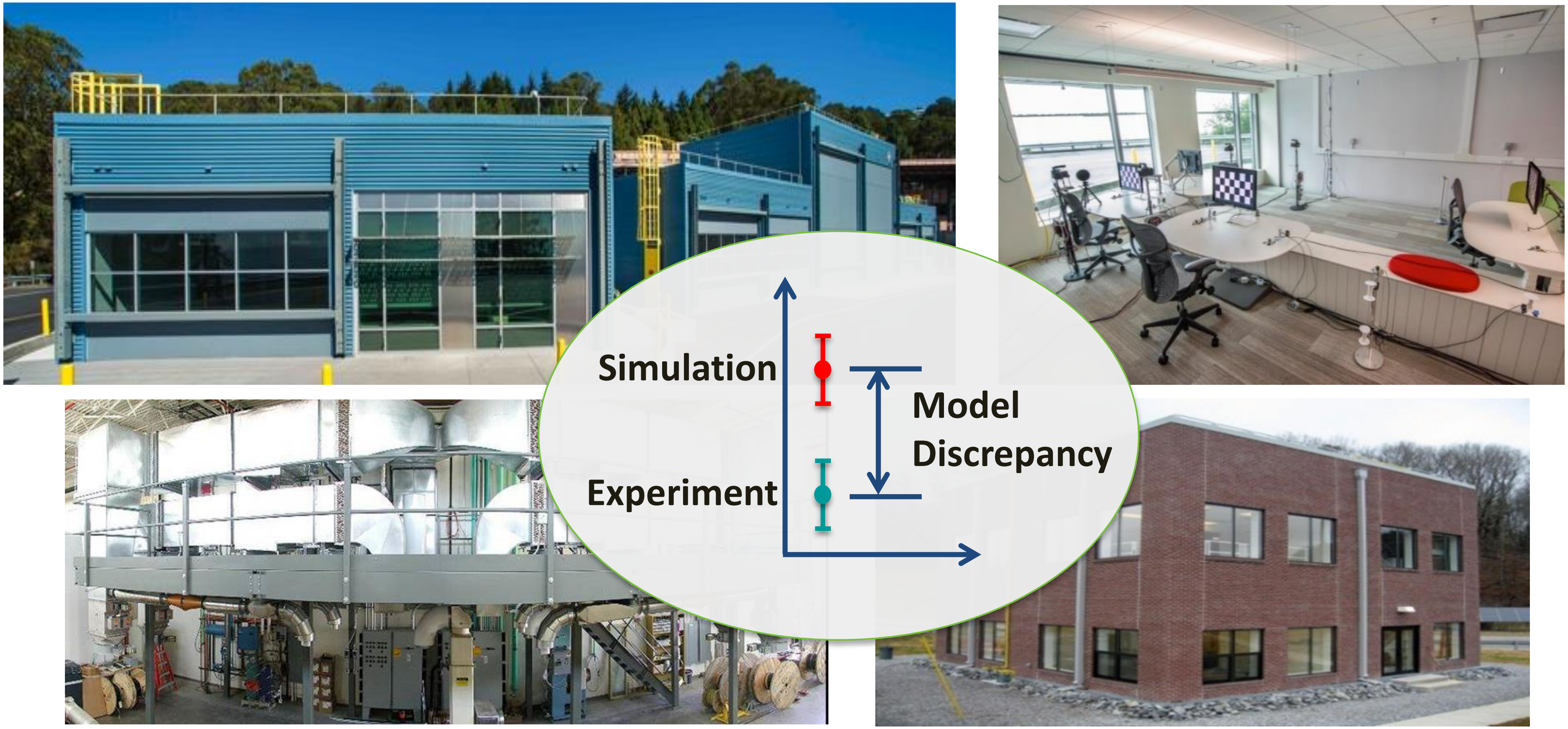
Validation and Uncertainty Characterization for Energy Simulation

2017 Building Technologies Office Peer Review



Simulation

Experiment

Model Discrepancy

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

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Project Summary

Timeline:

- Start date: 10/1/2015
- Planned end date: 9/30/2018

Key Milestones:

1. First submission to SSPC 140; 5/31/2017
2. Final submission to SSPC 140; 5/31/2018

Budget:

Total Project $ to Date:

- DOE: $1,130k
- Cost Share: -

Total Project $:

- DOE: $3M
- Cost Share: -

Key Partners:

ASHRAE SSPC 140	Southern California Edison

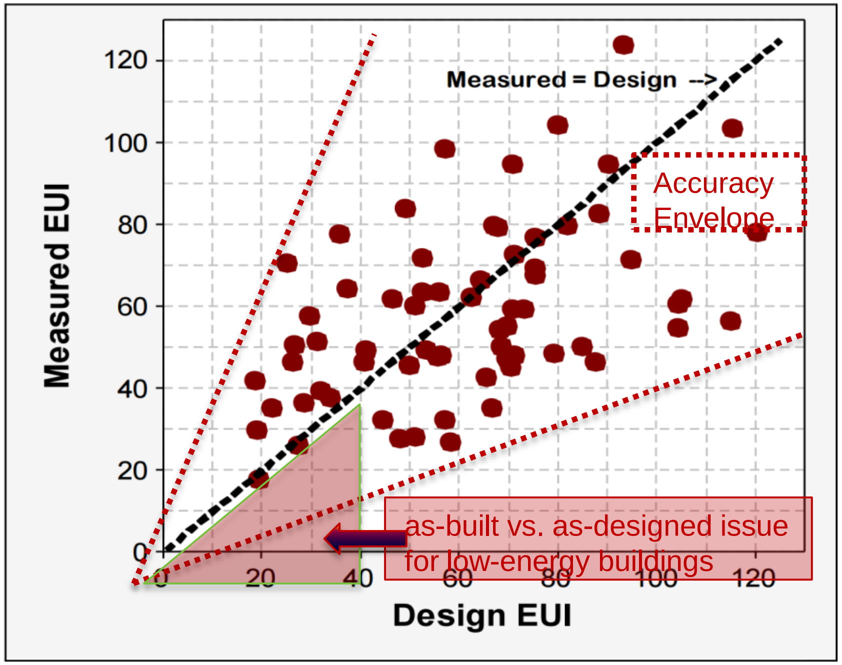
Project Outcome:

Provide empirical data for ASHRAE Standard 140 *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* to enable “Improved characterization of BEM engine accuracy and improved accuracy as necessary”, leading to:

- “Accurate BEM engines”
- Consistent and “validated” products
- “Confidence in all BEM tools”, leading to greater adoption and influence on design decisions, resulting in more efficient buildings

—MYPP, BEM logic model

Context: Uncertainty in BEM



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

Sources of differences between simulated and actual performance

- Uncertainty
  - **Algorithms**
  - Input parameters
  - Modeler decisions
- Variability
  - Weather
  - Occupancy
  - Operation

Most BEM applications are (by design) comparative, not predictive

- Most people don't understand this ➔ skeptical that BEM can be useful

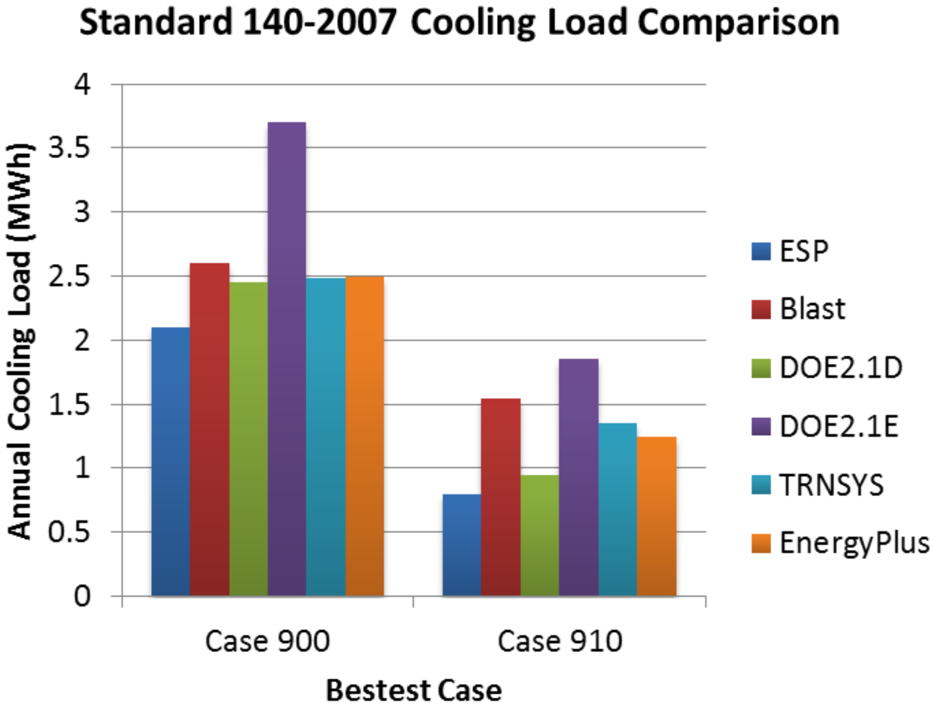
This project addresses algorithm uncertainty

- Most difficult for users to address, but "easiest" to address experimentally
- Will improve both predictive and comparative simulation applications
- Will increase confidence in BEM, increase BEM use

Context: ASHRAE Standard 140

ASHRAE Standard 140 *Method of Test for Evaluation of Building Energy Analysis Computer Programs* is based on IEA BESTEST procedures:

- Standard 140 tests & partially validates energy calculations:
  - **a major limitation is that the majority of the tests are analytical or comparative – no experimental measurements to provide 'ground truth'.**
- The Standard 140 framework accommodates empirical tests but does not yet include any
- We now have facilities to make cost-effective empirical testing possible:
  - LBNL FLEXLAB
  - ORNL FRP
  - NREL HVAC



Purpose and Objectives

Problem Statement

- Increased confidence in BEM needed for greater use and influence
- “Quantitative absolute statements about the accuracy and sensitivity of various aspects of energy simulation are largely missing.” (MYPP p104)
- Standard 140 needs to include empirical validation

Target Market and Audience

- BEM developers and users, including designers and energy code developers.

Target Market

- Immediate: design of high performance buildings - ~0.5 quads/yr.
- Ultimate: ~20 quads/yr, assuming wide adoption of energy codes.

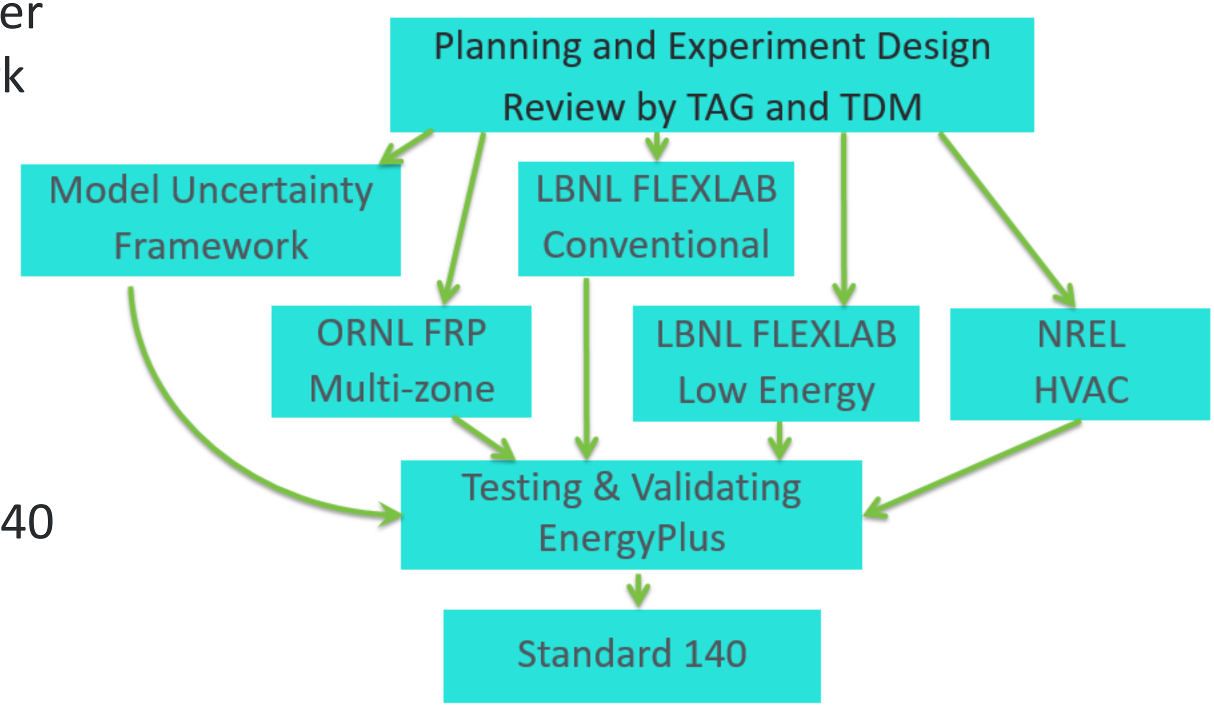
Impact of Project

- Near-term: accuracy improvements to EnergyPlus and other BEM tools
- Long-term: higher performing buildings, due to:
  - enhanced credibility for validated simulation tools resulting in greater use
  - accurate tools → better design and operation
  - investments stimulated by the reduced risk associated with validated tools

Approach

Approach

- Use test facilities to generate measure data for Standard 140 (LBNL, NREL, ORNL)
  - Conventional systems and low energy systems, controls, HVAC components
- Implement framework for estimating uncertainty of BEM results (ANL)
  - Representation of 'model form' uncertainty, driven by validation data
  - Extend input parameter uncertainty framework



Key Issues

- Reproducibility between different BEM engines

Distinctive Characteristics

- Collaboration with SSPC 140
- Multi-lab collaboration
- Unique lab facilities
- Representation of uncertainty

Technical Advisory Group (TAG)

Heterogeneous group of stakeholders with different expertise:

- model developers
- simulation tool developers/vendors
- experimentalists
- uncertainty analysts
- end users
- Some cross-membership with the Standard 140 committee (SSPC 140)**

Godfried Augenbroe – Georgia Tech
Chip Barnaby
Fred Bauman – UC Berkeley, CBE
David Bosworth - Buildlab
Liam Buckley – IES-VE
Philip Fairey – Florida Solar Energy Center
Joe Huang – Whitebox Technologies
Erik Kolderup – Kolderup Consulting

Neal Kruis – Big Ladder Software
Matthew Lynch - Bractlet
Rich Raustad - Florida Solar Energy Center
Paul Strachan – Strathclyde University
Mike Witte – GARD Analytics**
Doug Wolf – The Weidt Group
Tim McDowell – Thermal Energy Storage Systems**

Progress and Accomplishments

Accomplishments:

- Testing plans presented to the TAG and SSPC 140
- Reconfiguration of FLEXLAB cells to make them easier to model with programs having limited modeling capabilities
- Major upgrade to NREL HVAC test facility: instrumentation and data acquisition
- Initial results from FLEXLAB and FRP presented at Jan. 2017 Standard 140 committee meeting
- Independent model of FLEXLAB produced by ANL to estimate effect of input uncertainties

Market Impact: (too soon)

Awards/Recognition: (too soon)

Lessons Learned:

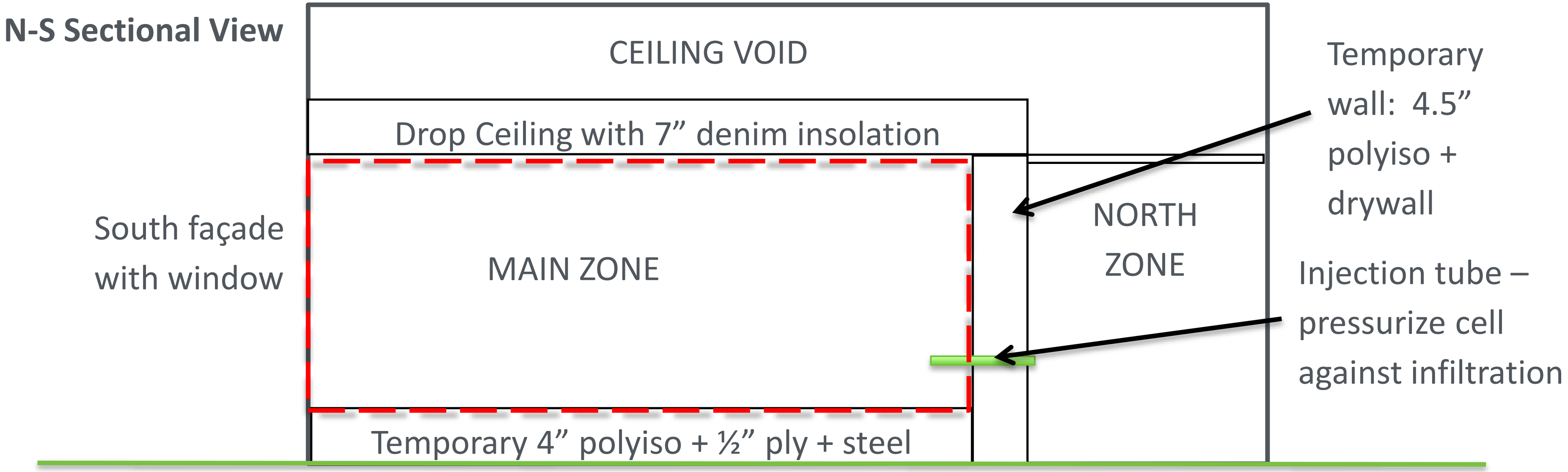
- Substantial time and effort required to fully commission and reconfigure a general purpose test facility for the simple configuration but high measurement accuracy required for model validation

LBNL – FLEXLAB testing approach

Focus on heat transfer in occupied spaces

- Space conditioning:
  - Mixing ventilation
  - Radiant panels and slabs
- Ideal vs realistic conditions:
  - **Ideal**: model assumptions: no furniture, ideal internal heat sources, good mixing
  - **Realistic**: furniture, lights, simulated occupants, imperfect mixing
- Zone type:
  - Interior: no fenestration, ~adiabatic walls
  - Exterior: window, opaque part of window wall has lower R-value

FLEXLAB Configuration and Tests



Test cells reconfigured to have a simple main zone that can be modeled by programs having limited modeling capabilities:

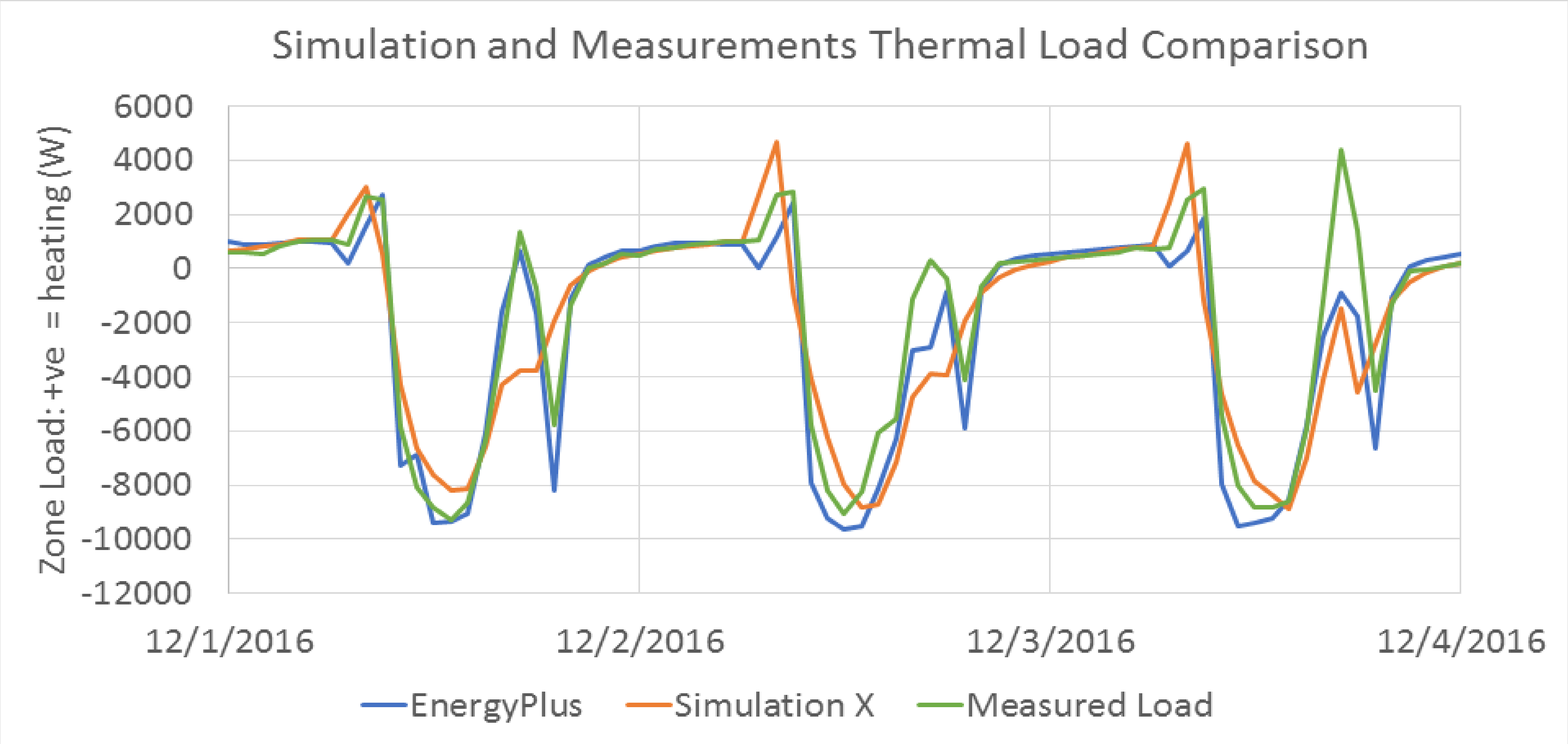
- insulated drop ceiling
- temporary north wall

Decouple main zone from construction complexities in ceiling void and north zone

Tests performed:

- Low mass (insulation covering slab)
- High mass (exposed floor slab)
- Constant zone temperature
- Night set-back

FLEXLAB Preliminary Results – Load Comparison

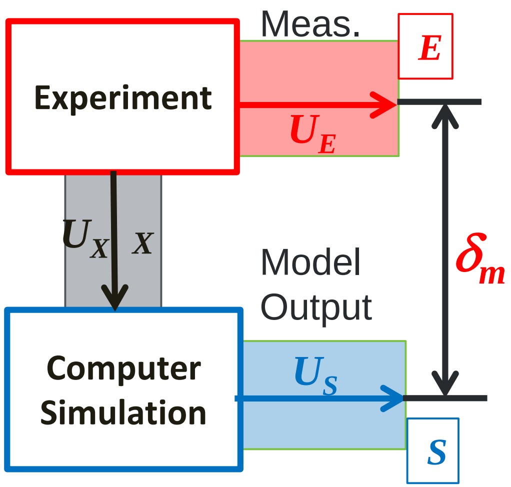


- low mass, night set-back test – zone air temperature set-point: 30°C 8am-6pm, 20°C 6pm-8am
- N.B. timing and calibration not yet finalized, and error estimates not yet propagated, so too early to draw conclusions

ANL - Preliminary Uncertainty Analysis for FLEXLAB

- FLEXLAB model was generated from ‘as-built’ drawings
- Experimental and model input uncertainties were estimated
- Uncertainties were propagated through model to estimate sensitivity to input errors, which re-enforced need to:
  - reduce the level of infiltration and then pressurize the space with air at known flow rate and temperature
  - measure the ground-reflected insolation incident on the windows
  - remove the carpet

The study will be used to assess the accuracy with which building properties and performance measurements need to be reported in the Standard 140 submissions.

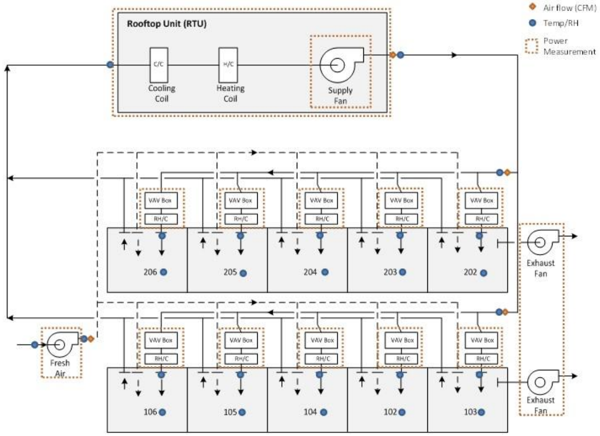


Uncertainty ratio (UR) is a simple measure of the confidence with which an experiment detects a real difference between the model predictions and the measured performance:

$$\mathrm{UR} = \frac{\delta_m}{\sigma_S + \sigma_E}$$

ORNL – Multi-Zone HVAC System

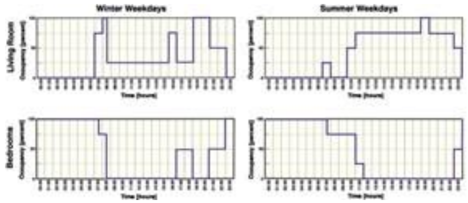
Multizone HVAC - RTU with VAV Reheating

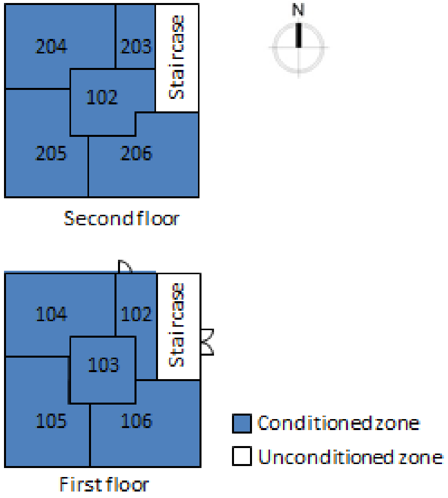


Weather Station

Flexible Research Platform (FRP)

Simulated Occupancy





Flexible Research Platform (FRP): 2 story small office building (40’ x 40’). 10 thermal zones.

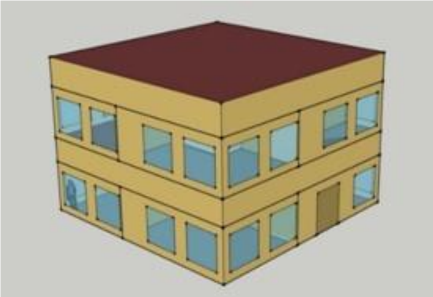
Multizone HVAC system: Rooftop Packaged Unit with Variable Air Volume (VAV) Reheating

Occupancy emulation: control of lighting, heaters and humidifiers

Primary purpose is to collect data to validate simulation of multi-zone controls

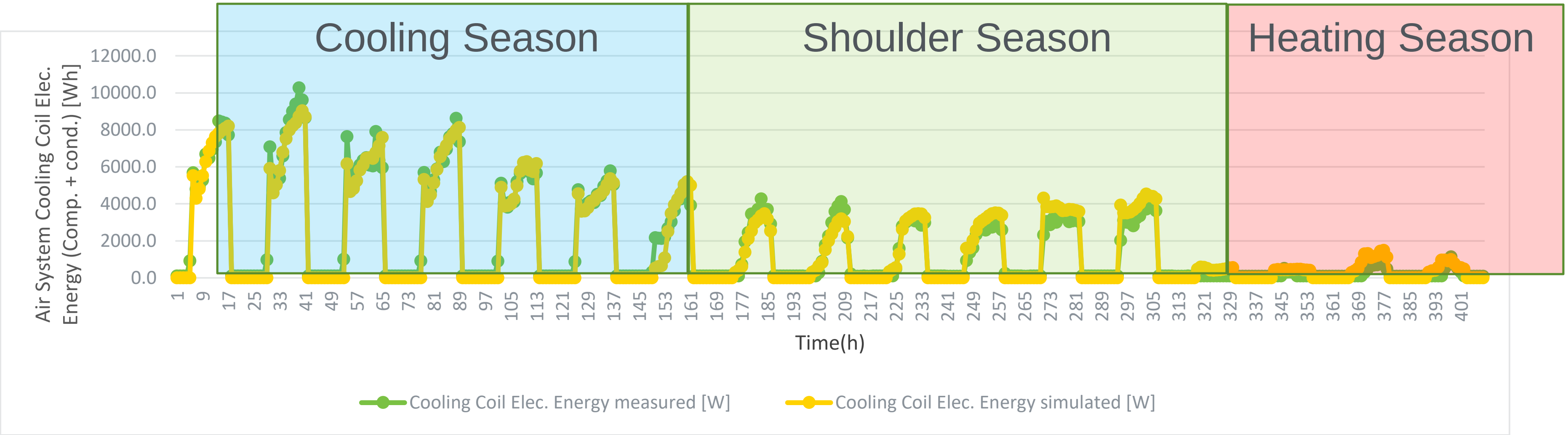
ORNL - Calibrated FRP Building Energy Model

Calibrated FRP model – purpose:



- Quality control: verify data consistency and completeness by comparing simulation results with measured data.
- Identification of model input parameter values for building envelope modeling
- **Ensuring that the simulated building load (envelope + internal gains) matches the delivered cooling/heating loads is a important prerequisite to HVAC system/control model validation**

Preliminary Results: RTU Cooling



NREL HVAC Test Plan

- An experimental plan for testing two high efficiency RTU's has been developed. The test apparatus is "flow-thru", facilitating rapid measurement of performance map test points (twin chambers not required).
  - A wide variety of dry bulb temperatures, humidity, and loads will be imposed on the test object.
  - The power to maintain "interior" dry bulb and wet bulb at "comfort" under the conditions of each test point will be measured.
  - The unit will be tested under full load and many part load conditions so that data (performance maps) suitable for annual simulation is collected.
- A SEER 17 unit has been procured and a purchase order for a SEER 20 unit is being prepared.
- Future Work: Use measured performance maps from this project to update the test suites in HVAC BESTEST Vols 1 & 2 in ASHRAE Standard 140.

Project Integration and Collaboration

Project Integration:

- Formal coordination with stakeholders on TAG and ASHRAE Standard 140 committee
- Informal collaboration with other researchers using the same facility, e.g. Center for the Built Environment at UC Berkeley – instrumentation and other equipment

Partners, Subcontractors, and Collaborators:

- Project partners: LBNL, ANL, NREL and ORNL
- ANL subcontracted independent model development to Georgia Tech
- Informal in-kind cost share from Southern California Edison (SCE). SCE is funding a project to use FLEXLAB to adjudicate between EnergyPlus, DOE-2.1e and DOE-2.2/eQuest and there have been significant synergies in configuring FLEXLAB for the two projects

Communications:

- ASHRAE Standard 140 committee (as noted earlier)

Next Steps and Future Plans

Immediate next steps:

- Continue testing at LBNL and ORNL
- Start testing at NREL
- Implement extended uncertainty framework (ANL)

Medium term next steps:

- Prepare pilot submission of measured data and documentation for Standard 140
- Initiate detailed discussions with the Standard 140 committee on formal submission requirements
- Validate EnergyPlus – also contributes to quality control of measurements and documentation
- Repeat key tests as required

Future plans

- Propose a follow-on project for FY2018-2020 to address additional systems, as prioritized by the TAG, to reduced uncertainties associated with the adoption of new, energy-efficient systems and components.

REFERENCE SLIDES

Project Budget

Project Budget: $1M/yr for 3 years.

Variances: FY16 budget cut 30%; cut restored at end of FY16. The effect was to slow down work in FY16, causing some missed milestones – see next slide

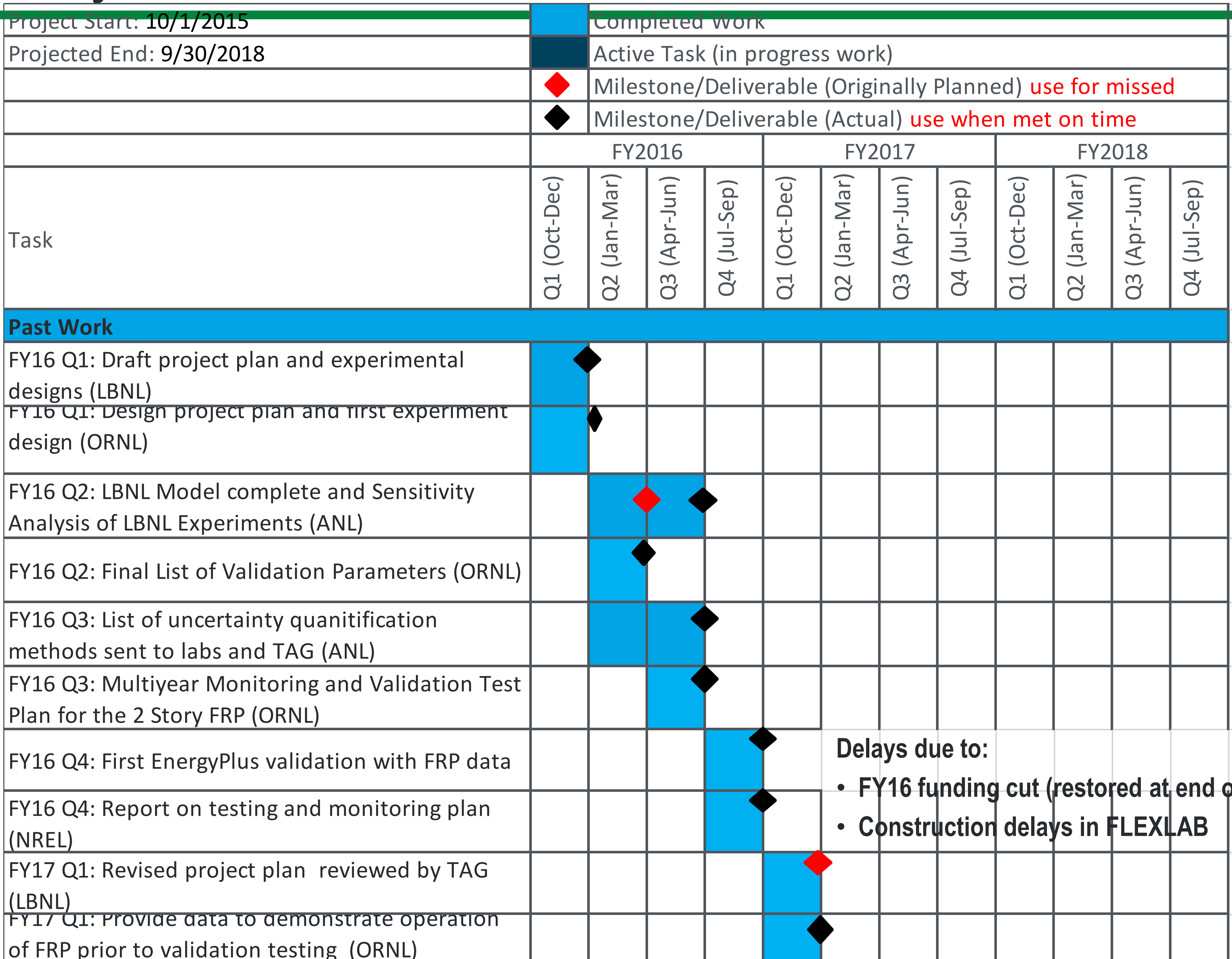
Cost to Date: $1,130k spent as of 1/31/2017 = 38% over 16 months = 44% of project duration

Additional Funding: Informal in-kind cost share from Southern California Edison from synergies in FLEXLAB set-up for a project to use FLEXLAB to adjudicate between EnergyPlus, DOE-2.1e and DOE-2.2/eQuest.

Budget History

10/1/2016 – FY 2016 (past)		FY 2017 (current)		FY 2018 – 9/30/2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1M	-	S1M	-	$1M	-

Project Plan and Schedule



Project Start: 10/1/2015	🟦	Completed Work
Projected End: 9/30/2018	⬛	Active Task (in progress work)
	♦	Milestone/Deliverable (Originally Planned) use for missed
	◆	Milestone/Deliverable (Actual) use when met on time

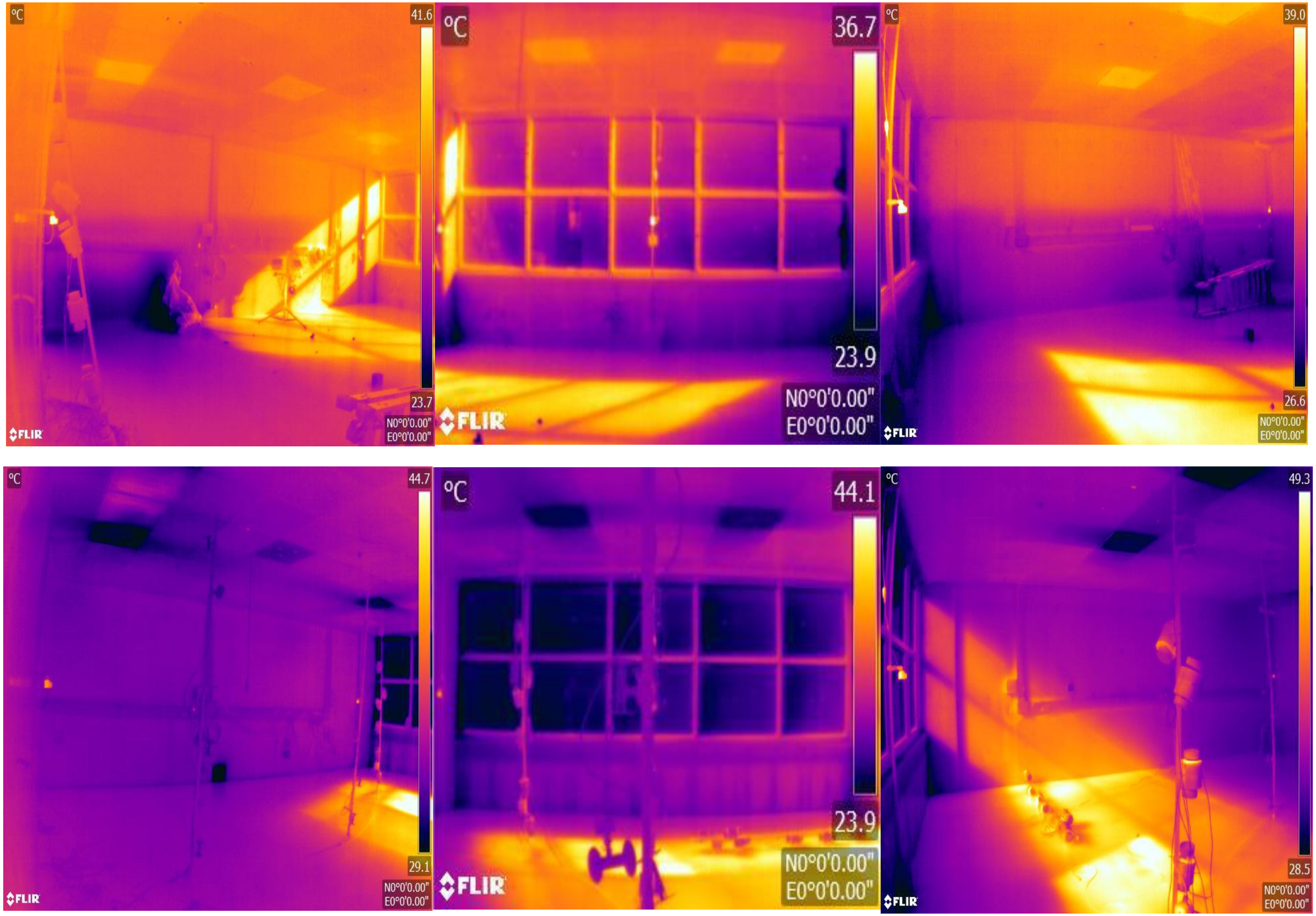
	FY2016				FY2017				FY2018			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
FY16 Q1: Draft project plan and experimental designs (LBNL)	🟦 ◆											
FY16 Q1: Design project plan and first experiment design (ORNL)	🟦 ◆											
FY16 Q2: LBNL Model complete and Sensitivity Analysis of LBNL Experiments (ANL)		🟦 ♦	🟦 ◆									
FY16 Q2: Final List of Validation Parameters (ORNL)		🟦 ◆										
FY16 Q3: List of uncertainty quanitification methods sent to labs and TAG (ANL)		🟦	🟦 ◆									
FY16 Q3: Multiyear Monitoring and Validation Test Plan for the 2 Story FRP (ORNL)			🟦 ◆									
FY16 Q4: First EnergyPlus validation with FRP data				🟦 ◆								
FY16 Q4: Report on testing and monitoring plan (NREL)				🟦 ◆								
FY17 Q1: Revised project plan reviewed by TAG (LBNL)					🟦 ♦							
FY17 Q1: Provide data to demonstrate operation of FRP prior to validation testing (ORNL)					🟦 ◆							

Delays due to:

- **FY16 funding cut (restored at end of FY16)**
- **Construction delays in FLEXLAB**

BACK-UP SLIDES

FLEXLAB Thermal Imaging



daytime – sun patches, night time – construction anomalies

Data needed for a Standard140 submission

- Building description:
  - As-built plans and specs
  - Source of each parameter documented
- On-site weather data:
  - Dry bulb and dew point, wind speed & direction, global & diffuse insolation, sky IR irradiance
  - Consistency checks with other local sources
- Control data: set-points
- Performance data:
  - Surface (~100 per cell) and air temps (35 per cell), heat fluxes (~10 per cell)
  - Vertical insolation on window: total, ground, transmitted
  - Internal heat sources (electrical input)
  - HVAC sensible loads: air-side / water-side heat balance on coils and fan
- Delivered:
  - Access to all measurements @ 1 min
  - Averaged and consistency-checked: TBD (15 min, surface averages, … ?)