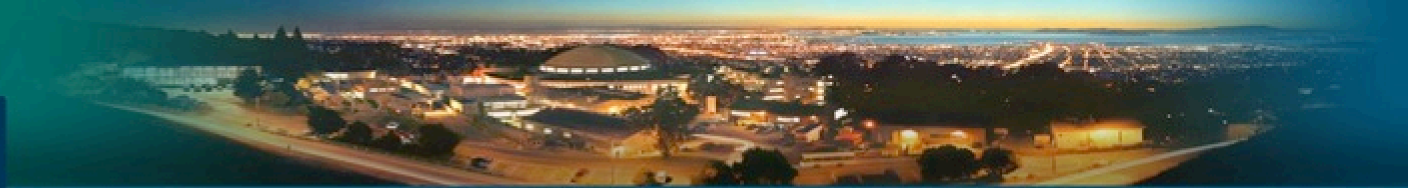


BERKELEY LAB

Environmental Energy Technologies Division Lawrence Berkeley National Laboratory

FLEXLAB

FACILITY FOR LOW ENERGY EXPERIMENTS IN BUILDINGS

The Potential Role of a New Generation of Outdoor Building Test Facilities for Validation of Whole Building Simulation Tools

S. Selkowitz

Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Program

Outline

- Background and Context for Systems Testing
- 30 years of Field Test Experience and Model Validation
- Design Criteria for FLEXLAB
- FLEXLAB Features and Status
- Initial FLEXLAB test projects
- FLEXLAB Calibration Status

DOE Goals: 50%+ Savings at Affordable Cost

Current Design and Research Paradigm – Silo Approach

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

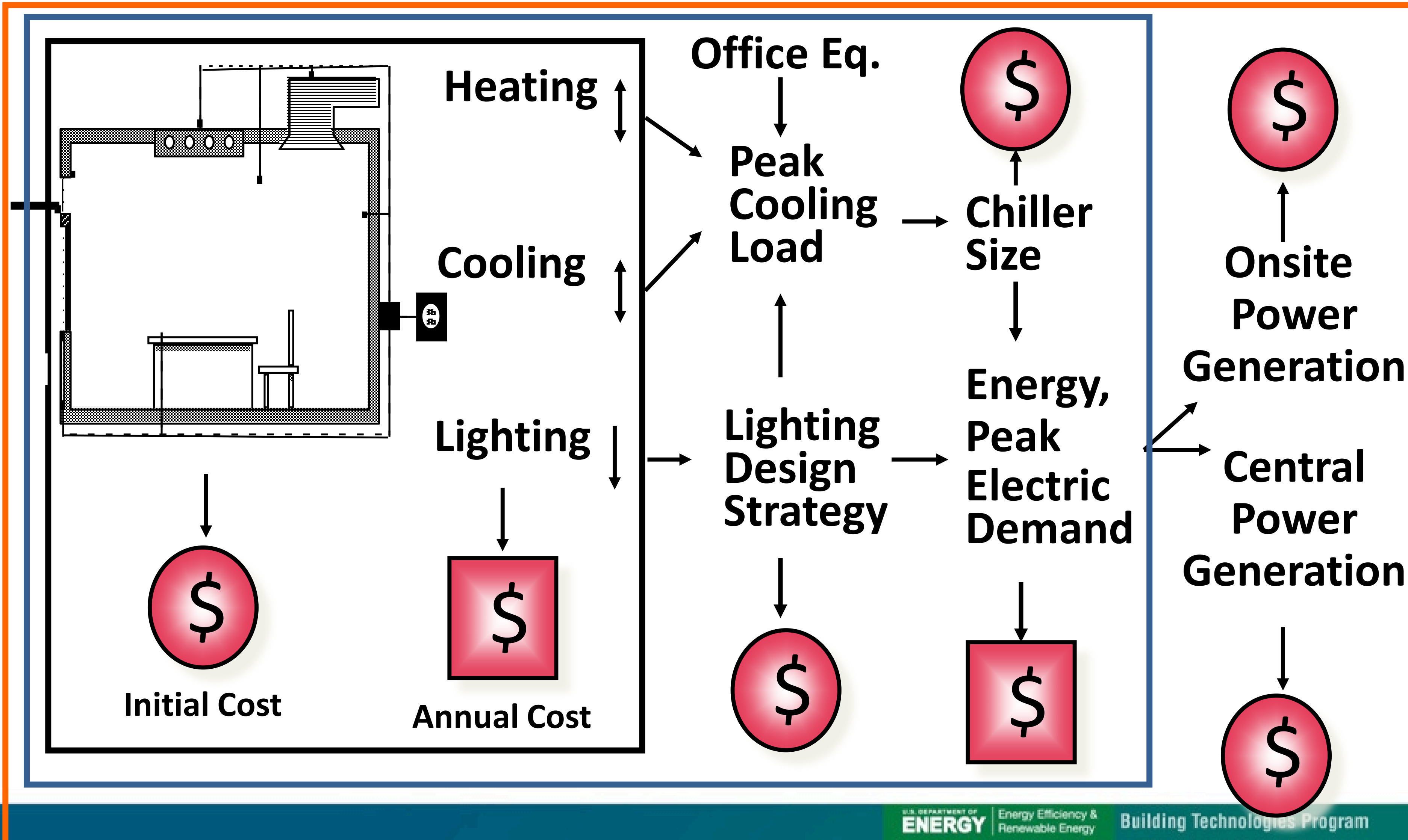
Integrated Building Systems Approach

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

Related Goals: **"All Buildings Net Zero Energy By 2030"**

Integrated Systems Performance:

Need Models/Data to Quantify Investment Tradeoffs
Loads -> Systems -> Supply



FLEXLAB Background

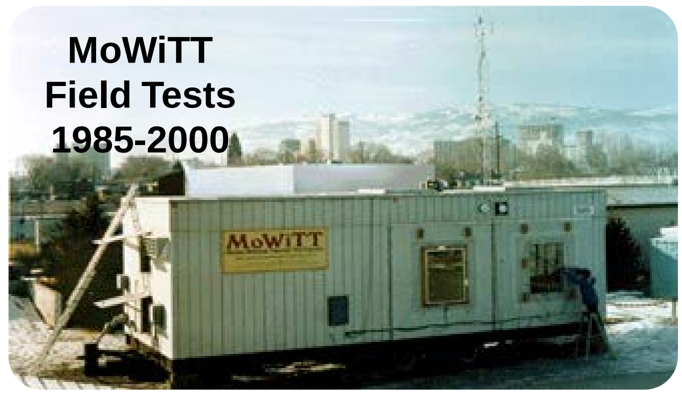
- LBNL responded to a 2009 RFP for ARRA funds to develop a facility that:
  - o Develops new test methods and solutions for low energy buildings including **low-energy, integrated building systems** under realistic operating conditions
  - o Focuses on:
    - Comprehensive whole building **systems integration**
    - **Specific end use integration and component interactions** (e.g., HVAC, lighting, windows, envelope, plug loads control systems)
    - **Controls hardware and sensors**
    - **Simulation and tools for design through operations**

- FLEXLAB developed with input from 35 industry partners
- Commercial buildings focus - retrofit and new construction

Past LBNL "Testbed" Experience

NY Times Mockup and Test bed 2003-2007

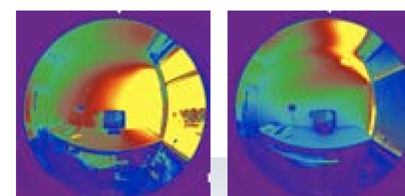
DOE- EC and Dimmable Lighting 2010

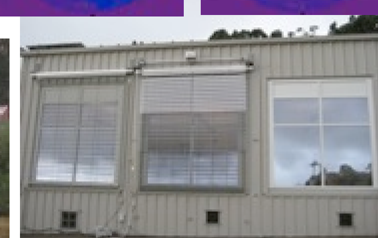


MoWiTT Field Tests 1985-2000

DOE/CEC/PG&E Electro-chromic Daylighting Testbed Oakland CA, 1999

DOE/CEC Advanced Façade SystemsTestbed LBNL 2004-2012





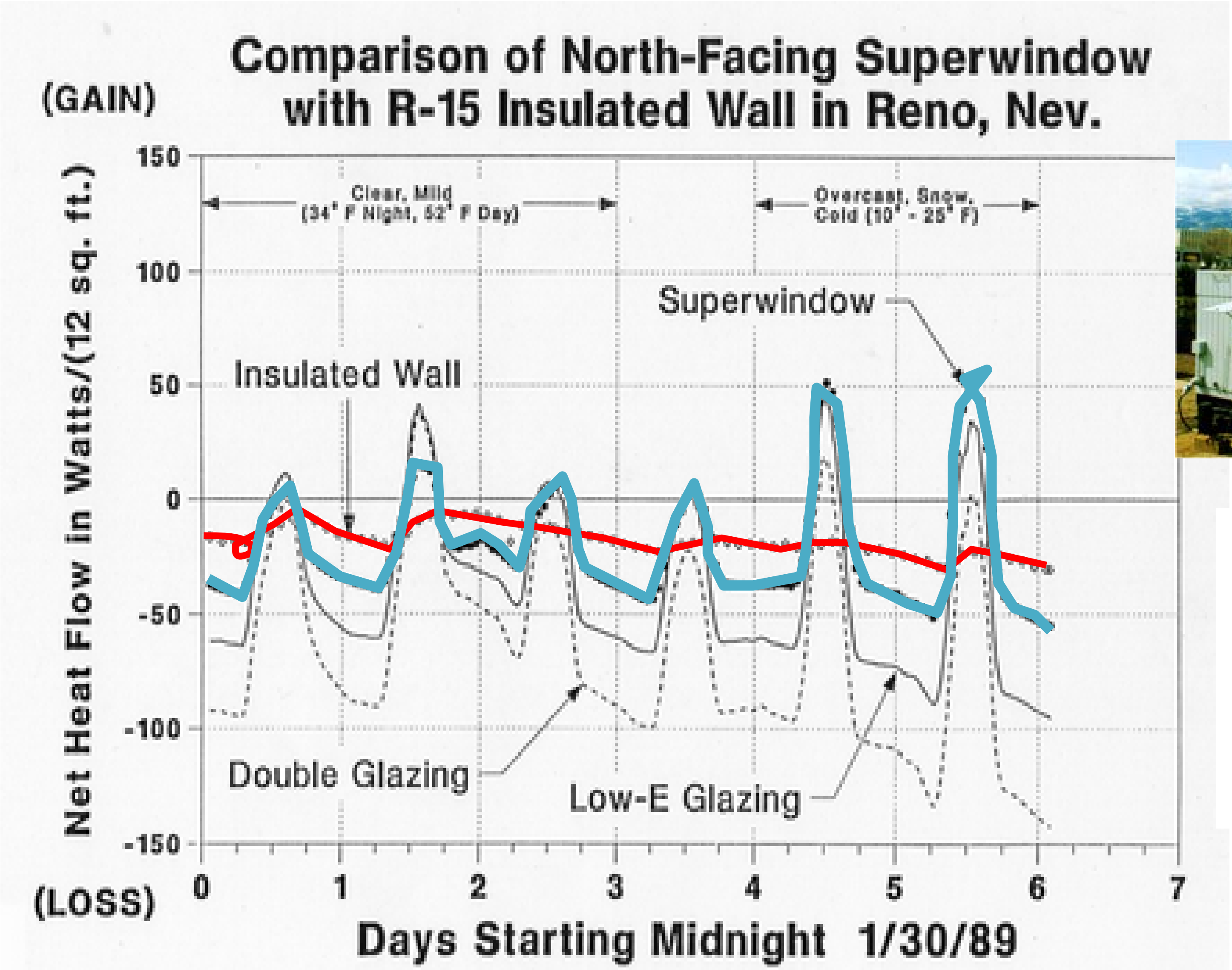
MoWiTT: Mobile Window Thermal Test Facility

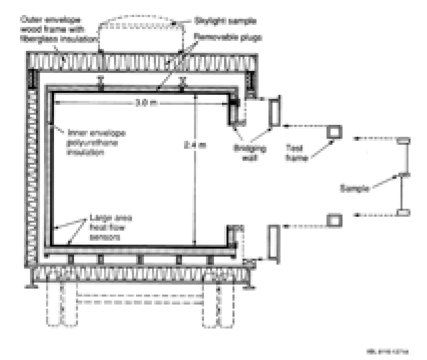
Reno, NV, 1985-2000; Berkeley 2012+

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

"North-facing Windows Outperform Insulated Walls during winter heating season"





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“71T” - Advanced Façade Test Facility

Features

- 3 side by side spaces, south
- Room size, can be occupied
- Façade/lighting - changable
- HVAC- accurate measured response

- High precision measurements
- Complex glazing characterization
- Lighting controls integration
- Visual comfort analysis
- Shading system characterization
- Control algorithm development

Outcomes

- New technology development
- Control systems optimization
- **Simulation model validation**
- Guidance for AEC community
- Input to Codes and Standards

LBNL Advanced Façade Testbed Facility

2003-2006
Electrochromic windows

- Berkeley, South facing 3 Rooms
- Changeable façade
- Lighting, HVAC
- Heavily instrumented
- Static/Dynamic
- Occupant Studies
- Controls/Automation

Industry Advisory Groups:

Manufacturers
Glazing, Shading
Framing, Lighting
Controls

Designers
Architects, Engineers
Specifiers

Owner/Operators
Public, Private

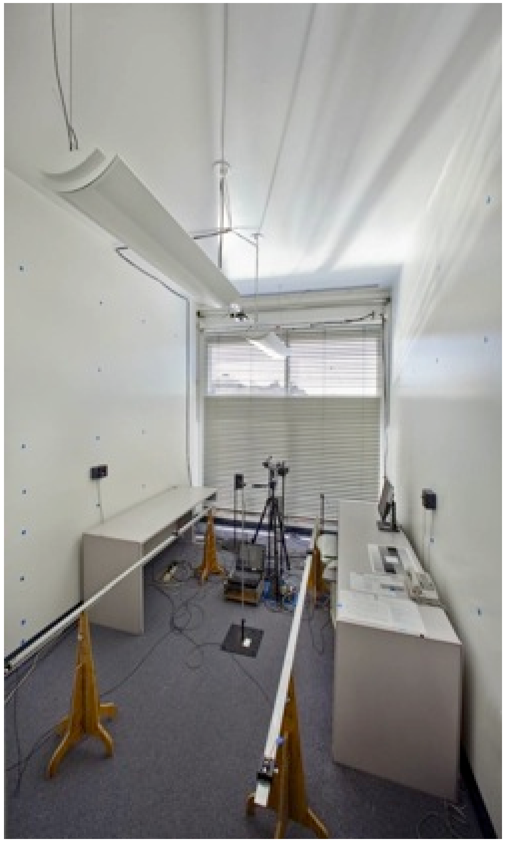
Utilities

2007-2015
Automated Shading

Integrated Shading and Lighting Controls in LBNL Facade Testbed Facility

External Dynamic Shading

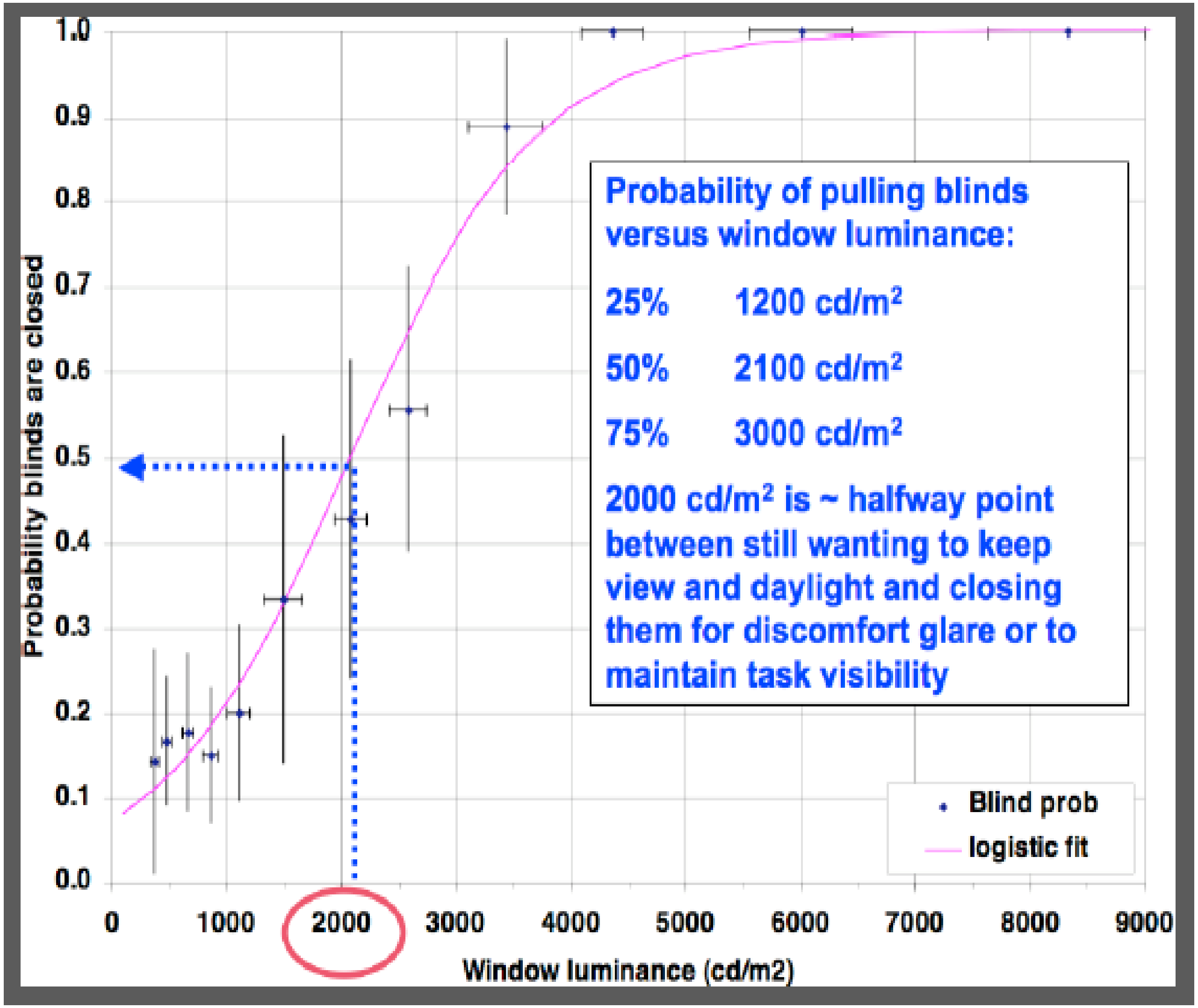
Daylight Redirecting Glass



Electrochromic Glass

Occupant Studies in Testbed Identify When to (automatically) Close the Blinds….

Probability Blinds are Closed



Window Luminance (cd/m2)

What is FLEXLAB?

Exterior Testbeds

Integrated Systems and Components

1 story/2 story, rotating

Lighting & Plug Load Testbed

Occupied Space

Fixtures, Controls,

Visual Comfort & Behavior

Virtual Design/Visualization

Virtual Integrated Design & Visualization of Experiments

"To transform commercial building industry practice from a component-based focus to integrated systems in design and operations, achieving cost-effective, aggressive net-zero energy goals in new and existing buildings."

Reconfigurable, "Kit-of-Parts"

Interchangeable lighting and controls

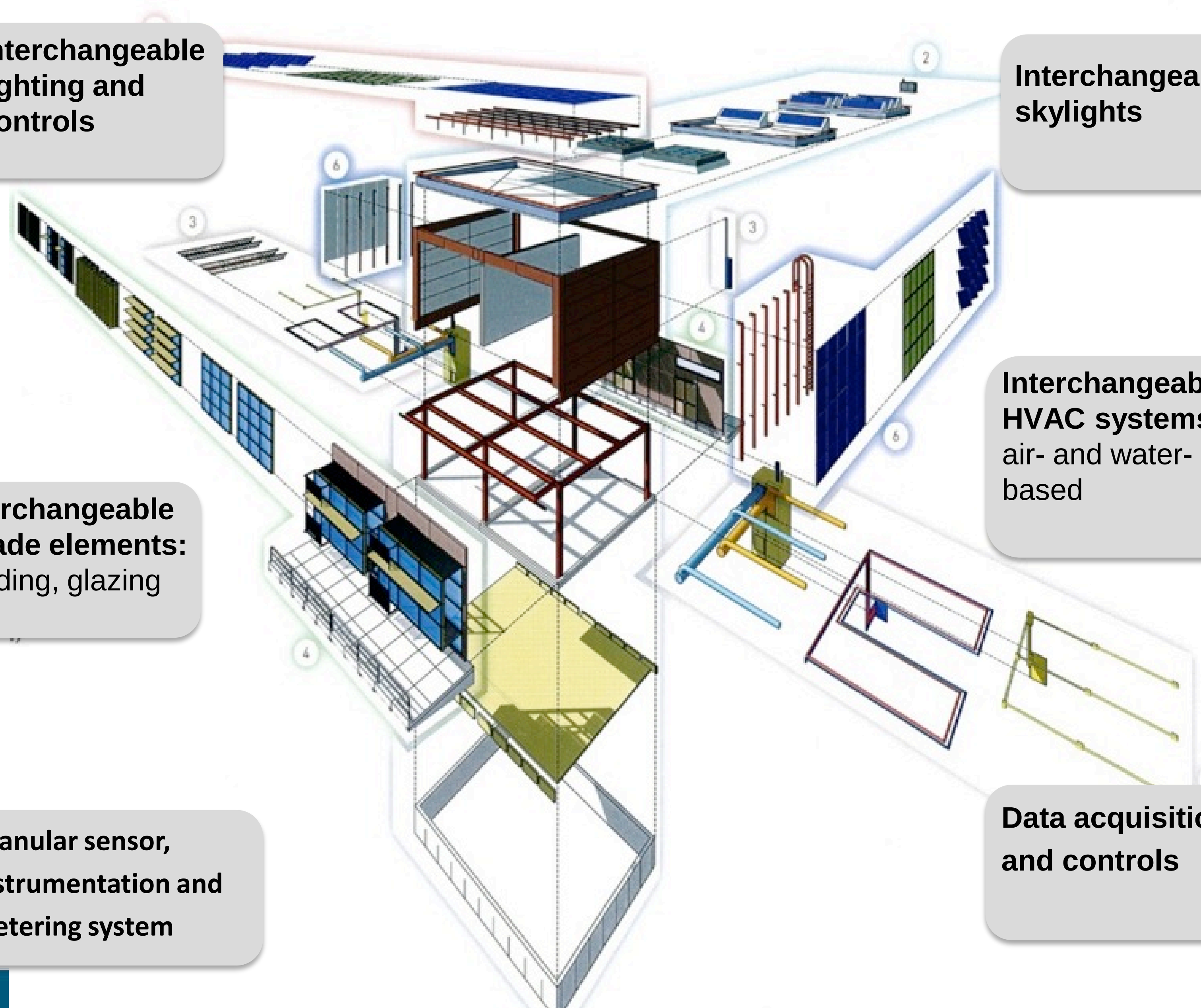
Interchangeable skylights

Interchangeable HVAC systems: air- and water-based

Interchangeable façade elements: shading, glazing

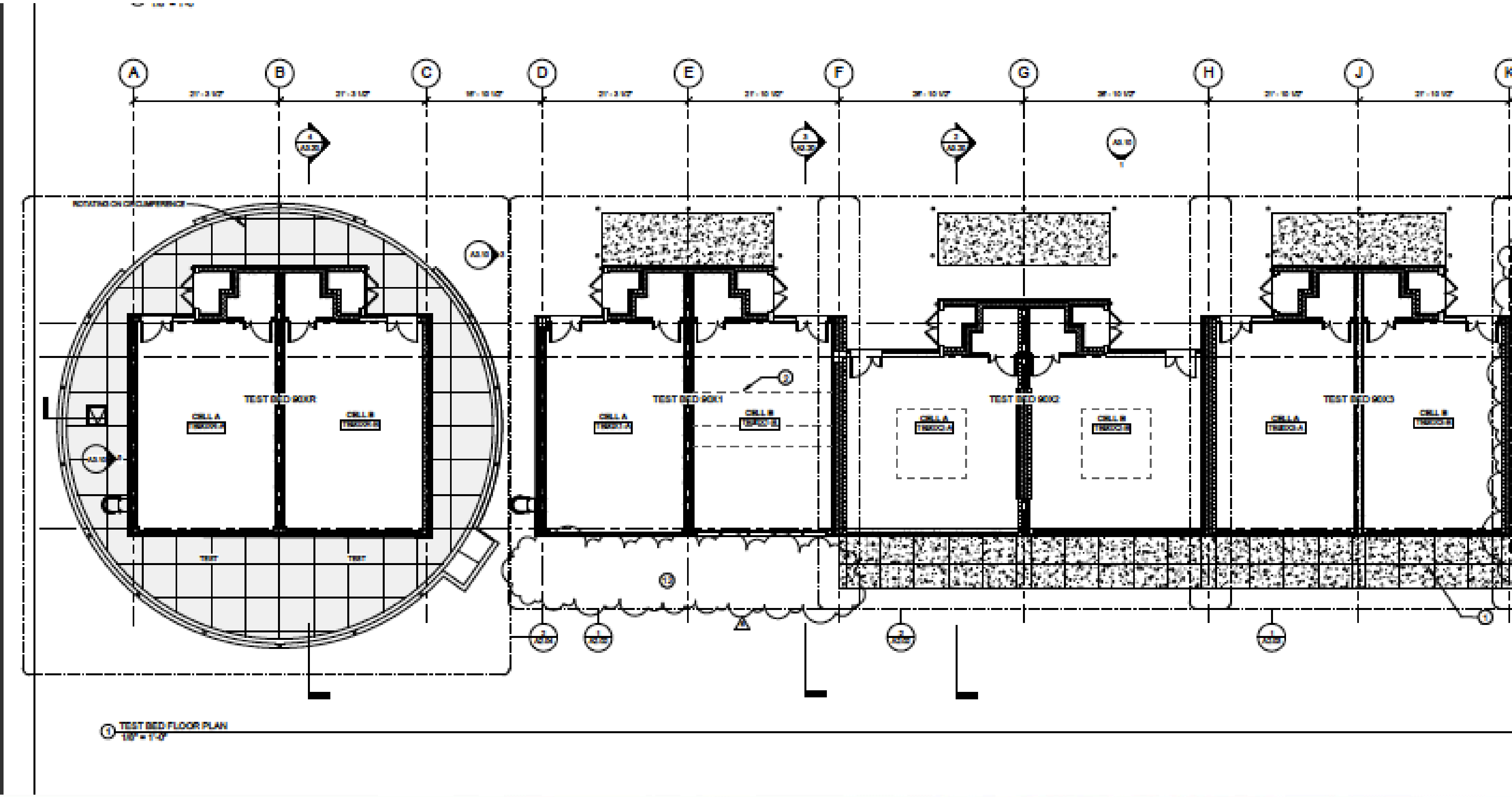
Granular sensor, instrumentation and metering system

Data acquisition and controls



Construction 2013

Plan view of 4 exterior testbeds; rotating unit on left



Left: Rotating Testbed

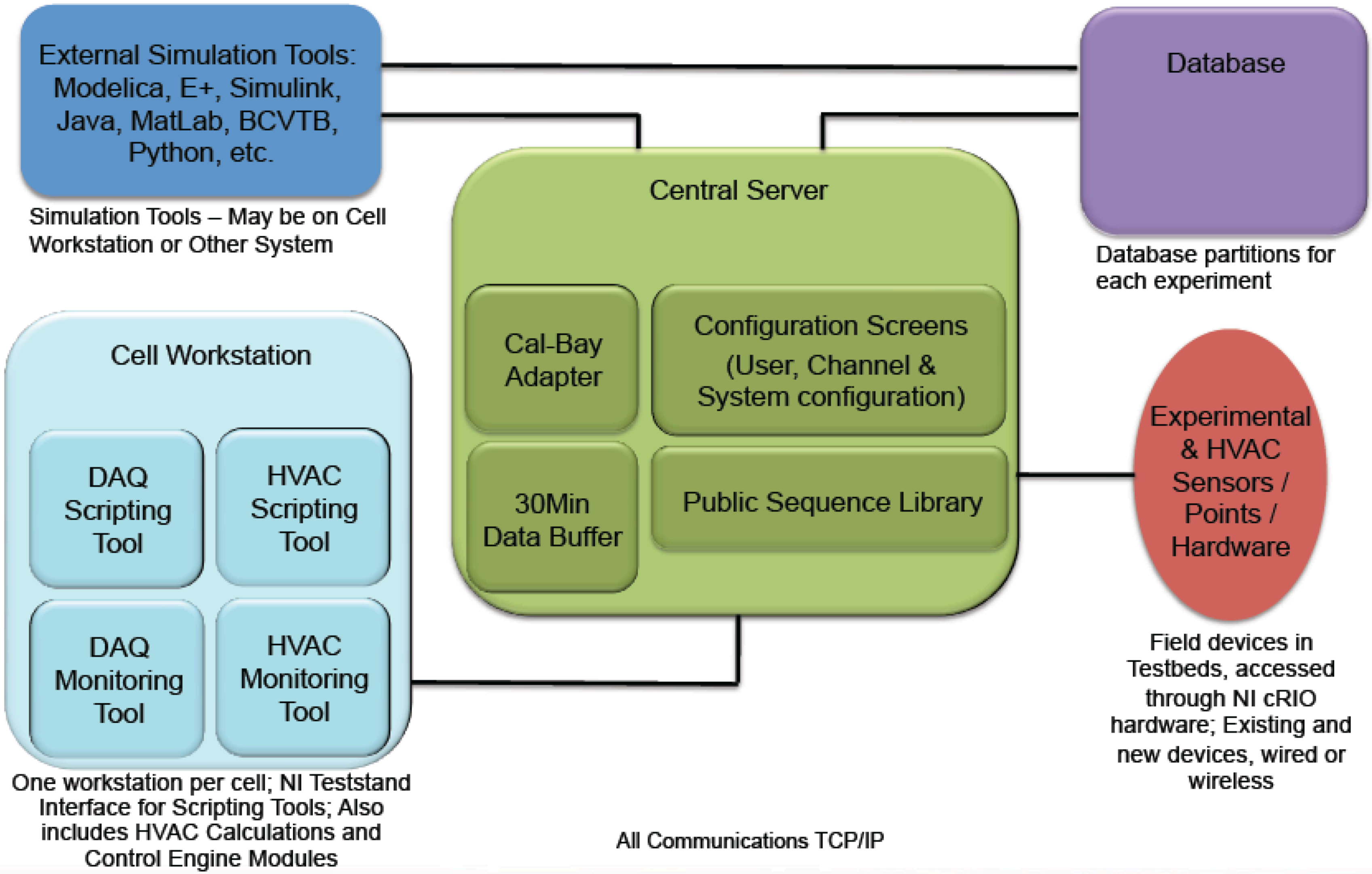
Below: three south facing testbeds

FLEXLAB Capabilities – Exterior Testbeds

- **Comparative testing**
- **Controlled environment**
  - Capabilities to simulate other climates
  - Controlled internal loads
- **Well instrumented and metered facility**
  - High granularity of power measurement
  - High accuracy sensors – temperature, pressure, air and water flow, heat flux, etc.
- **Highly flexible testbeds – interior and exterior**
  - HVAC, lighting, glazing, skylights, shading, etc.
- **Mockup new construction and retrofit conditions**
  - First fit outs represent 1980s, current code and net zero
- **Provides access to multiple flexible systems**
  - Many manufacturers don't have testing facilities to integrate controls with other systems

Interior view, to back of room; Nominal ducts and fixtures in place; unfinished ceiling plane

DAQ and Controls Architecture

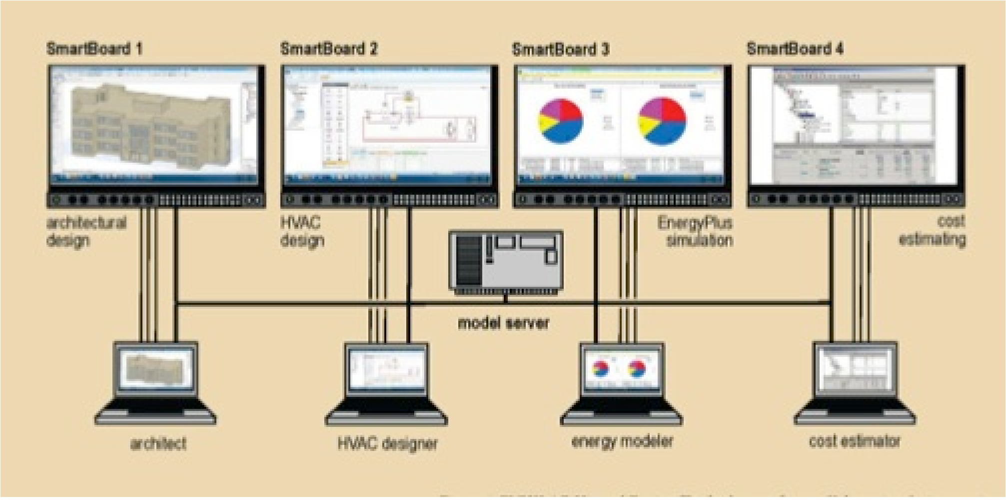


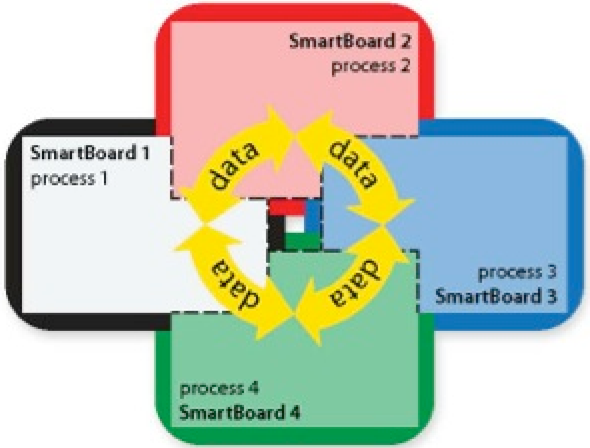
Features – Lighting and Plug Loads Testbed

- 3000sf occupied workspace
- Occupancy sensors at lighting zone level and workstation/occupant level
- Capable of multiple zones for comparative testing
- Photosensors at individual workstations
- Reprogrammable lighting and plug loads controls
- Individual occupant controls – workstation digital switches reprogrammable to control lights or plugs
- Power measurement at individual outlet level and each light fixture

Features – Virtual Design Testbed

- Interactive collaborative design environment
- Work interactively on design problems
- Reliable data sharing
- Modify designs and analysis impacts immediately
- Simultaneous platforms
  - Energy modeling tools
  - Energy data tools
  - Design tools
  - Cost estimation tools
- Enable value engineering decisions analysis
- Infrastructure:
  - 4 SmartBoards
  - Common server
  - Full wireless internet connectivity
  - Seating for 30 people





Purpose and Objectives of FLEXLAB

Problem Statement: Key challenges for 3 target users:

	Challenges
Utilities	**Component** level ET reaching cost-effective max. **System** level ET opportunities need comparison studies to determine savings. **Field demo variable conditions** unsuited for systems assessment.
	Design assistance programs need **validated strategies**
	Modeling tools need to include ET, and predict with confidence
Manufacturers	**Manufacturers lack facilities** and expertise to develop & test integrated solutions across building systems
	Products and solutions need **validated performance** against baselines for integration into codes and standards
	Design tools need to accurately represent new ET for adoption
AECO (Architects, Engineers, Contractors, Owners))	**Technology** performance data needed to design with **confidence**
	Performance based mockups optimize and quantify performance to allow **design** to be predicted with **confidence**. Opportunities for better construction, Cx **lowering change orders and total costs**.
	Buildings tend to use more energy than design predictions. **Simulation tool algorithms need validation**.

FLEXLAB Delivers

High accuracy comparative tests

Develop/test integrated system solutions

Validated tools close gap-predicted to actual performance

Building Design Tools -> Performance

- Energy Goal
- “Model”
- “Optimize”
- VE
- (re-Model?)
- Code
- LEED
- Build--
- CX
- Occupy
- Operate

How Can We Guarantee Performance???

Gap: Design Predictions -> Measured Performance?

Measured Performance =

- o Design Goals x
- o Simulation Tool Accuracy x
- o Simulator Skill x
- o Value Eng'ing "Aftermath" x
- o Construction "Artifacts" x

Design/Construct
A/E Team

- o Schedule "Adjustments" x
- o Facility Operations x
- o Occupant "Adjustments x
- o Weather "Adjustments"

Operate
Facilities Team

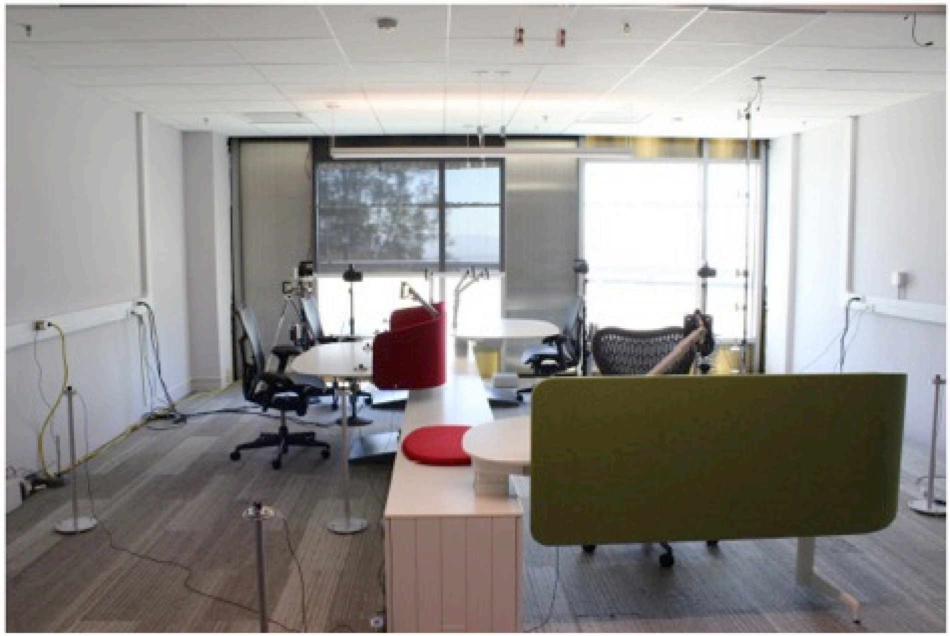
What is the Sensitivity/Uncertainty Associated with Each Factor?

FLEXLAB Launch – FY14

- Complete Construction
- Calibrate
- Operate
  - Validate tools
  - Test systems….

4 Questions for a Building Owner
(Phil Williams, Delos/Webcor)

- **Do We Understand Predicted Performance vs Actual?**
- **Will We Be Providing Comfort for Occupants?**
- **Is the Space Plan Optimal?**
- **Does the FM Team Know How to Operate the Systems?**

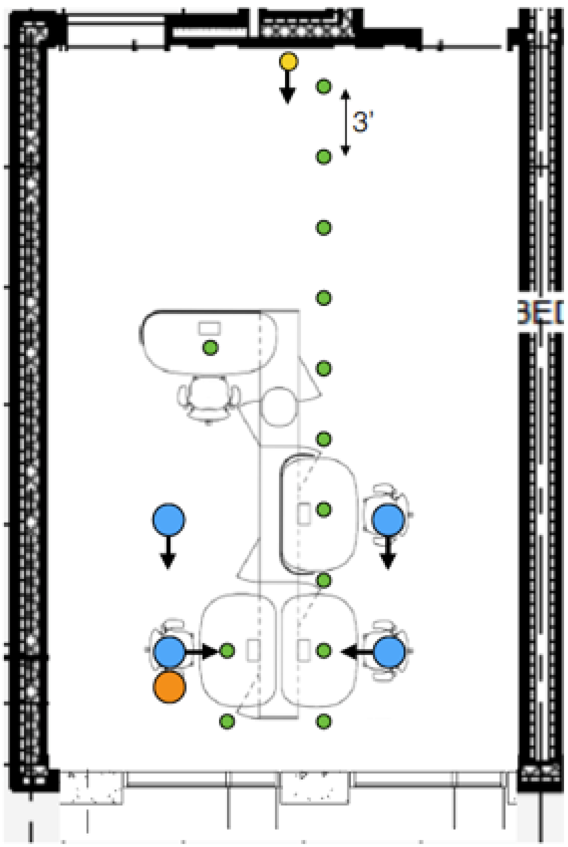



Ceiling
Diffuser
Light Fixtures
Facade
Furniture
Carpet

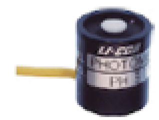
We're measuring light, glare, temperature and thermal comfort. And heating/cooling, lighting, ventilation,…

Typical Instrumentation for Evaluating Illuminance Distribution and Glare:

HDR Unit (right) automatically calculates DGP every 5 min and sends data over wifi



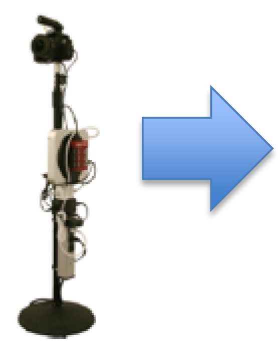
Licor photometer

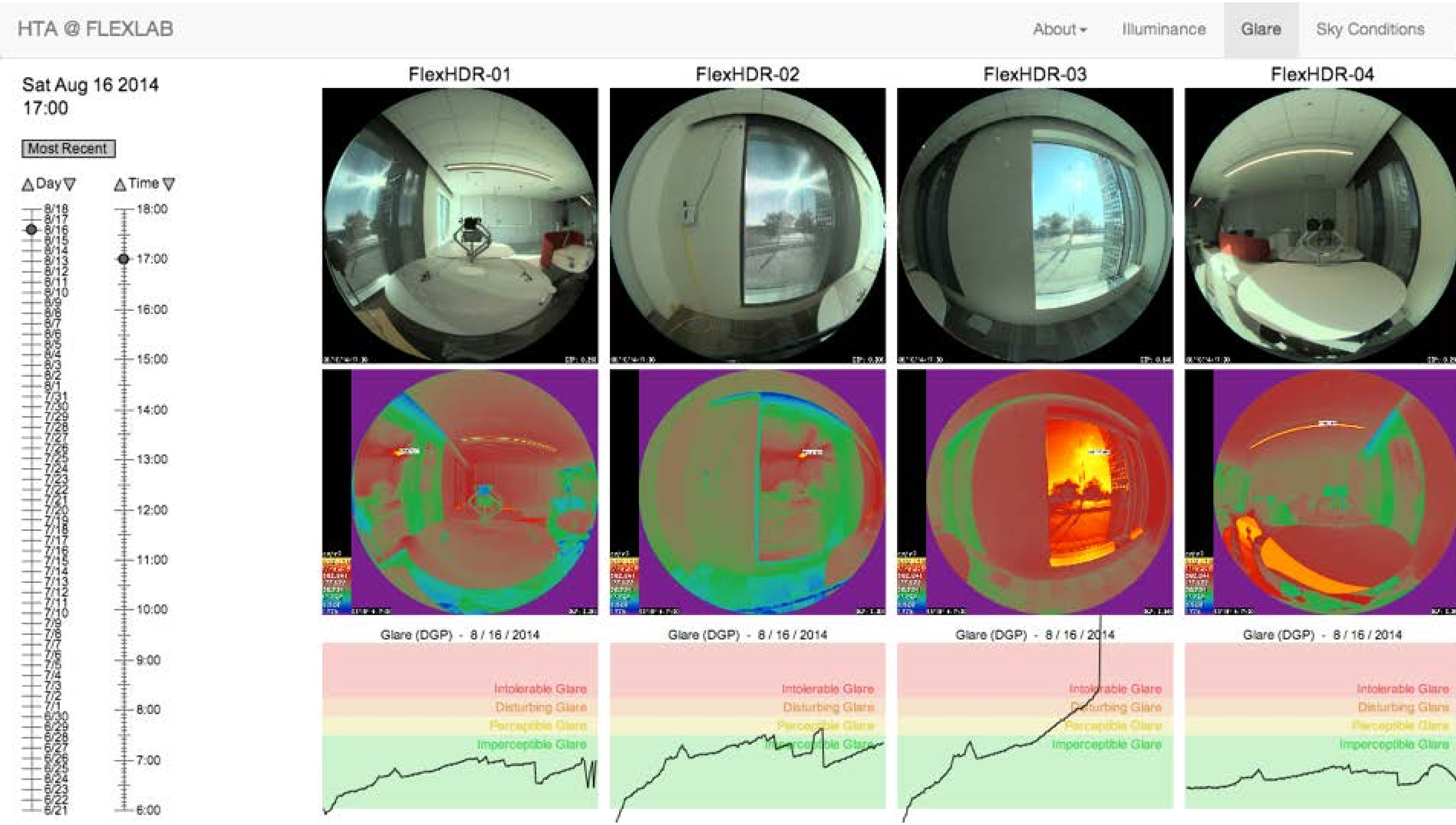


HDR Camera

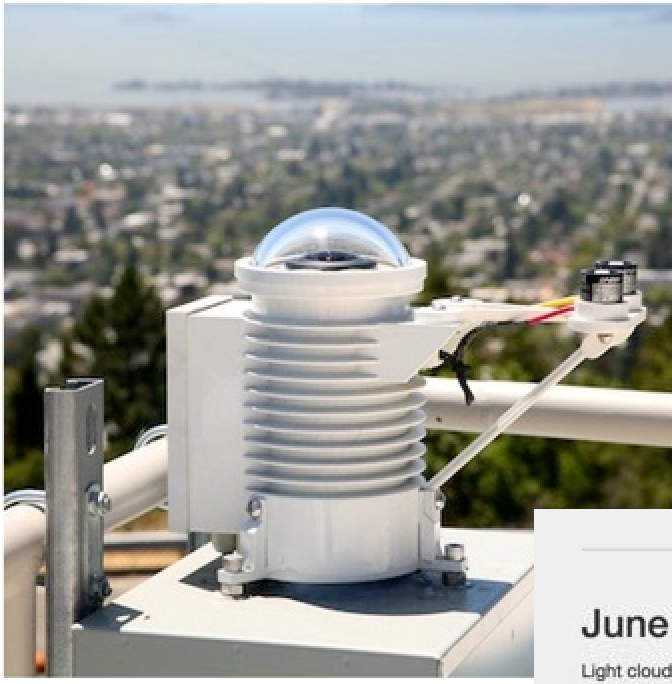
Thermal Comfort Sensing Package

Webcam

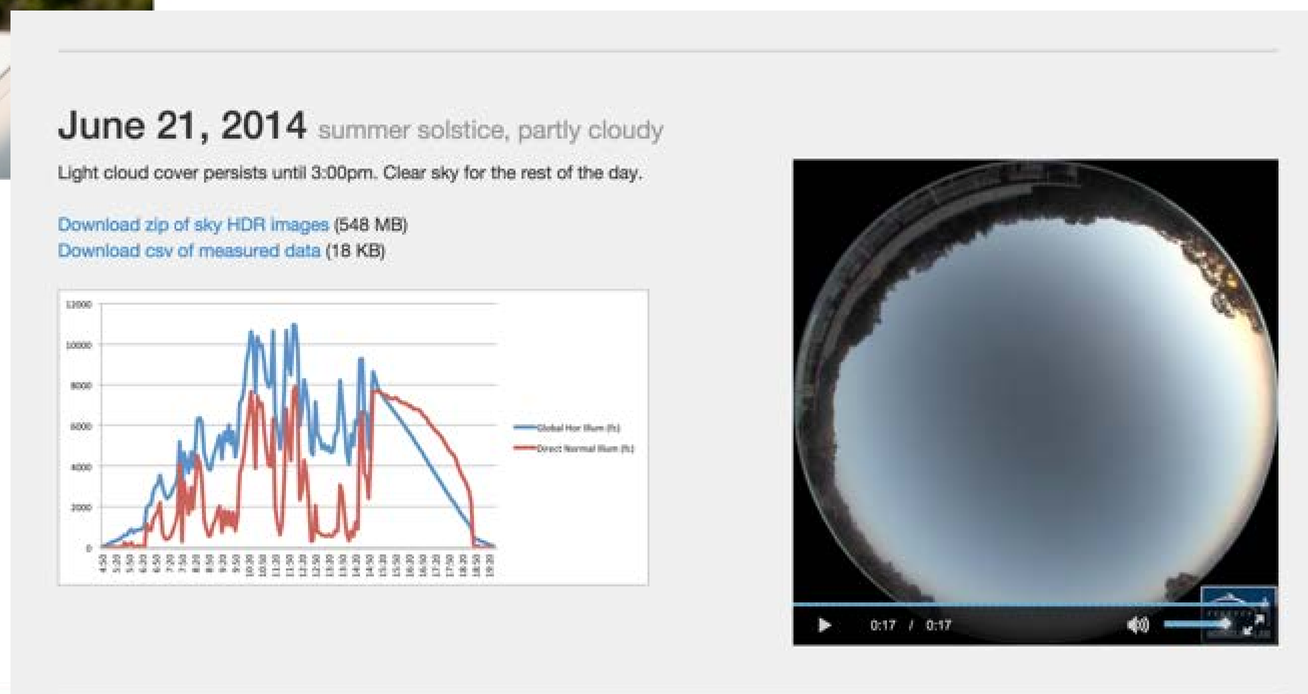



HTA @ FLEXLAB
About
Illuminance
Glare
Sky Conditions
Sat Aug 16 2014
17:00
Most Recent
Day
Time
FlexHDR-01
FlexHDR-02
FlexHDR-03
FlexHDR-04
Glare (DGP) - 8 / 16 / 2014
Intolerable Glare
Disturbing Glare
Perceptible Glare
Imperceptible Glare

High Dynamic Range HDR Sky Scanner

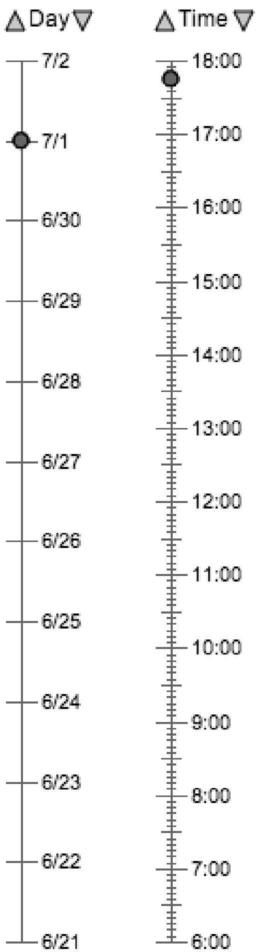


http://flexskycam.lbl.gov/data/140621/140621.mp4

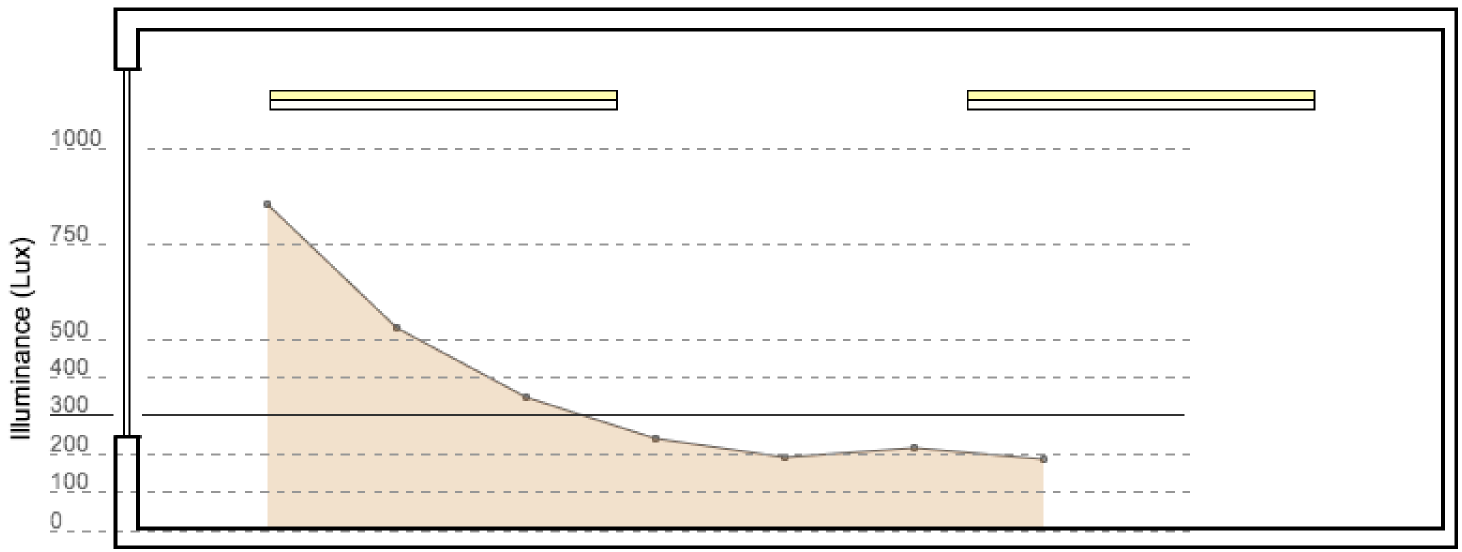


Tue Jul 01 2014
17:45

Most Recent



Mean: 318 Lux
Minimum: 186 Lux
Maximum: 849 Lux



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New FLEXLAB Project – PG&E (Utility)

- 2 Tasks Funded (~$900K, 1 year)

- **High Performance Envelope with Optimized Lighting, Daylighting, and Office Equipment Loads**
  - Test and demonstrate systems that provide 20-40% energy savings over California's T24 Energy code
  - Focus on 50-65% Window-to-wall ratio glazing assemblies, and deep daylighting strategies

- **High Performance Building HVAC and Controls**
  - Summer, winter and swing season testing of a suite of low energy HVAC strategies
  - Comparison study of systems
  - Focus on load shape reductions, peak reduction, overall energy savings

Explore

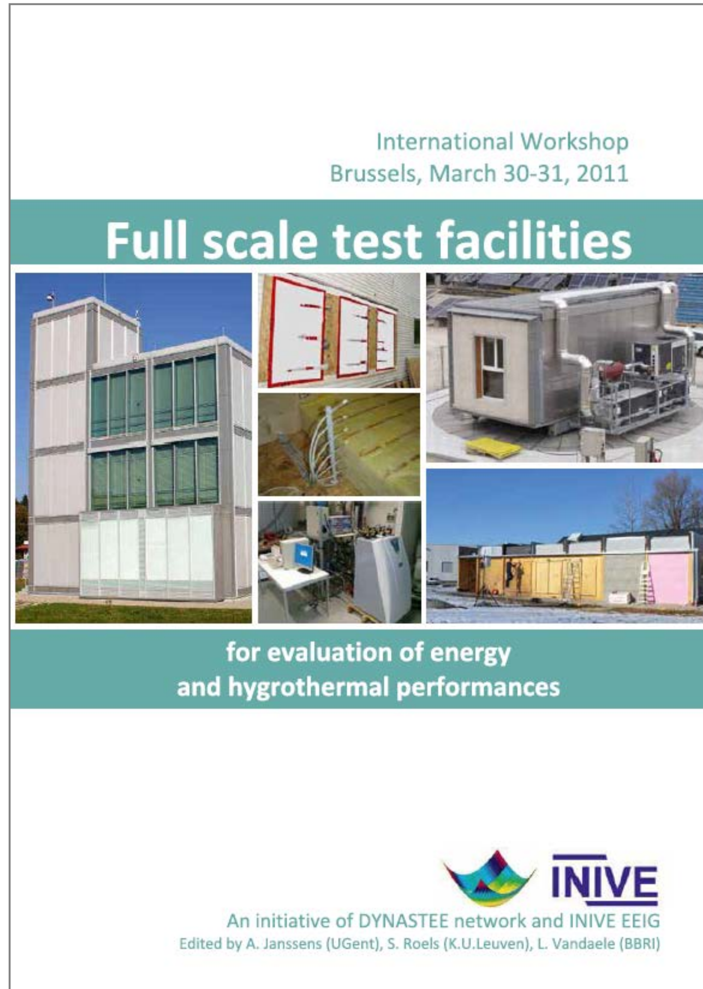
- "Reuse Data Sets" from PG&E Study?
- Extend PG&E tasks to collect, process "validation data"?

IEA Annex 58: Reliable Building Energy Performance Characterization Based on Full Scale Dynamic Measurements

Inventory of full scale test facilities

For each facility:

- General description
  - Main objectives
  - Overall lay-out
  - Inside and outside boundary conditions
  - Special limitations and possibilities
- Data analysis
  - Typical equipment
  - Accuracy and resolution
  - Analysis of data
- Examples



Lawrence Berkeley National Laboratory

FLEXLAB Calibration

Stephen Selkowitz
Windows and Envelope Materials Group Leader

January 28, 2015

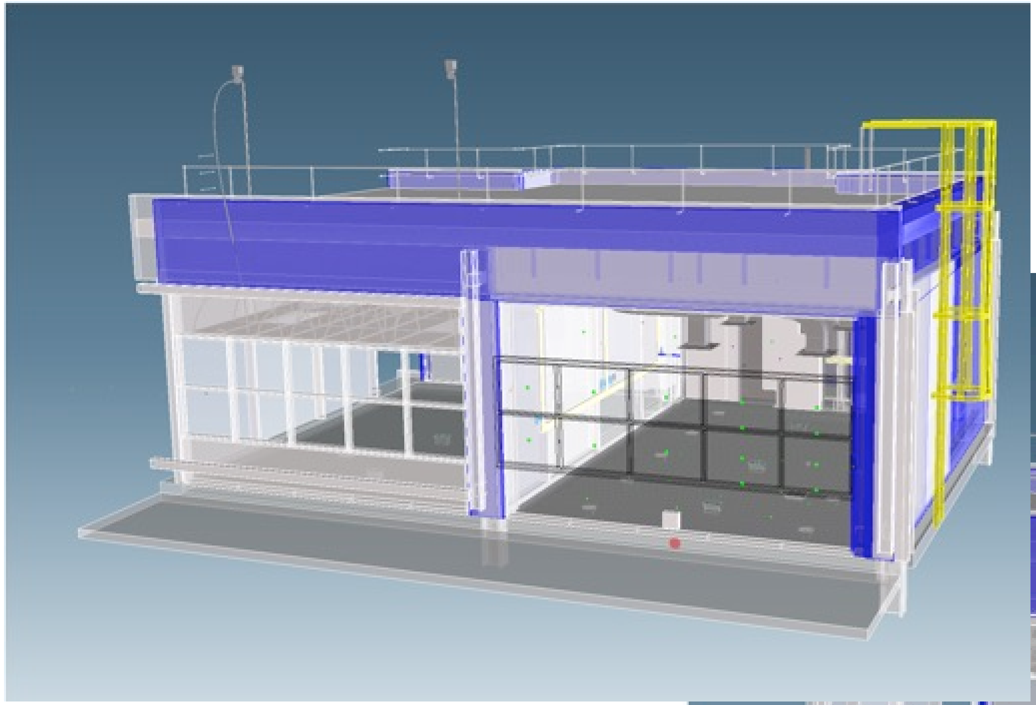
SENSOR CALIBRATION

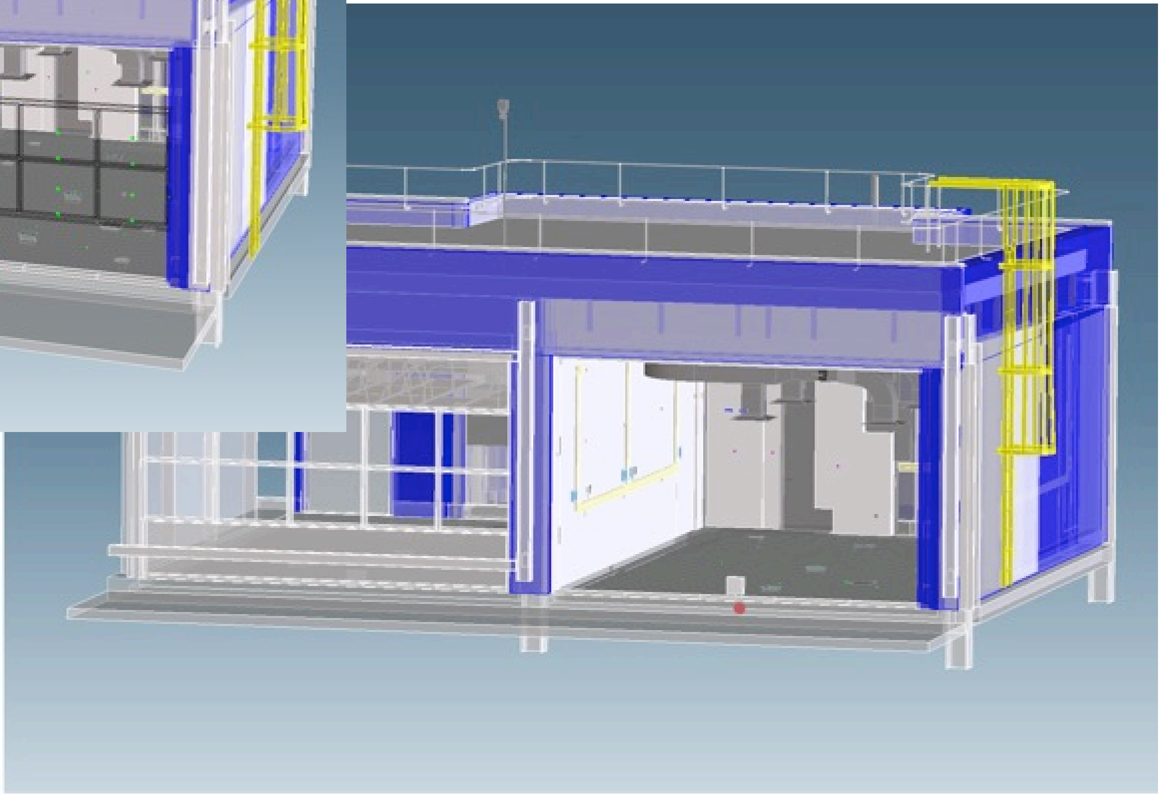
- Built-in sensors
- Additional sensors
- Absolute accuracy
- Uncertainty
- Repeatability
-

BUILT-IN SENSORS

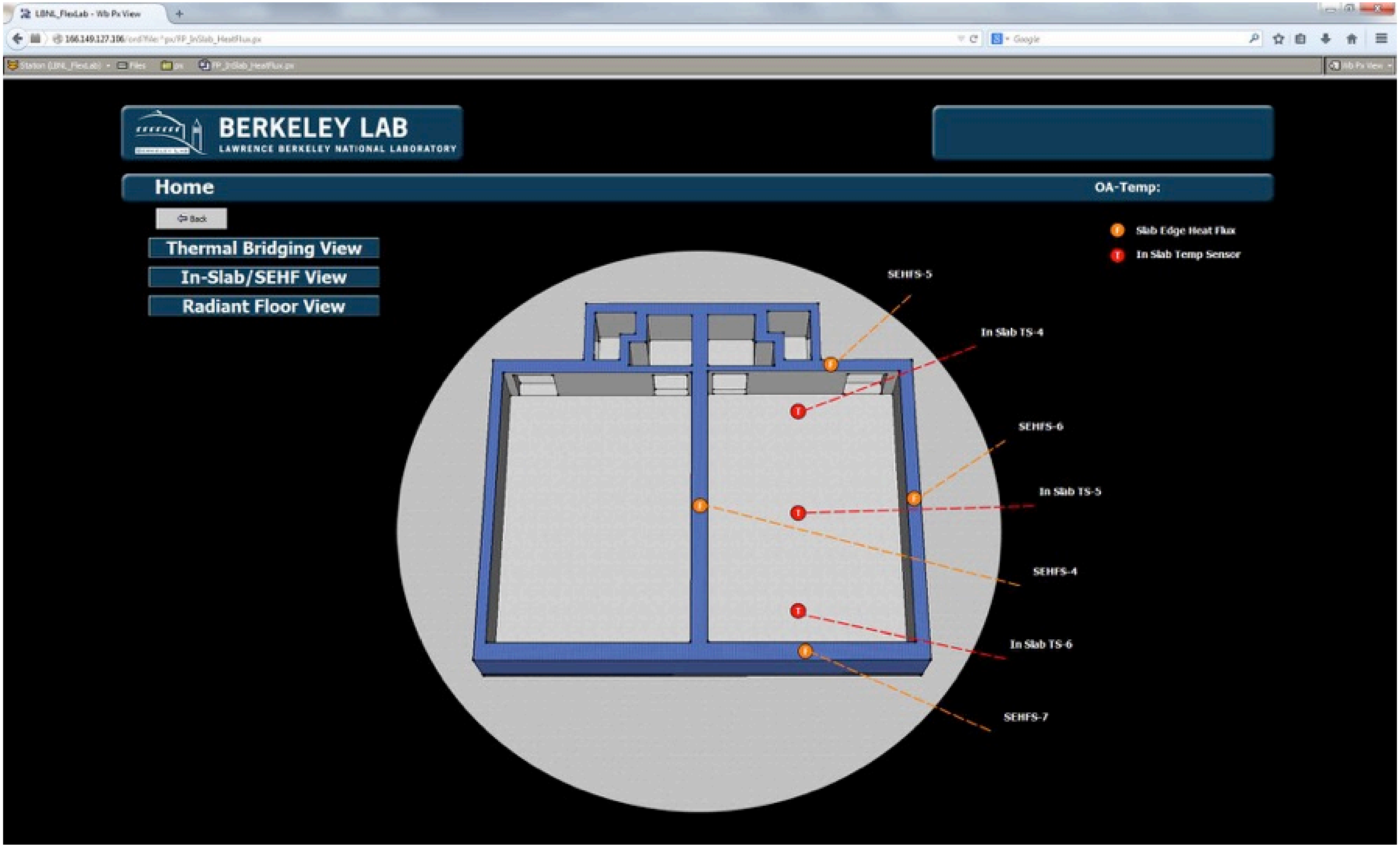
- Thermistors installed (embedded) at selected locations
- Heat flow sensors embedded at selected locations
- Air and water flow meters embedded at selected locations
- Accuracy and uncertainty reported by manufacturer
- Further calibration difficult without removing sensors from their embedded locations

3-D MODEL OF FLEXLAB TESTBED

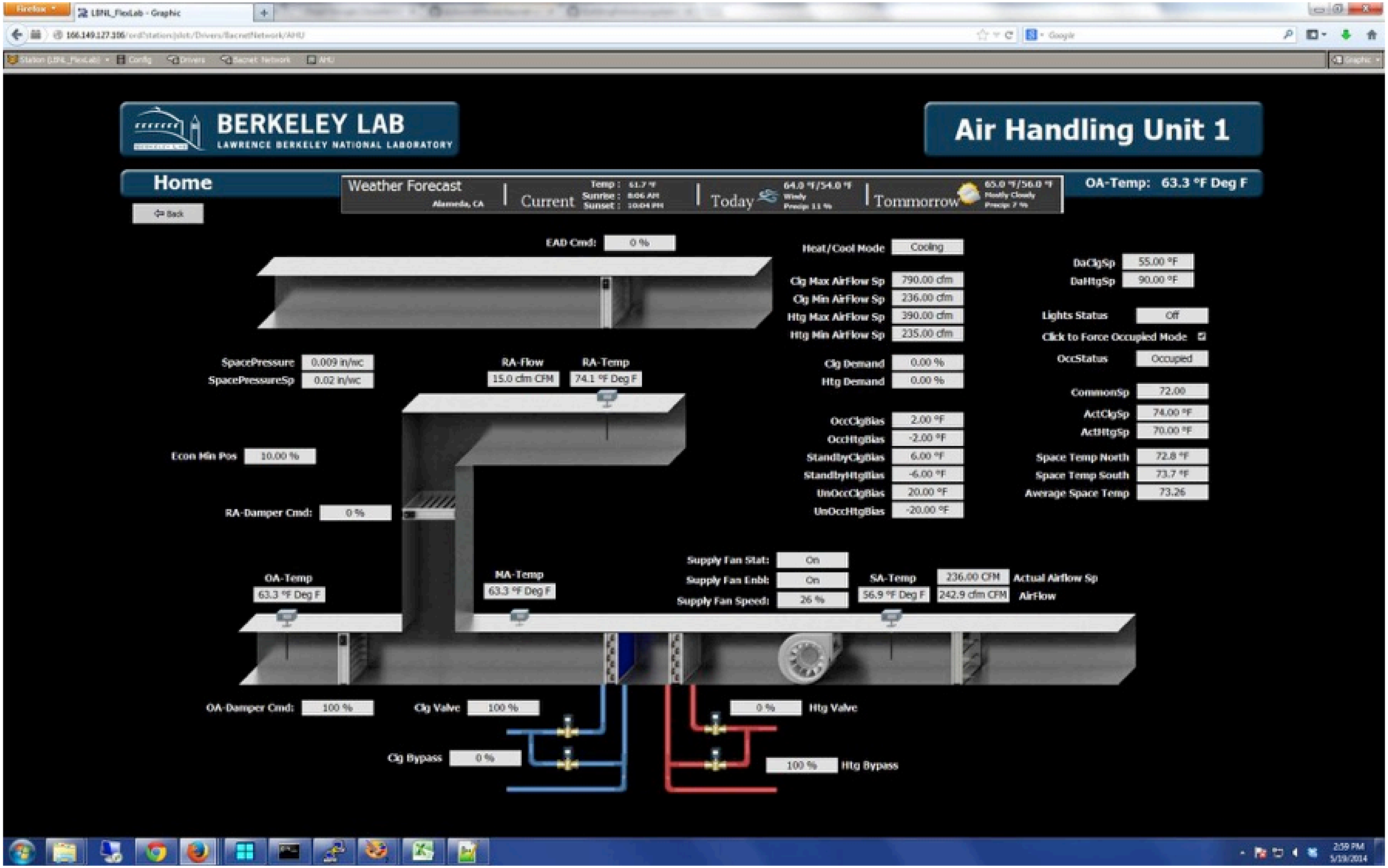




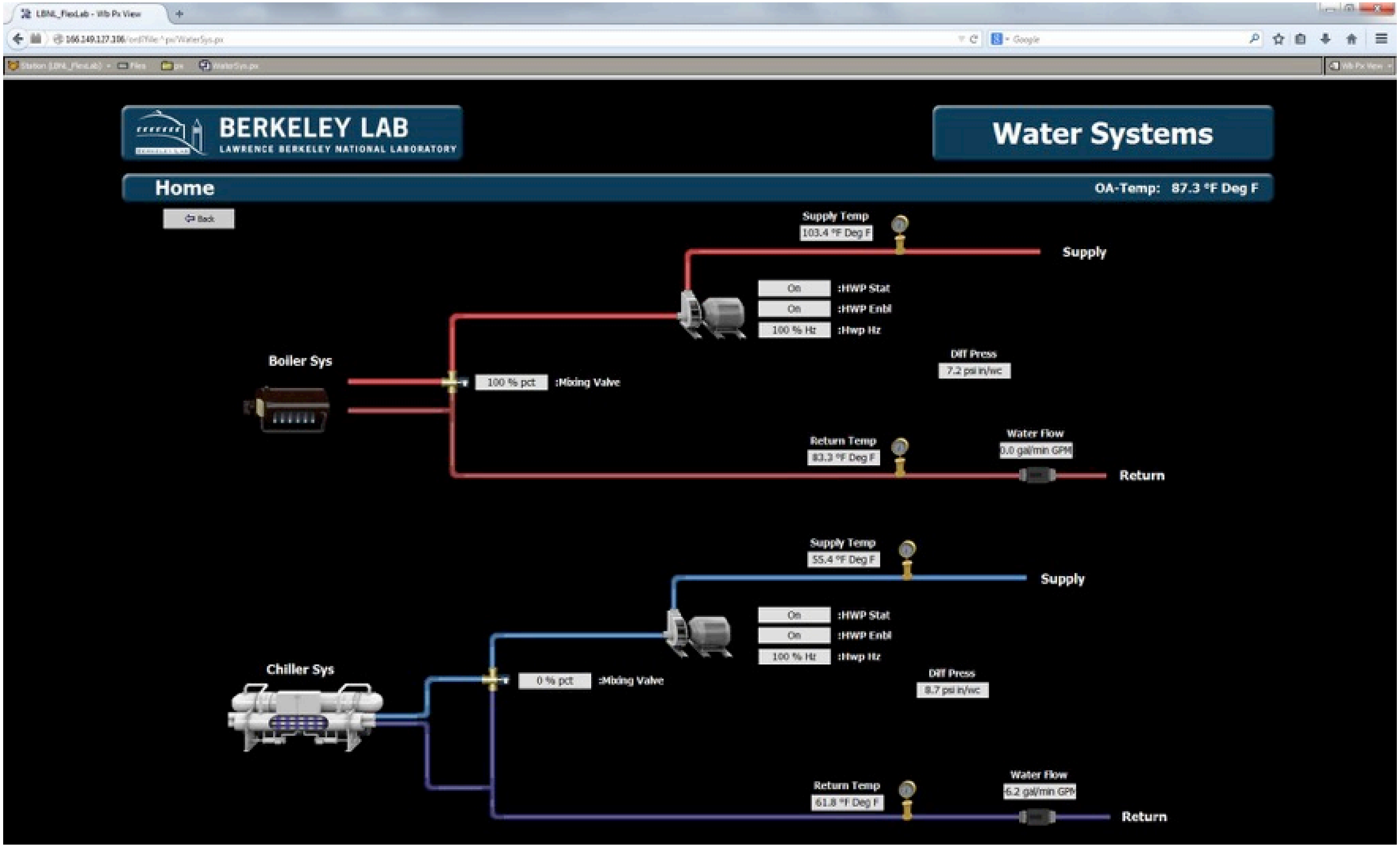
BUILT-IN SENSORS IN TB SPACE



BUILT-IN SENSORS IN AIR SIDE



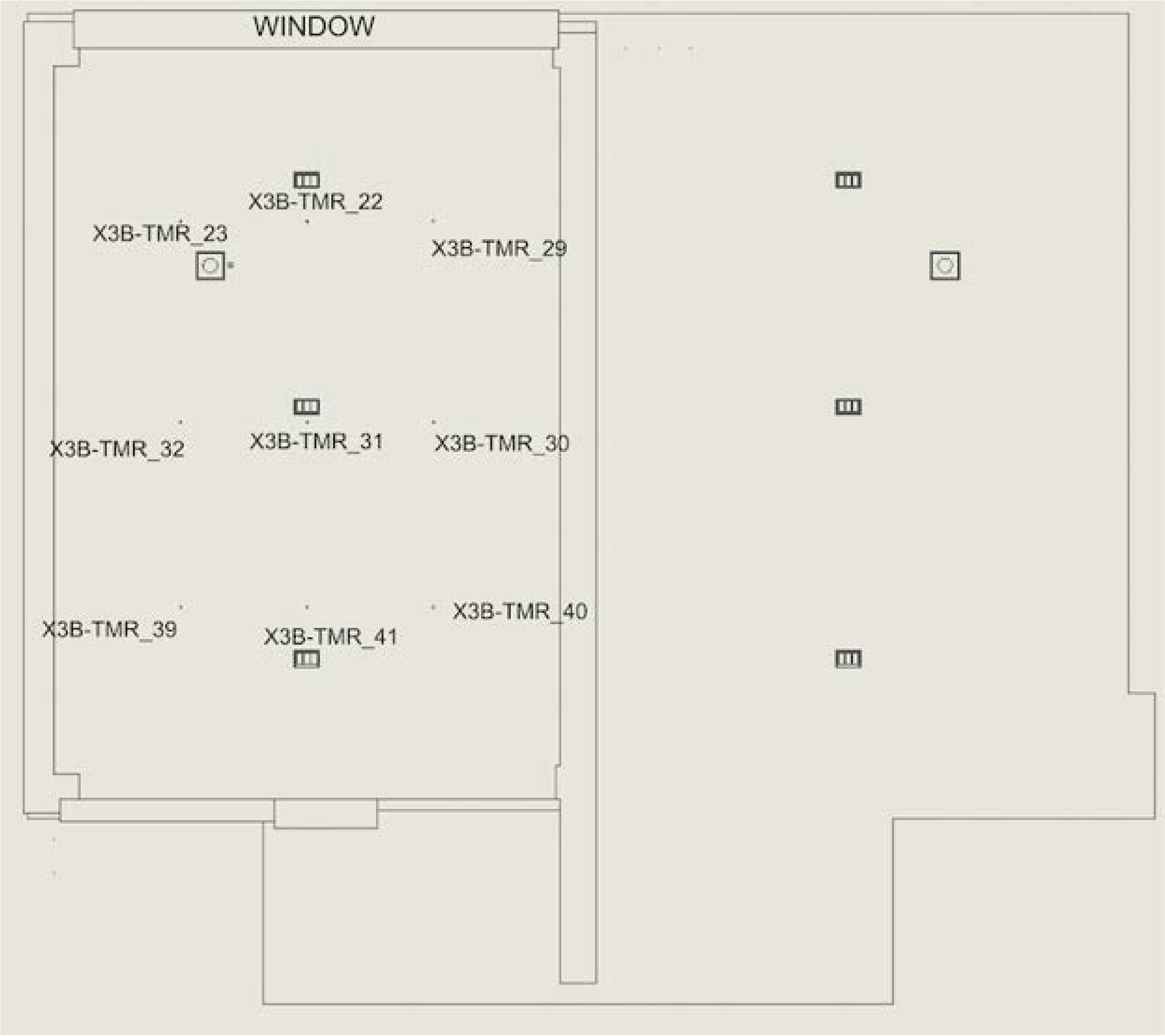
BUILT-IN SENSORS IN WATER SIDE



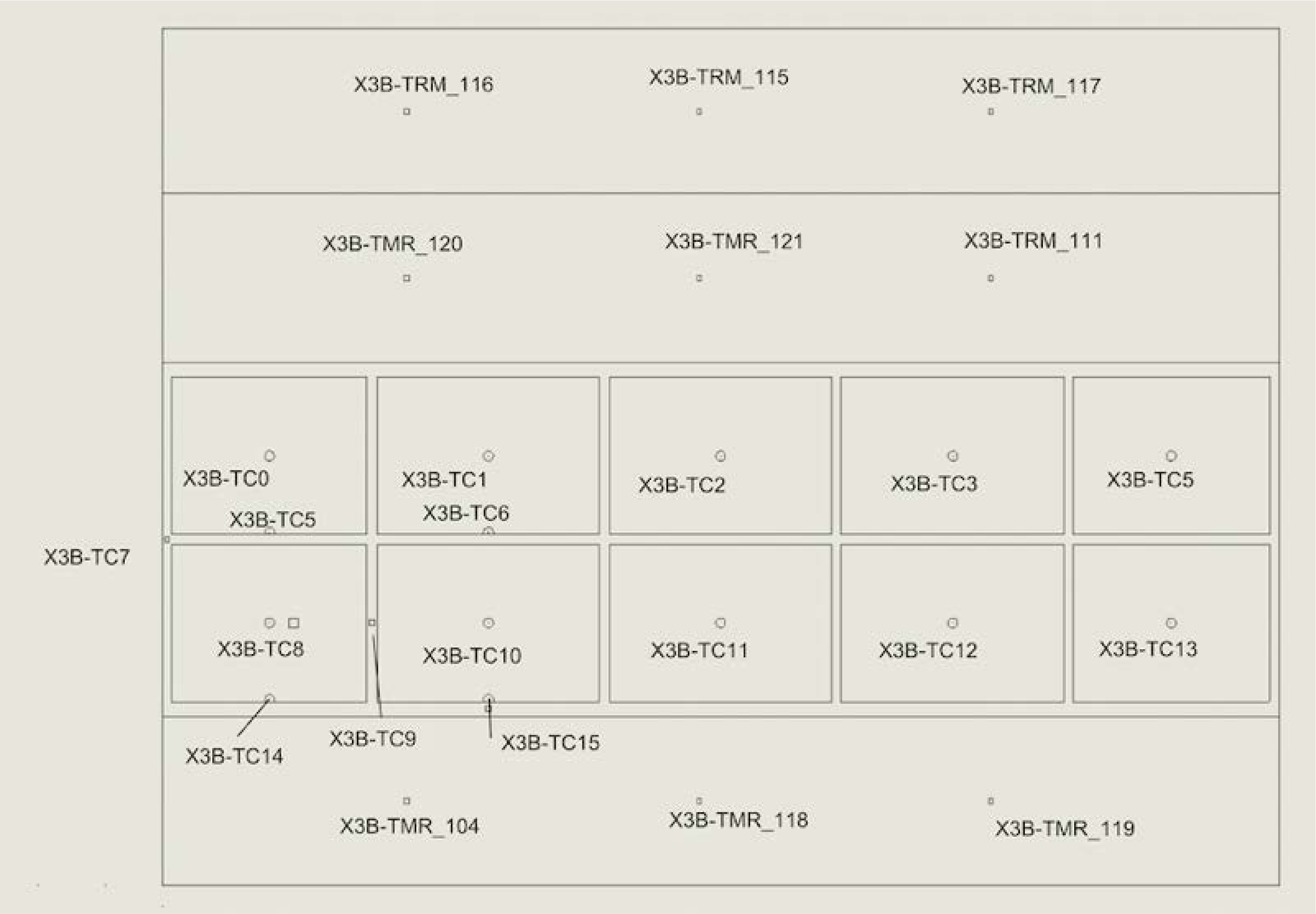
ADDITIONAL SENSORS/INSTRUMENTATION

- Thermistors on wall surfaces – each wall surface has array of 9 sensors and selected additional temperature sensors
- Heat flow sensors on wall surfaces – each wall has one sensor and selected additional heat flux sensors
- Stratification trees
- HDR Imaging

THERMISTORS – FLOOR

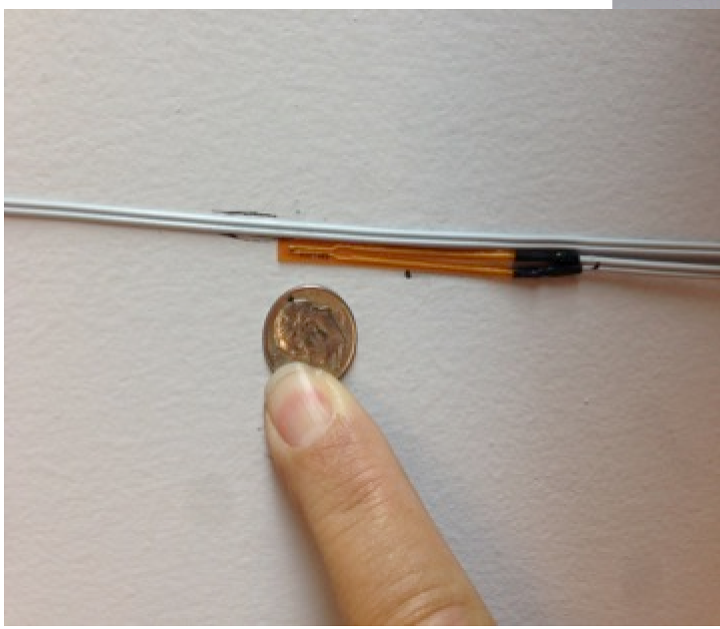


THERMISTORS – FRONT WALL



TEMPERATURE SENSOR CALIBRATION

Batch thermistor calibration

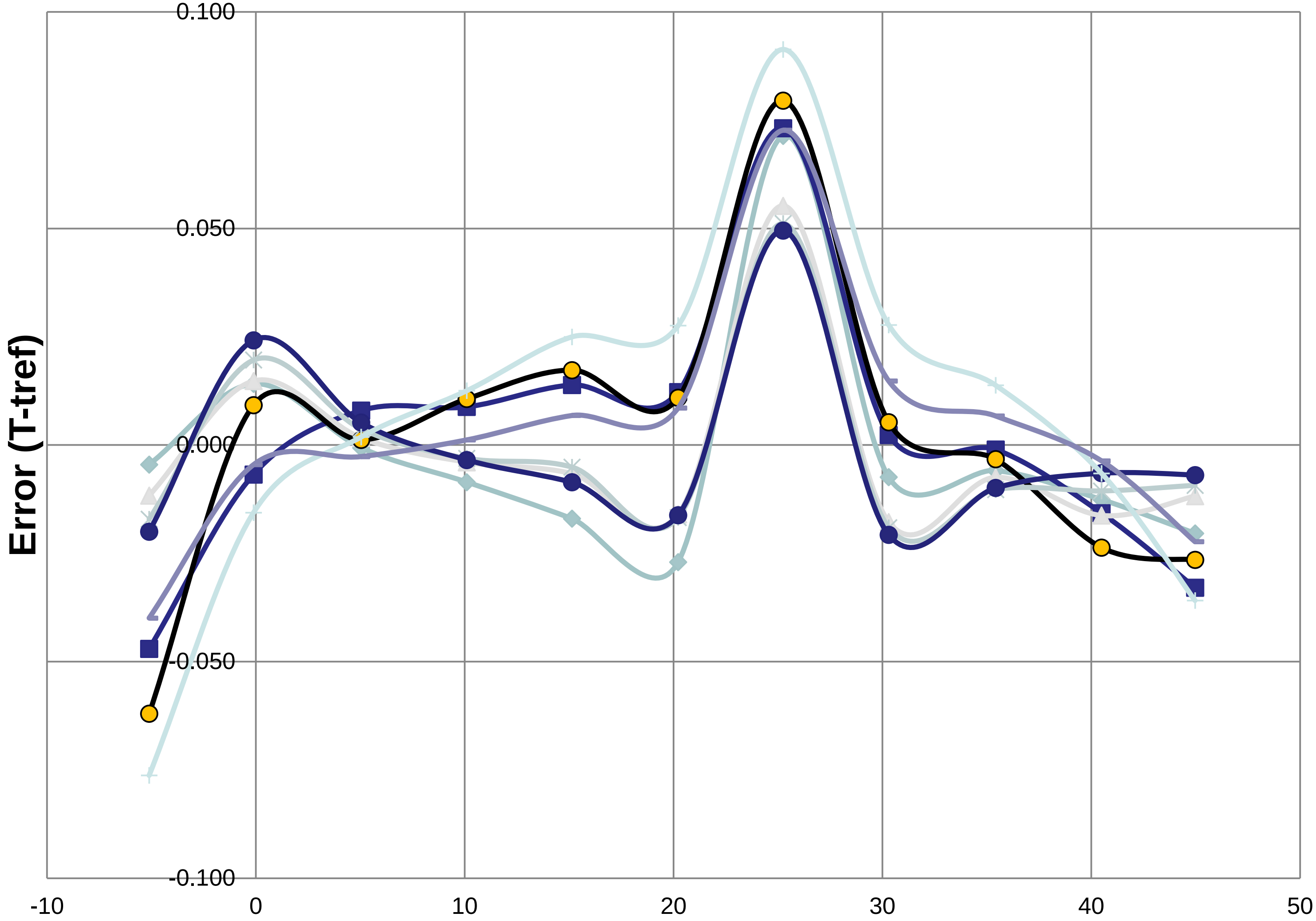


Thermistor on the wall surface

TEMPERATURE SENOSR MOUNTING TECHNIQUES

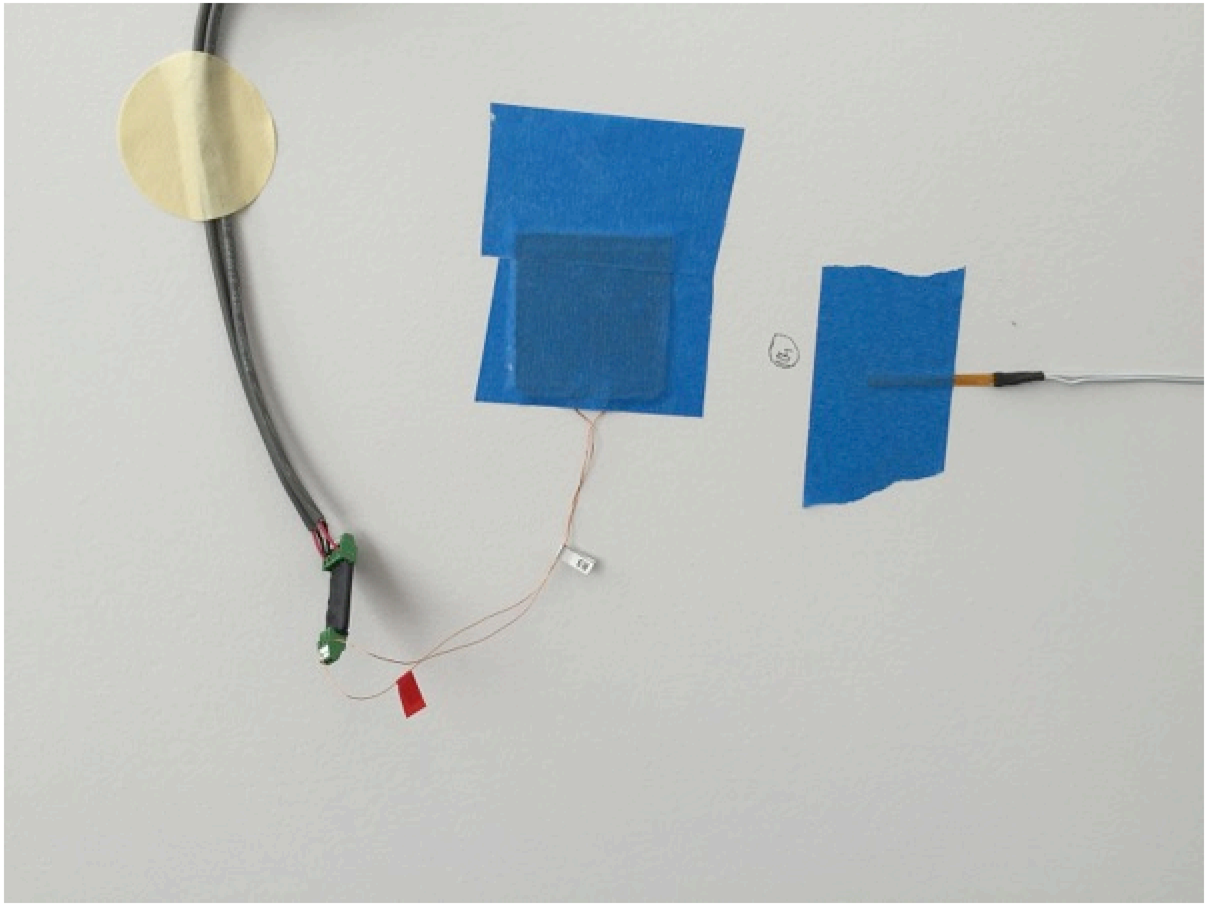
- Sensor installation techniques on glass

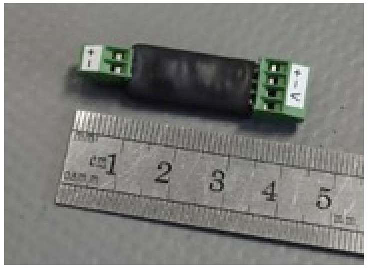
TEMPERATURE SENSOR CALIBRATION



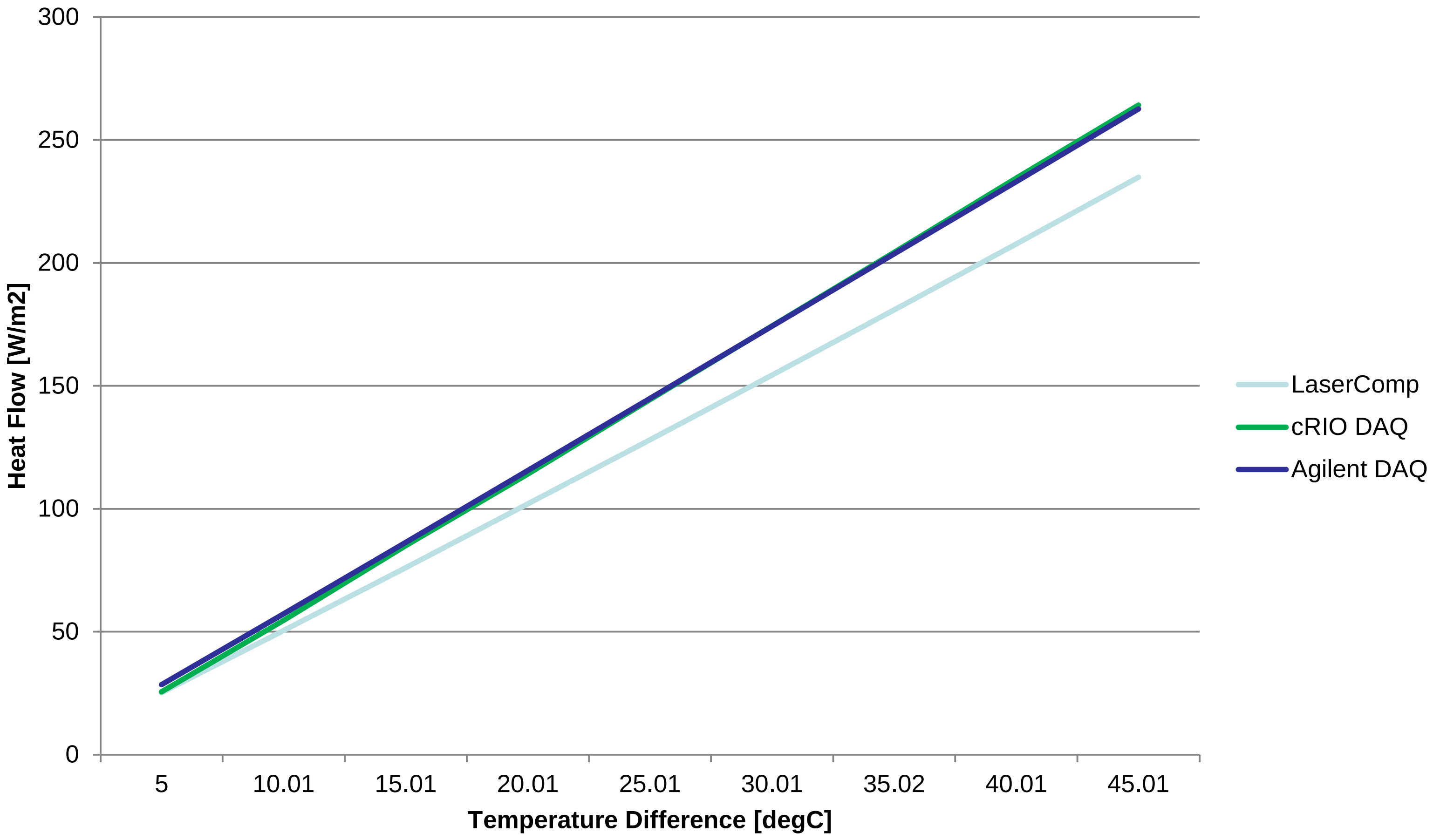
HEAT FLUX SENSOR MOUNTING

- Image of heat flow sensors and mounting



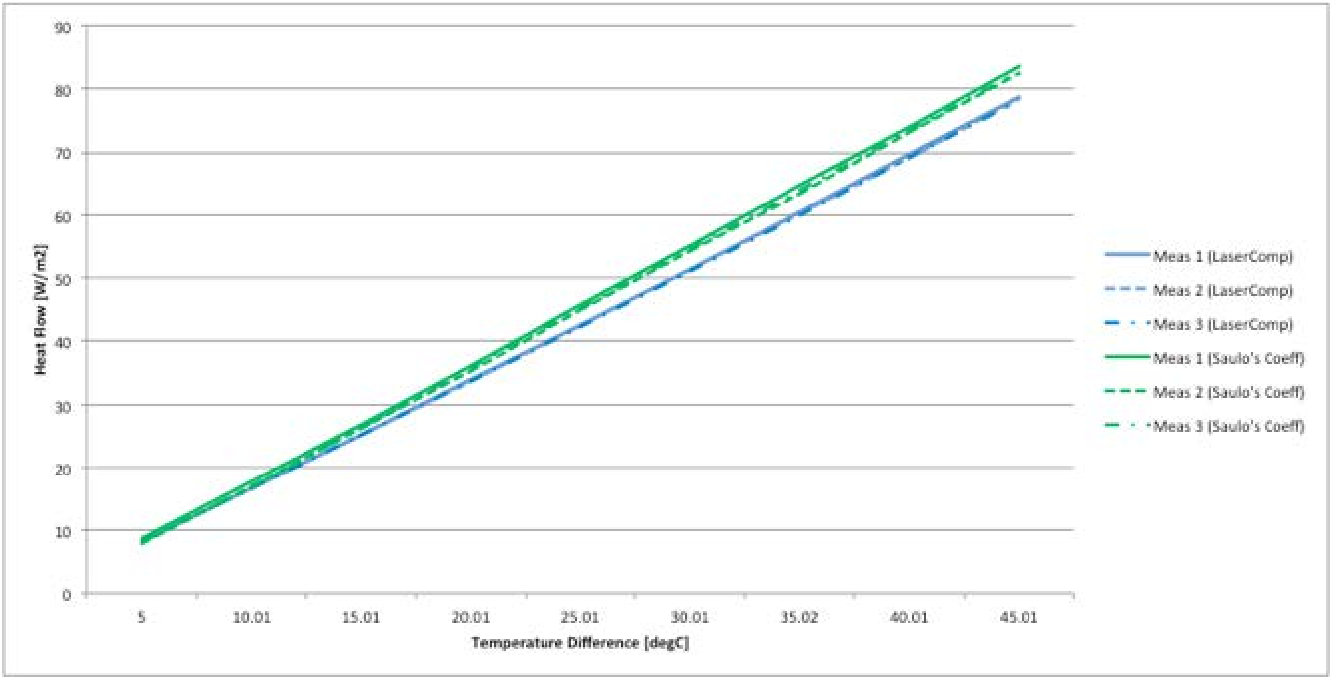


HEAT FLUX SENSOR SENSOR CALIBRATION



Reference measurement used in updating heat flux sensor coefficients – Reference is LaserComp Heat Flow Meter w/ NIST calibrated sample

REPEATIBILITY MEASUREMENTS



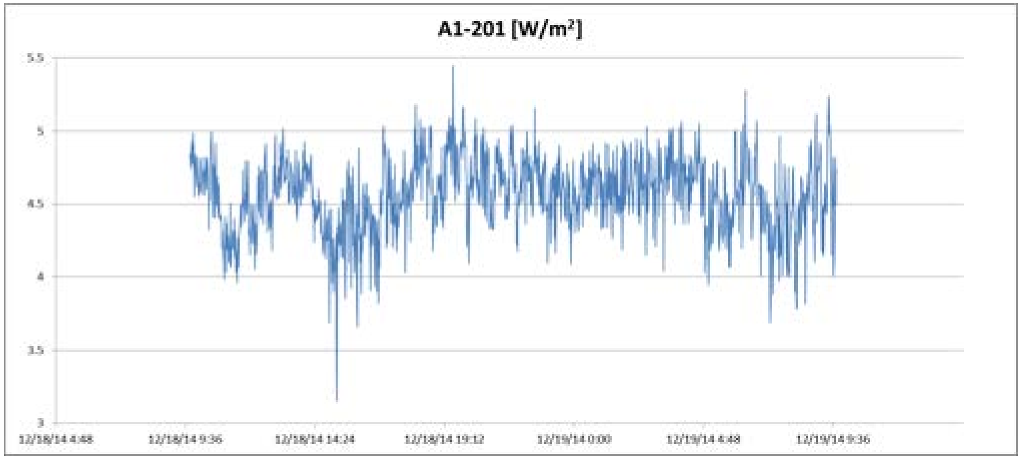
$\Phi_1 =$ 0.141372 [W/m^2/mV]

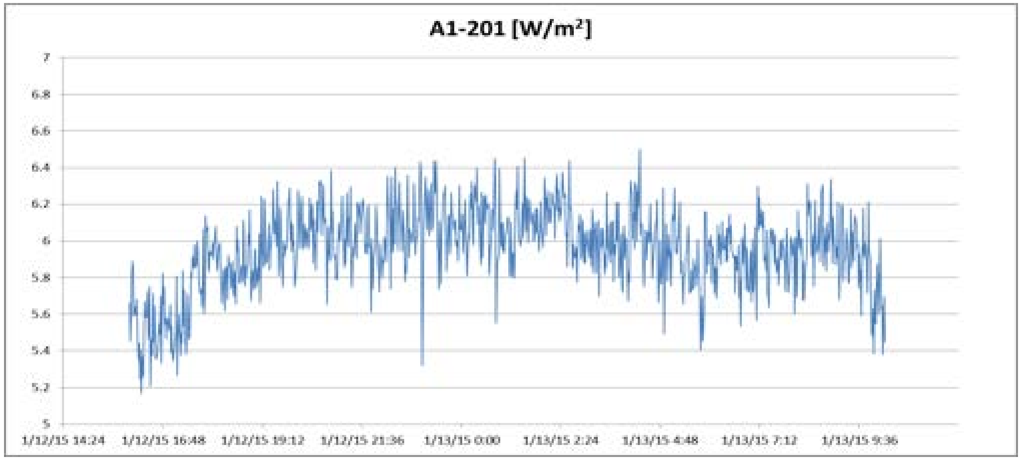
$\Phi_2 =$ 0.145371 [W/m^2/mV]

$\Phi_3 =$ 0.143485 [W/m^2/mV]

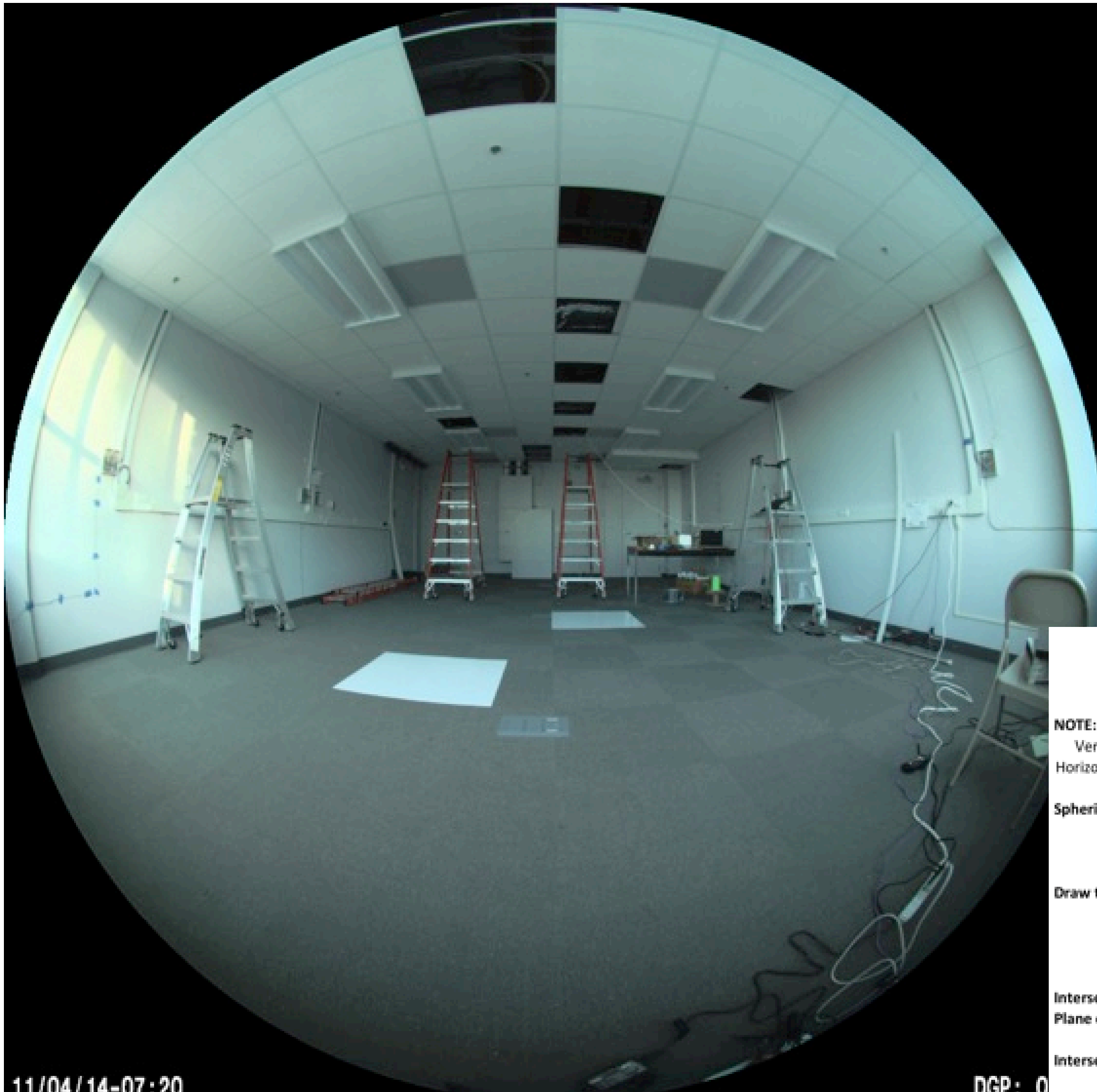
REPEATIBILITY OF SENSOR ACCURACY

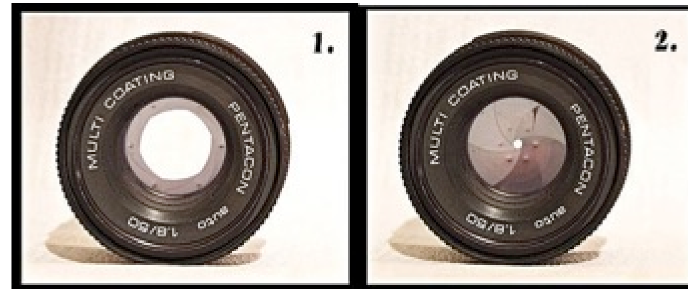
- Results of repeatability (short-wired) test in X3B

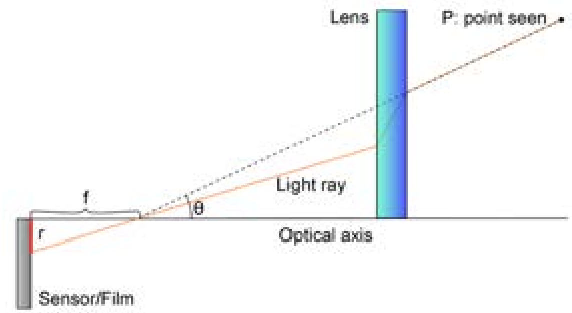




HDR IMAGING AND CONVERSION TO BSDF







y_1 =	0.796925	[m]				
Horizontal pixels =	860					
Vertical pixels =	860		dθ =	0.003653 [rad/pixel]		

NOTE: Pixels are measured from center of the image

Vertical pixel number =	-200	Max Vertical =	430		
Horizontal pixel number =	0	Max Horizontal =	380.6573	Pixels on projection =	200

Spherical coordinate system assuming that radius is equal to one

φ =	-1.5708	[rad] =	-90	[deg]
θ =	0.730603	[rad] =	41.860465	[deg]

Draw the line from coordinate center to sphere intersection

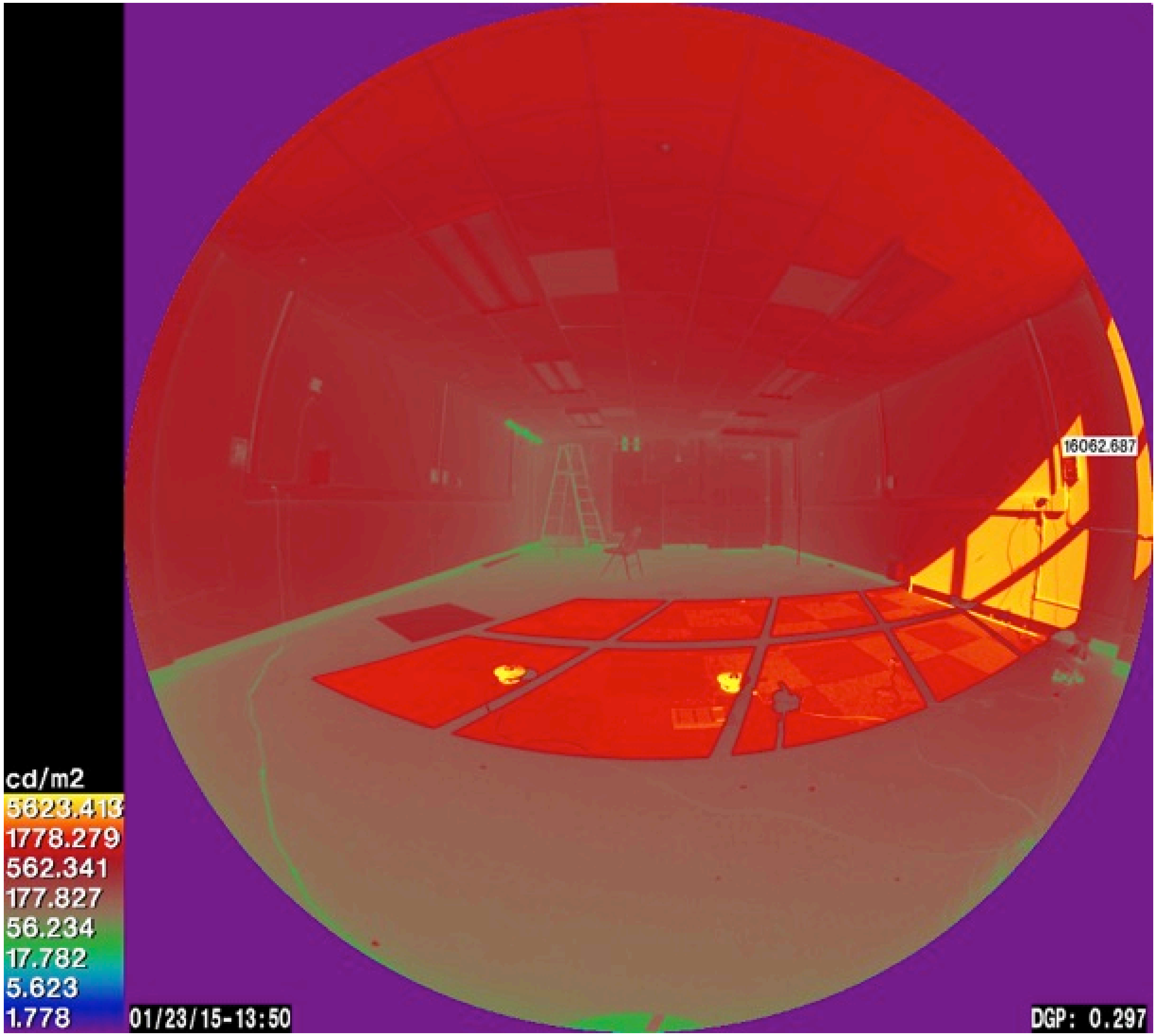
x =	4.09E-17	·t
y =	-0.66732	·t
z =	0.744772	·t

Intersection of line with horizontal plane

Plane equation	y =	-0.79693	[m]
	t =	1.194219	
Intersection point	x =	4.88E-17	[m]
	z =	0.889421	[m]

BERKELEY LAB

SOLAR/DAYLIGHTING PREDICTION WITH HDR IMAGING



Calculation of energy flow for the test cell

- Energy flow into the cell

$$Q = C_p \cdot \rho \cdot \dot{V} \cdot (T_{supply} - T_{return}) \qquad [W]$$

- Air side
  - Specific heat (C_p) is calculated using cubic interpolation of Air properties.
  - Density is calculated using ideal gas law.

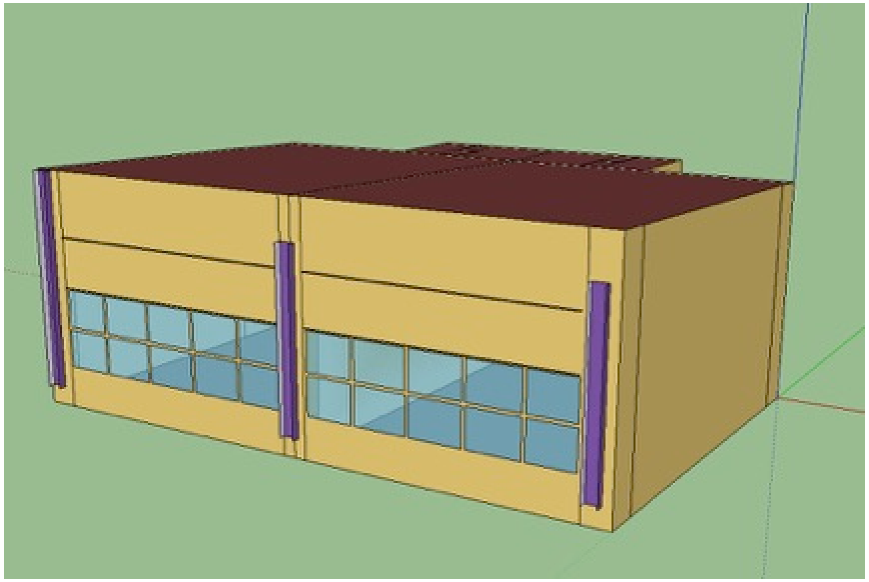
$$\rho = \frac{p \cdot M}{R \cdot T} \qquad [\frac{kg}{m^3}]$$

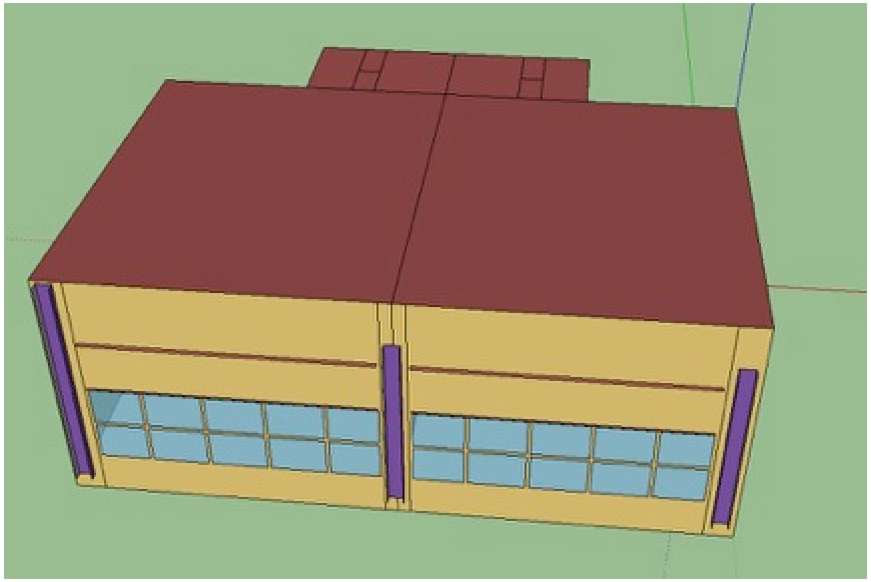
- Water side
  - Specific heat and density are calculated using cubic interpolation of liquid water.

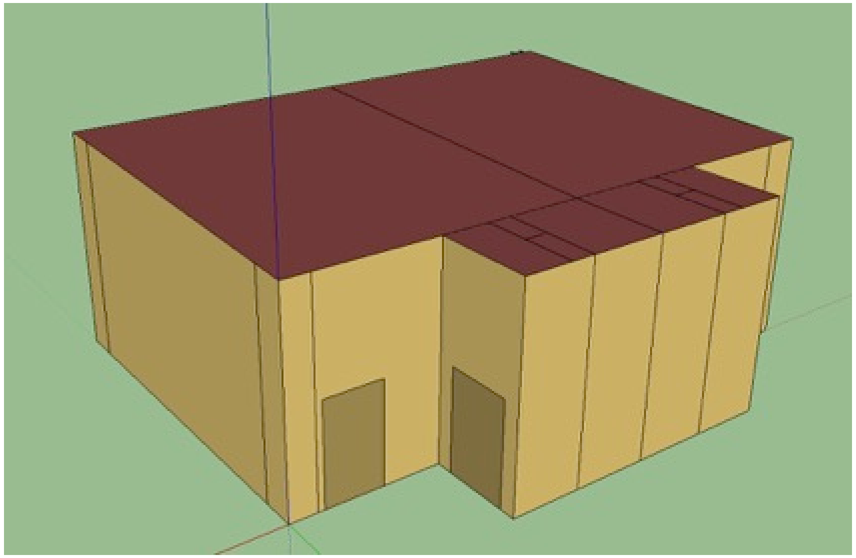
Calculation of energy flow for the test cell

- Data are collected and calculated in real time and stored onto SMAP

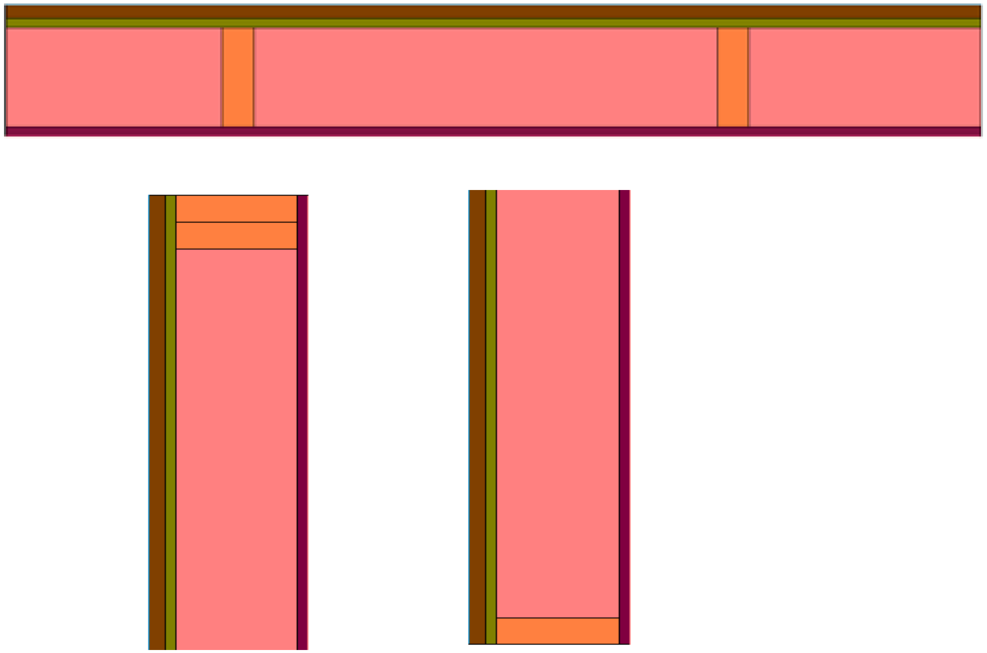
ENERGY PLUS MODEL





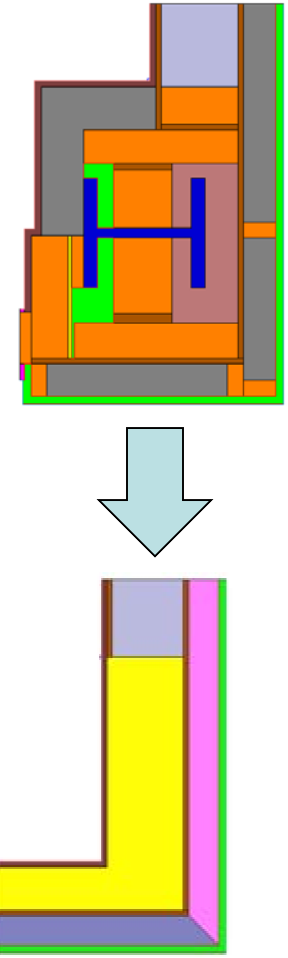


COMPONENT MODELING PREDICTION



	Frame	Edge	Center
Hor-Intermediate	0.0241	0.0240	0.0230
Hor-End1	0.0235	0.0233	
Hor-End2	0.0235	0.0234	
Ver-Head	0.0474	0.0315	
Ver-Sill	0.0496	0.0385	

U =	0.024	$Btu/hr \cdot ft^{2} \cdot {}^{\circ}F$



$U = 0.0371\ Btu/hr \cdot ft^2 \cdot F$

ADDITIONAL ISSUES

- Electrical noise
- Thermistor power supply stability
- Electrical wire length effects