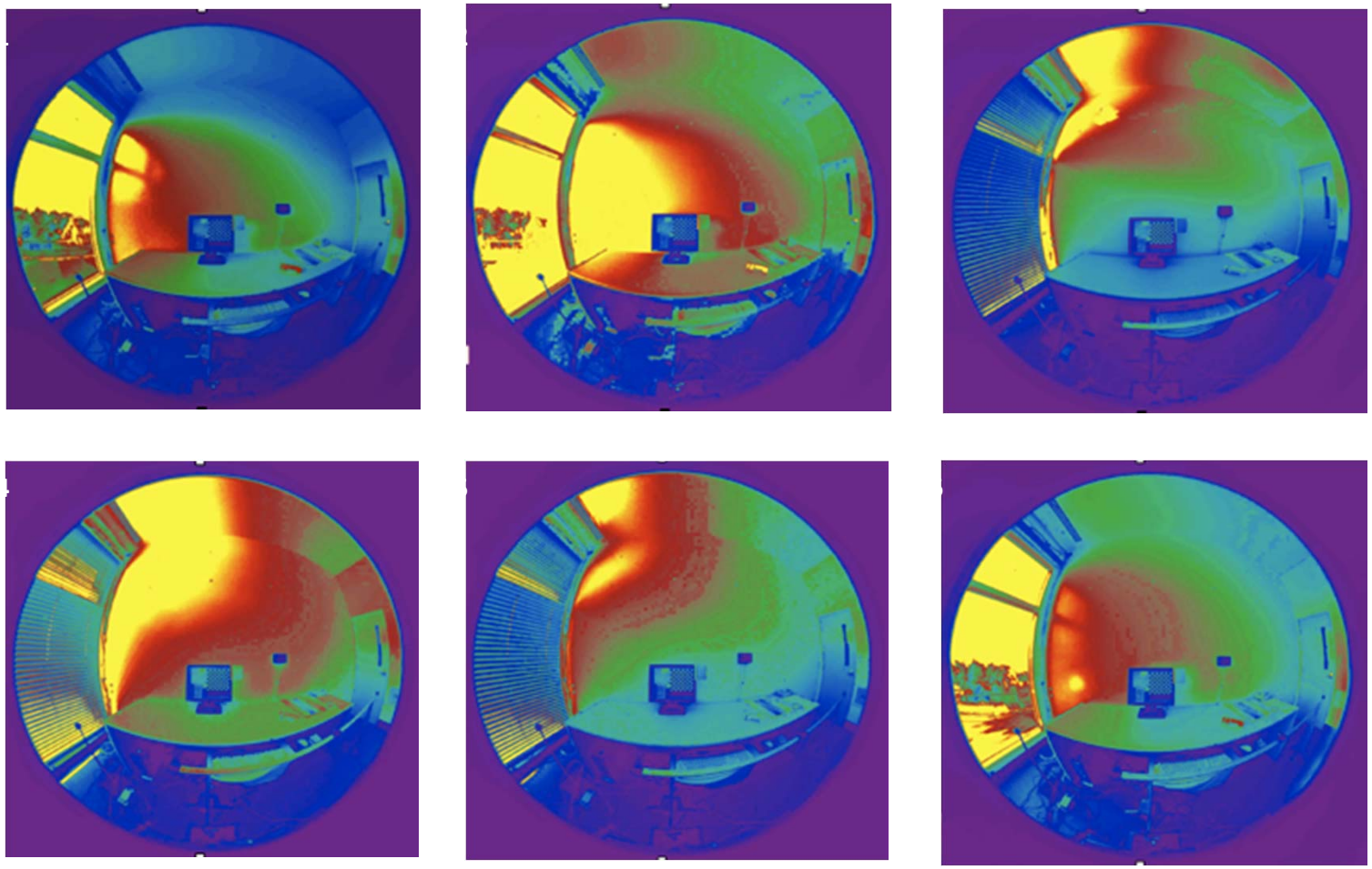
Owner/Operators
Public, Private

Utilities

2007-2012
Automated Shades

Automated Shading Controls Glare Throughout the Day

Optimize Energy **and** Occupant Comfort;
Measure Dynamic Patterns of Interior Daylight Luminance



Time lapse images from tests in LBNL Façade Test Facility

Test Bed -> **Pilot Demonstration**: Emerging Integrated Systems

- **Electrochromic Windows**
  - Automated control
  - Manual override
- **Lighting Controls**
  - DALI dimmable ballasts
  - Architectural scenes, occupancy, daylight controls

FLEXLAB – An Overview

- **Why: Advances DOE, Utility, & Industry Energy Efficiency Priorities**
  - Enables development, testing, validation of slow energy systems
- **What: Unique, "Swiss-Army Knife" Facility to Fill RDD&D Gaps**
  - 4 outside cells with interchangeable components
  - Indoor living lab space in Building 90
  - Full suite of controls, sensors, submeters
- **Who: Available for critical stakeholders & decision-makers**
  - Manufacturers & Suppliers
  - Utilities, Emerging technology programs
  - Design Firms, Buildings Owners & Investors
- **How: Quickly evaluate range of technologies, model scenarios**
- **Where: LBNL**
- **Funding: U.S. DOE, ARRA funding, $15.9M, FY10**
- **When: Begin operation early FY13; Full operation in FY14**

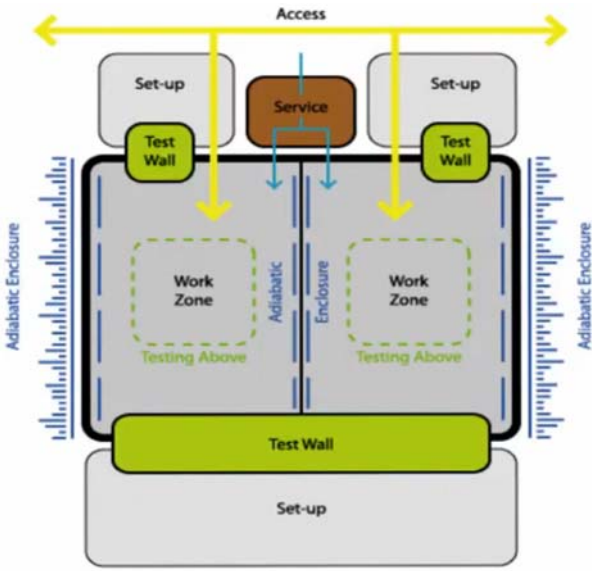
DOE RFP → Lessons Learned → Solutions New Functional Needs and Design Criteria

- Realistic Performance: "weather" and "systems" essential
  - Realism vs Flexibility in Construction, Operations
  - Occupant impacts are key: Building system <-> People
- Data collection, Processing, Sharing → Real time
- "Side by Side" needed to "unravel" climate impacts
- Orientation: South -> Variable
- Space Size and Type:
  - 1 zone deep -> 2 zones deep
  - 1 story -> 2 stories and high bay
- Systems: Envelope/Lighting -> Thermal impacts, Comfort
- Energy vs Occupant Impacts
- Facility Operating cycle/costs: Optimize for partners, facility efficiency
- Climate: extend with "operating strategy" and by Simulation

FLEXLAB Capabilities

- **Comparative "outdoor" testing**

- **Controlled indoor environment**
  - Capabilities to extend to larger interior/exterior delta T to simulate other climates
  - Controlled internal loads – lighting, plug loads, occupancy/thermal generation
  - No externalities such as occupant behavior

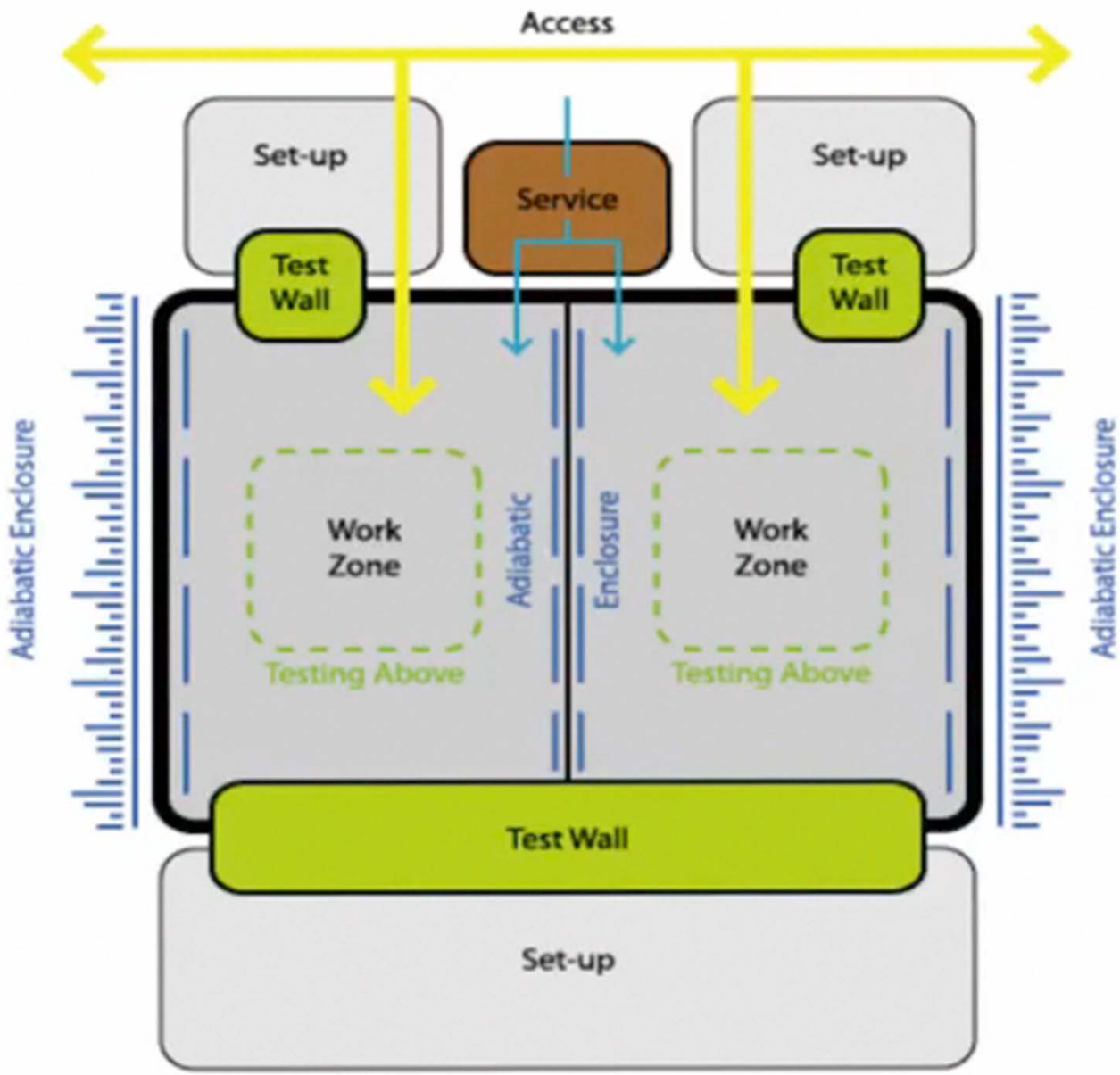


- **Heavily instrumented and metered facility**

- **Provides access to multiple flexible systems**
  - Many manufacturers don't have testing facilities that can be used to integrate controls with other systems

- **Highly flexible testbeds – interior and exterior assemblies**

- **Kits of parts available to mockup new construction and retrofit conditions**



Test Bed Diagam

Functionality → Technical Features and Performance Requirements

Interchangeable Glazing/Facade Elements
- High performance Integrated façade systems

Flexible HVAC
- Air-based & water-based capabilities

Flexible Interior Designs
- Ceiling/floor height
- Furniture systems
- Lighting system & control

1 Large Space for Multizone Studies – or –
2 Adjacent Cells for Comparative Studies

High-Bay Space for Air flow, Lighting, Skylights – or-
Intermediate Floor for 2 story space

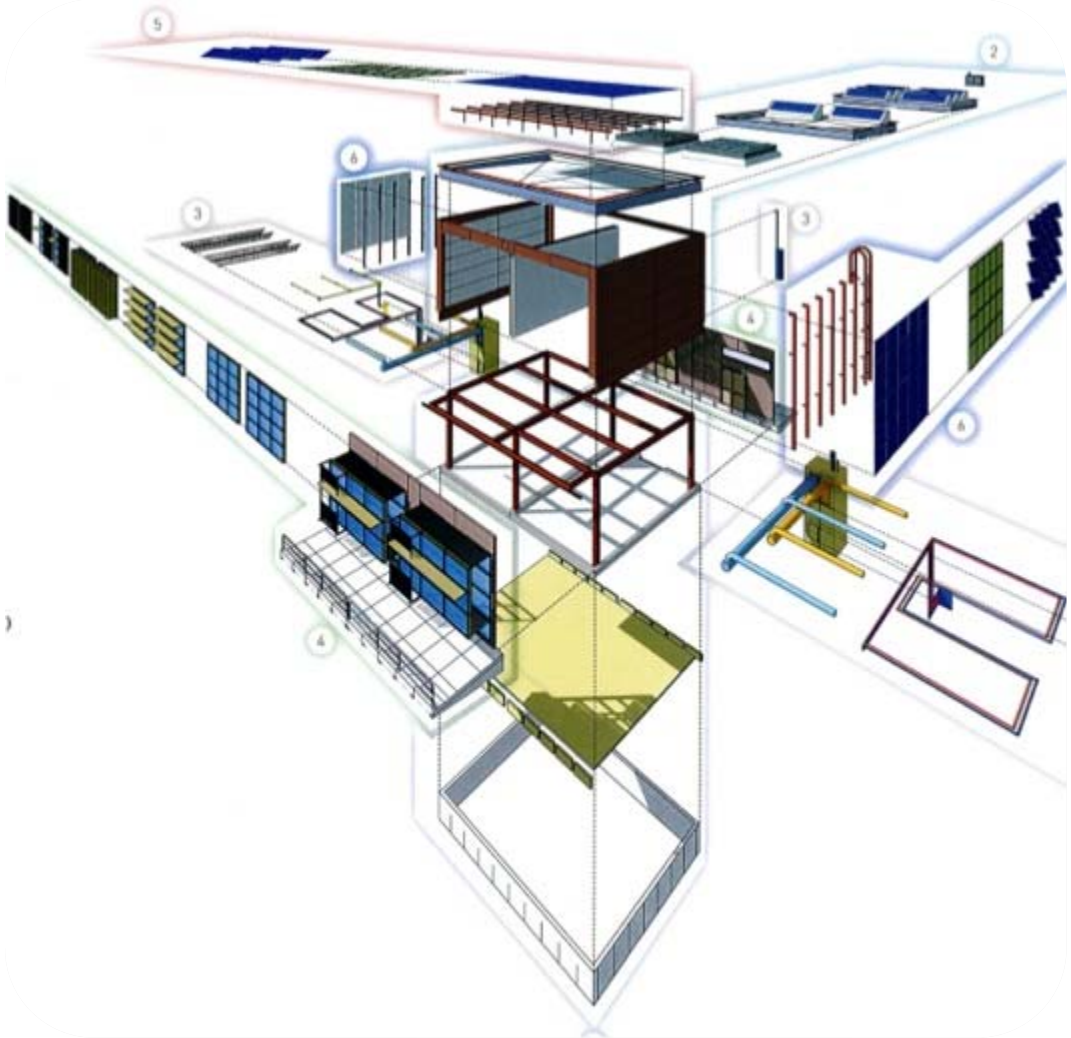
Rotating Test-Bed – Sun Tracking or Non-South, Fixed

Robust Sensing & Controls

Open Source Data Acquisition

Sensors/Controls Lab
Demand Response Integration

Design Integration and Visualization Lab



3 “Types” of Integrated Systems Test Beds

New Construction Test Beds

- Focus on Integrated Systems & retrofit
- 4 units; 4800SF
- Outside B90
- Opens in 2013

Occupied Lighting & Plug Load

- ~3000SF inside B90
- Span width of B90
- Controls, Visual Comfort & Behavior

Controls & Visualization

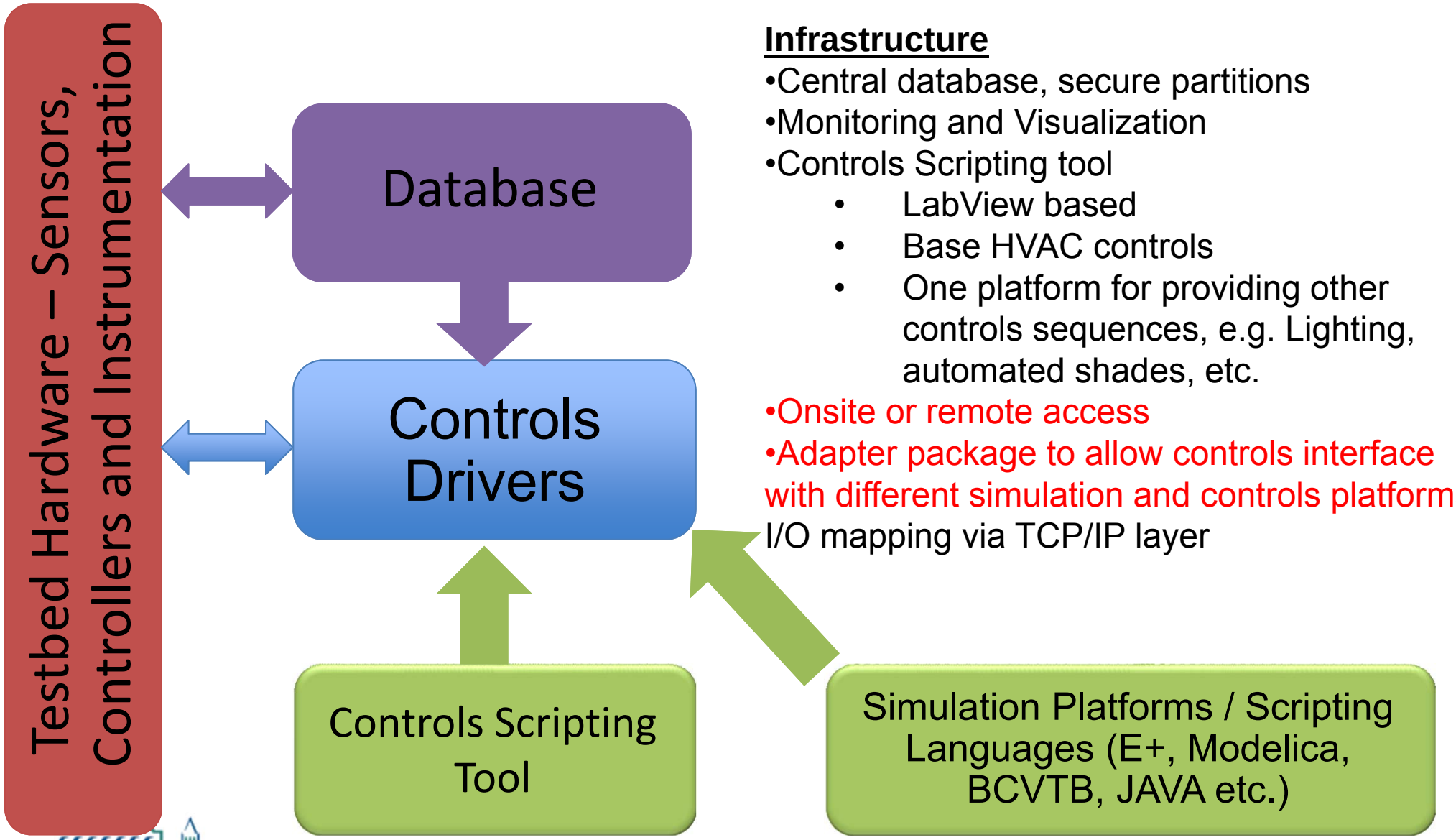
- Virtual Design & Modeling
- Controls Interoperability
- DR Integration
- ~1000SF inside B90

Overview of Initial 'Fit Out' of Outdoor Testbeds

Ranges from 1980's Retrofit Options to Net Zero Solutions

- Suites of envelope, lighting and HVAC terminal system fitouts around a "technology" theme
  - 1A/B: ASHRAE 2010 baseline;
    ASHRAE 2010 baseline w/ exterior shading
  - 2A/B(High Bay): CA T24-2013 baseline;
    CA T24-2013 baseline w/ext. shades
  - 3A/B: 1980s baseline;
    1980s baseline w/exterior shading
  - 4A/B: CA T24-2013 baseline w/ext. shades;
    'Net Zero' baseline w/ext. shades

Data Acquisition and Controls



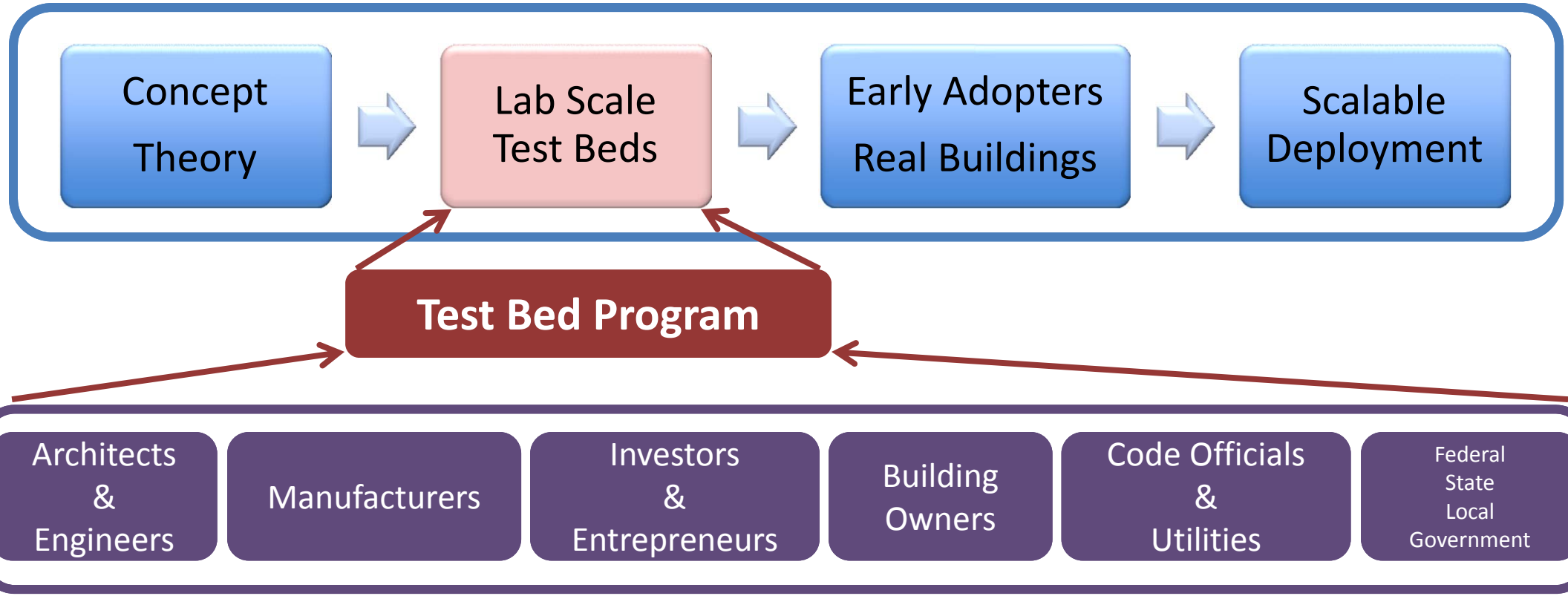
Infrastructure

- Central database, secure partitions
- Monitoring and Visualization
- Controls Scripting tool
  - LabView based
  - Base HVAC controls
  - One platform for providing other controls sequences, e.g. Lighting, automated shades, etc.
- Onsite or remote access
- Adapter package to allow controls interface with different simulation and controls platforms; I/O mapping via TCP/IP layer

User Requirements and Facility Functionality

- **Focus on the Key Enabling Science for Very Low Energy Buildings**
  - Integrated Systems focus
  - Integrated Whole Buildings focus
  - Integration of technology, people, process
  - Extend measurement impacts with advanced simulation
- **Aggressive Industry Engagement, Partnership**
  - Manufacturers, Designers/Engineers, Owners,
  - Multiple test beds allow broader industry engagement
  - Multiple “business approaches” to accommodate industry
  - Partner with other researchers - e.g., National Lab, university,….
- **Rapid Response in Facilities Operation**
  - Flexible hardware, systems change-outs
  - Ability to adapt over time to changing industry needs
  - Rapid turnaround for data availability and remote access

In Parallel with Facility Design Effort, Engage with Industry; Create Deployment Strategy



Key Challenge – Test Beds Must Support Different Outcomes for Different Users

- **Architect/Engineer/Contractor** – guide specification reducing performance risk, installation risk, total cost of ownership
- **Building Owner/Operator** – accurate performance information, reduce risks on investments
- **Manufacturer** – neutral source of testing data, ability to rigorously test system integration under controlled conditions

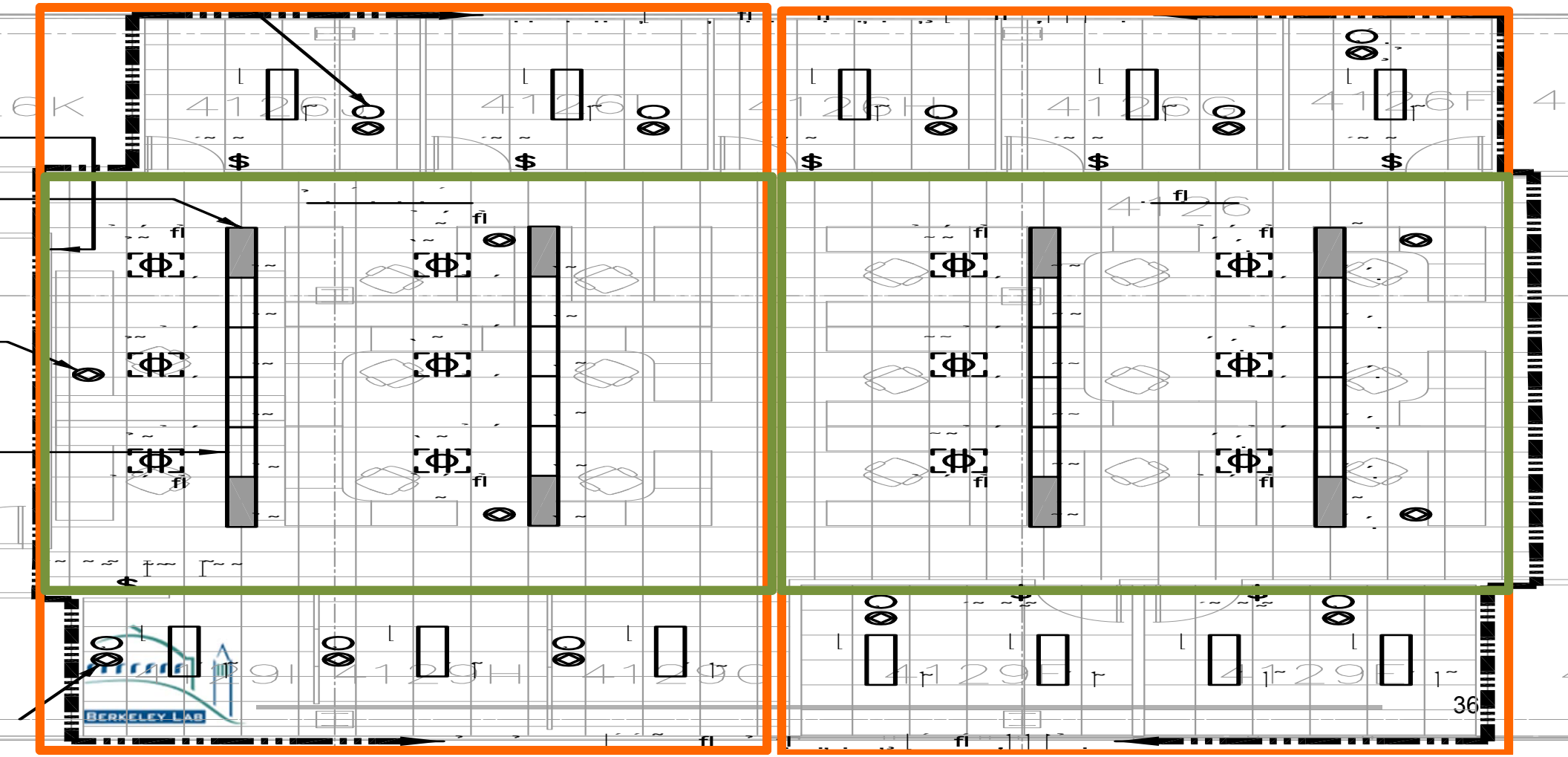
- **Emerging Technology** – neutral source of testing data, ability to test system at scale, neutral comparison to conventional technology
- **Utilities** – clarity on cost of operation and ownership, performance data, effect of controls strategies on demand
- **Public Sector** – objective performance data to drive policy

Examples: Partnering Opportunities

Facility Capability	Integrated Systems Testing	Product Development	Technology Validation
Partner	**Lighting Manuf.**	**HVAC Manuf.**	**Utilities**
Objective	Rapid-prototyping platform for controls development	Demonstrate efficiency of variable refrig flow systems and occupant acceptance	Assess efficiency potential of systems
Market Impact	Introduce improved control algorithms to market	Demonstrate scalable potential for technology adoption and new markets	Address cost and feasibility barriers for increased adoption
Benefits over existing resources	Extensive measurement scope	Ability to iterate through high-risk deployment strategies	Reduced risk for dissatisfaction in occupied building

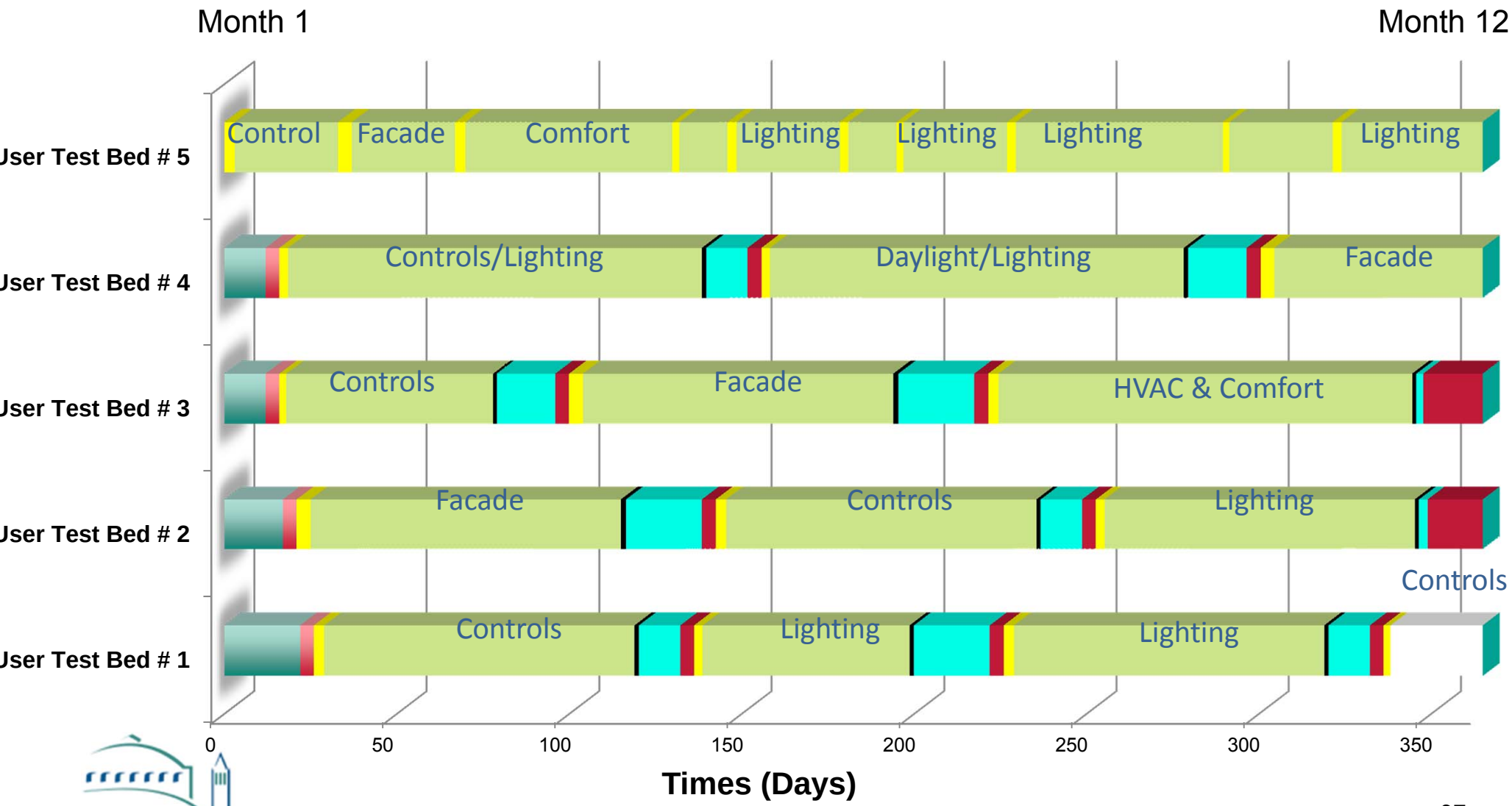
2012: Launch Occupied Lighting & Plug-Load Testbed

- 3000sf Office area on 4th floor of Building 90,
  - 18 open cubicles (interior zone)
  - 10 perimeter offices on the east and west sides of the building.



Planning for FLEXLAB Partner Use: Hypothetical Schedules to Assess Time and Cost to Users

(e.g. Setup <-> Sensor Calibration <-> Teardown cycle over 1 year)

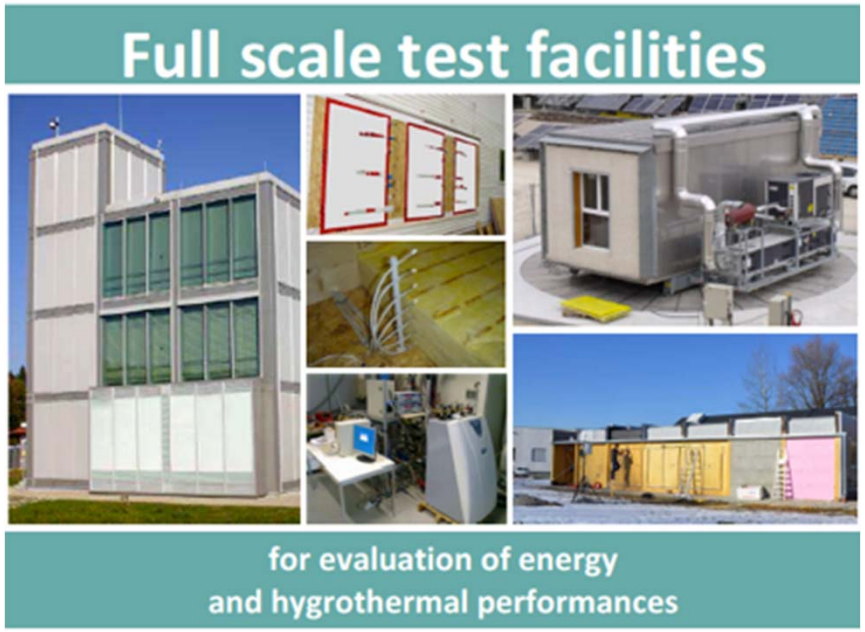


Leverage DOE Collaboration

- **DOE Commercial Building Partnerships Program ($40M)**
  - Explored performance of integrated technologies across different building types, climates, new/retrofit
- **DOE Shading/Daylighting Demo Programs**
  - Goal: quantify performance and cost/savings
  - New and Retrofit
  - Projects: Late planning stage, under construction
- **International Collaboration: IEA Annex 58**
  - Collaborative R&D: Share models, data, procedures,….
- **AECO Partnership- "Guaranteed Energy Performance"**
  - Close the gap between "design intent" and "measured performance"
  - Partnership with leading firms to test and deploy tools, findings,….
- **Simergy – New GUI for EnergyPlus**
  - Imports from BIM tools, life-cycle support; Extend FLEXLAB results

20+ years of International Collaboration: Dynamic Field Testing of Building Systems

International Workshop
Brussels, March 30-31, 2011



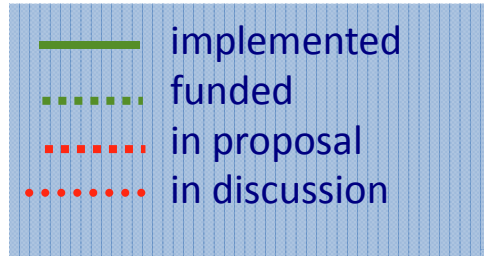
INIVE

An initiative of DYNASTEE network and INIVE EEIG
Edited by A. Janssens (UGent), S. Roels (K.U.Leuven), L. Vandaele (BBRI)

Building Control Virtual Test Bed

Open-source middle-ware based on UC Berkeley's Ptolemy II program.

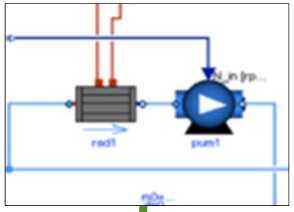
Synchronizes and exchanges data as (simulation-)time progresses.



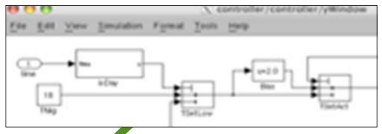
building energy
TRNSYS

building energy
EnergyPlus

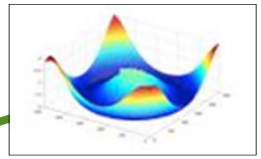
HVAC & controls
Modelica



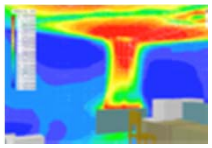
controls
Simulink



controls & data analysis
MATLAB



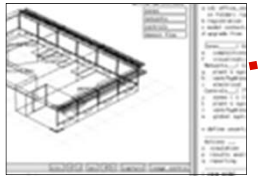
airflow
Fluent



BCVTB

wireless networks
Ptolemy II

building energy
ESP-r

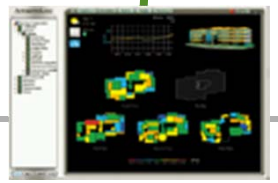


real-time data
www+xml

hardware in
the loop

fenestration
Window 6

building automation
BACnet



lighting
Radiance

Facility Launch and Timing
Operational Planning

1. **Operational Phase- In Plan**
   - Year 1 (FY12-13) Pre-planning, Construction
   - Year 2 (FY13-14) Shakedown & Initial Operations
   - Year 3-5 (FY14-16) Launch & Full Operations
2. **Develop All Management & Operations Tools**
   - User Agreements and Support Process
   - Efficient, Flexible, & Safe Operations
   - Industry Partnerships
   - National Network of Building Research Testing Facilities
   - Global Network IEA Annex 58: *Dynamic Field Performance of Buildings*
3. **Initial Partners and Projects - Discussions in Progress**
   - Public and Private: funding models
   - R&D ---- Emerging Tech ----- Deployment

Can FLEXLAB Support Current and Future Utility ET Research and Business Needs?

- **Current Design Provides Broad Functionality**
- **But Research and Business needs change**
  - **We have built Flexibility into the Design of the Facility**
  - **We have built Flexibility into our Operating Process**
- **Continued dialogue with partners as construction proceeds**
- **Developing "horizontal" and "vertical" public/private partnerships**

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