FLEXLAB: Facility for Low Energy eXperiments in Buildings: Supporting Progress Toward NZEB

Stephen Selkowitz
Principal Investigator
Building Technology and Urban Systems Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
seselkowitz@lbl.gov
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% \( \text{CO}_2 \) emissions
- 71% of electricity
- 54% of natural gas
- 5.8 terawatts (TW) of peak power
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?

- **Deep**
  - Major advances in components
  - Demonstration projects
  - Limited deployment in systems
e.g. Research, Demonstrations 50% to Zero Net Energy

- **Shallow**
  - Incremental change on existing technology
  - Tighten standards; tune up & retrofit programs
e.g. ESCOs 5-20% Savings

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

- **Breadth**
  - 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?

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

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

• **Major National Challenge**
  – Technically attainable - Difficult to achieve in scale
  – 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

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”

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

Interior and exterior sensors provide data
MoWiTT: Mobile Window Thermal Test Facility

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

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

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

Occupied 2007
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

Industry Advisory Groups:
Manufacturers
Glazing, Shading, Framing, Lighting Controls
Designers
Architects, Engineers Specifiers
Owner/Operators
Public, Private Utilities

2003-2006
Electrochromic windows

2007-2012
Automated Shades
Automated Shading Controls Glare Throughout the Day
Optimize Energy and Occupant Comfort;
Measure Dynamic Patterns of Interior Daylight Luminance
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
  o Enables development, testing, validation of slow energy systems

• **What:** Unique, “Swiss-Army Knife” Facility to Fill RDD&D Gaps
  o 4 outside cells with interchangeable components
  o Indoor living lab space in Building 90
  o Full suite of controls, sensors, submeters

• **Who:** Available for critical stakeholders & decision-makers
  o Manufacturers & Suppliers
  o Utilities, Emerging technology programs
  o 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**
  o Capabilities to extend to larger interior/exterior delta T to simulate other climates
  o Controlled internal loads – lighting, plug loads, occupancy/thermal generation
  o No externalities such as occupant behavior

• **Heavily instrumented and metered facility**

• **Provides access to multiple flexible systems**
  o 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**
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

**Simulation Platforms / Scripting Languages (E+, Modelica, BCVTB, JAVA etc.)**
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

![Diagram]

- Concept Theory
- Lab Scale Test Beds
- Early Adopters Real Buildings
- Scalable Deployment
- Test Bed Program

- Architects & Engineers
- Manufacturers
- Investors & Entrepreneurs
- Building Owners
- Code Officials & Utilities
- Federal State Local Government

-Berkeley Lab-
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

<table>
<thead>
<tr>
<th>Facility Capability</th>
<th>Integrated Systems Testing</th>
<th>Product Development</th>
<th>Technology Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner</td>
<td>Lighting Manuf.</td>
<td>HVAC Manuf.</td>
<td>Utilities</td>
</tr>
<tr>
<td>Objective</td>
<td>Rapid-prototyping platform for controls development</td>
<td>Demonstrate efficiency of variable refrigeration flow systems and occupant acceptance</td>
<td>Assess efficiency potential of systems</td>
</tr>
<tr>
<td>Market Impact</td>
<td>Introduce improved control algorithms to market</td>
<td>Demonstrate scalable potential for technology adoption and new markets</td>
<td>Address cost and feasibility barriers for increased adoption</td>
</tr>
<tr>
<td>Benefits over existing resources</td>
<td>Extensive measurement scope</td>
<td>Ability to iterate through high-risk deployment strategies</td>
<td>Reduced risk for dissatisfaction in occupied building</td>
</tr>
</tbody>
</table>
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
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, EnergyPlus, ESP-r
- airflow: Fluent
- building automation: BCVTB, BACnet
- fenestration: Window 6
- lighting: Radiance
- HVAC & controls: Modelica, Simulink
- controls & data analysis: MATLAB
- wireless networks: Ptolemy II
- real-time data: www+xml
- hardware in the loop

Implemented: Ptolemy II
Funded: in proposal
In discussion: in discussion
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

- More info:  flexlab.lbl.gov
  - SESelkowitz@lbl.gov  510/486-5064
  - Cindy Regnier  CMRegnier@lbl.gov
  - Oren Schetrit  Oschetrit@lbl.gov