Empirical Validation and Uncertainty Characterization for Energy Simulation

Berkeley Lab
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Project Summary

Timeline:

Start date: October 1, 2019

Planned end date: September 30, 2022

Revised end date: September 30, 2021

Key Milestones

1. LBNL: Deliver data-set to ANL
2. ANL: Deliver ASHRAE 140 Spec based on LBNL data

Budget:

Total Project $ to Date:

- DOE: $847k
- Cost Share: $0

Total Project $:

- DOE: $1,650k (planned)
- DOE: $1,100k (revised)
- Cost Share: $0

Key Partners:

Argonne National Lab
ASHRAE Project Committee 140

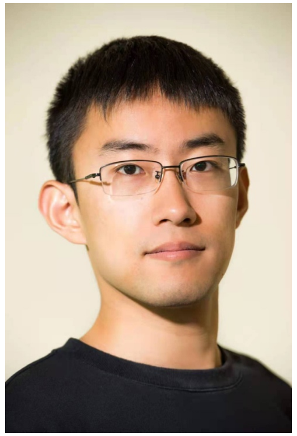
ASHRAE Standard 140

Project Outcome:

Empirical (measured) data for a single zone that can be used to validate Building Energy Modeling tools.

Team

Christian Kohler



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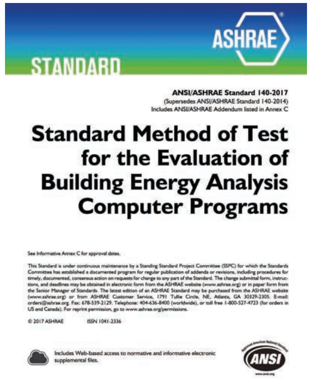
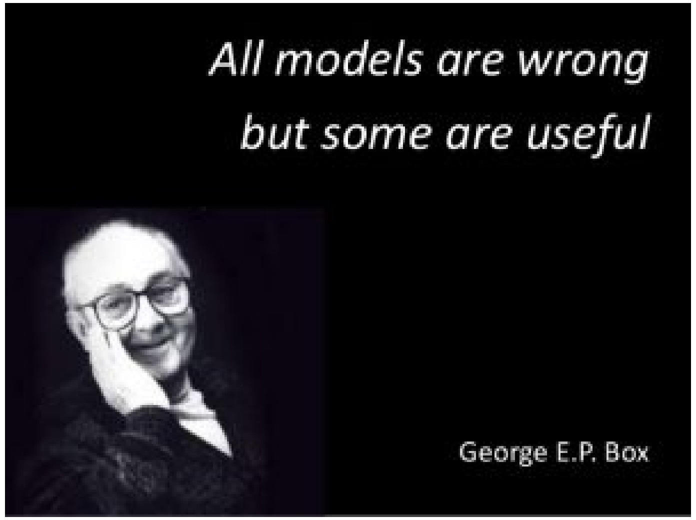


ASHRAE Project Committee 140

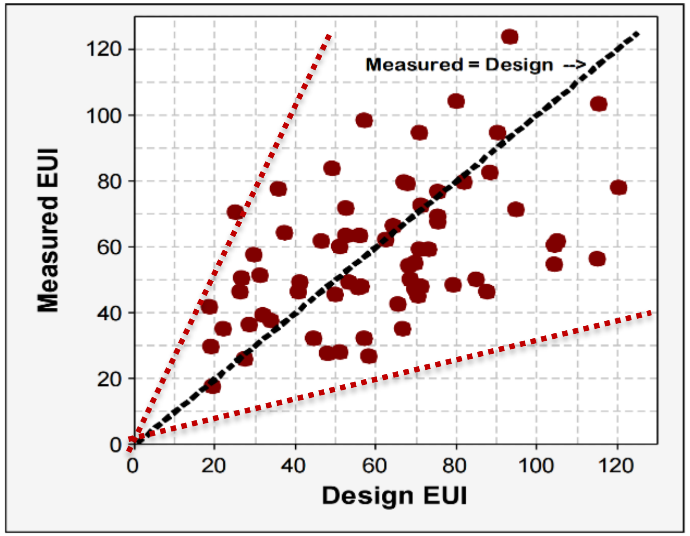
Challenge

- **Building Energy Modeling supports EE decision making but is underutilized**
  - Reputation for "inaccuracy" or "poor predictive capability" because it rarely matches the EUI of an operating building without calibration
- **Reality: EUI prediction is hard because of weather and occupancy variations and often besides the point**
  - For comparing the energy/carbon savings of an ECM, absolute prediction of the EUI is irrelevant – only comparative values need be accurate
- **Perception: If you can't predict EUI, how can you do anything?**



Reality

Credit: Twitter @archidose



Perception

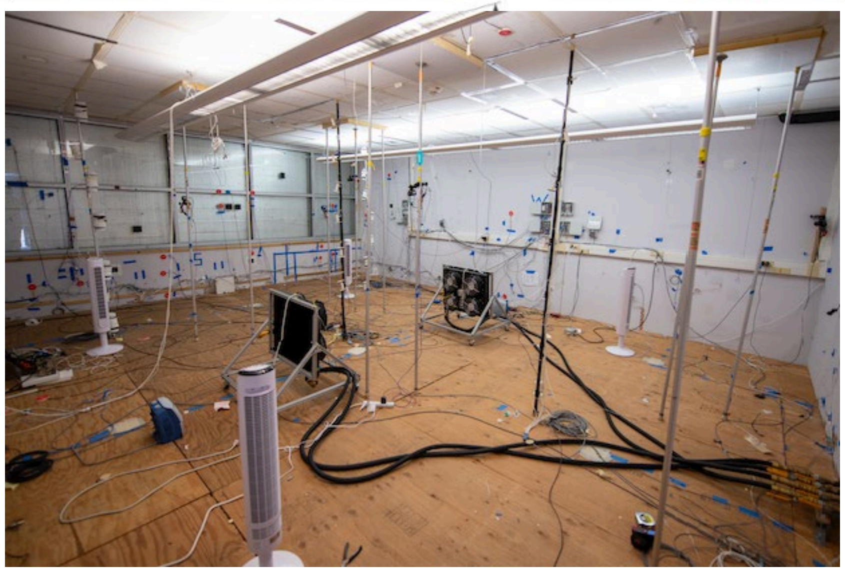
Approach

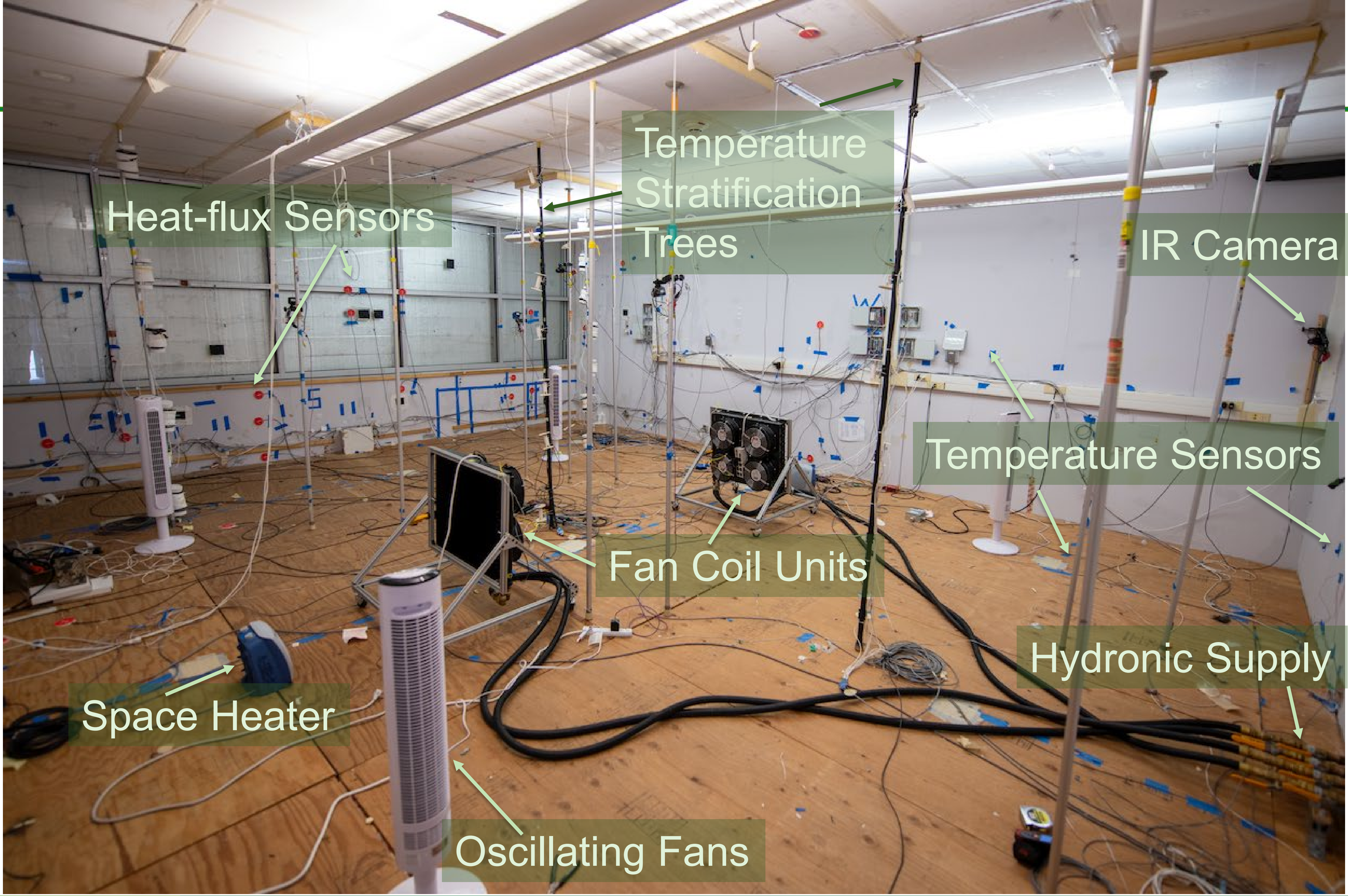
- Measure building performance data at a heavily instrumented facility
- Document the construction and details of this facility
- Document the conditions under which this data was collected

- Publish this curated data set to allow building energy modeling developers and users to validate their tools

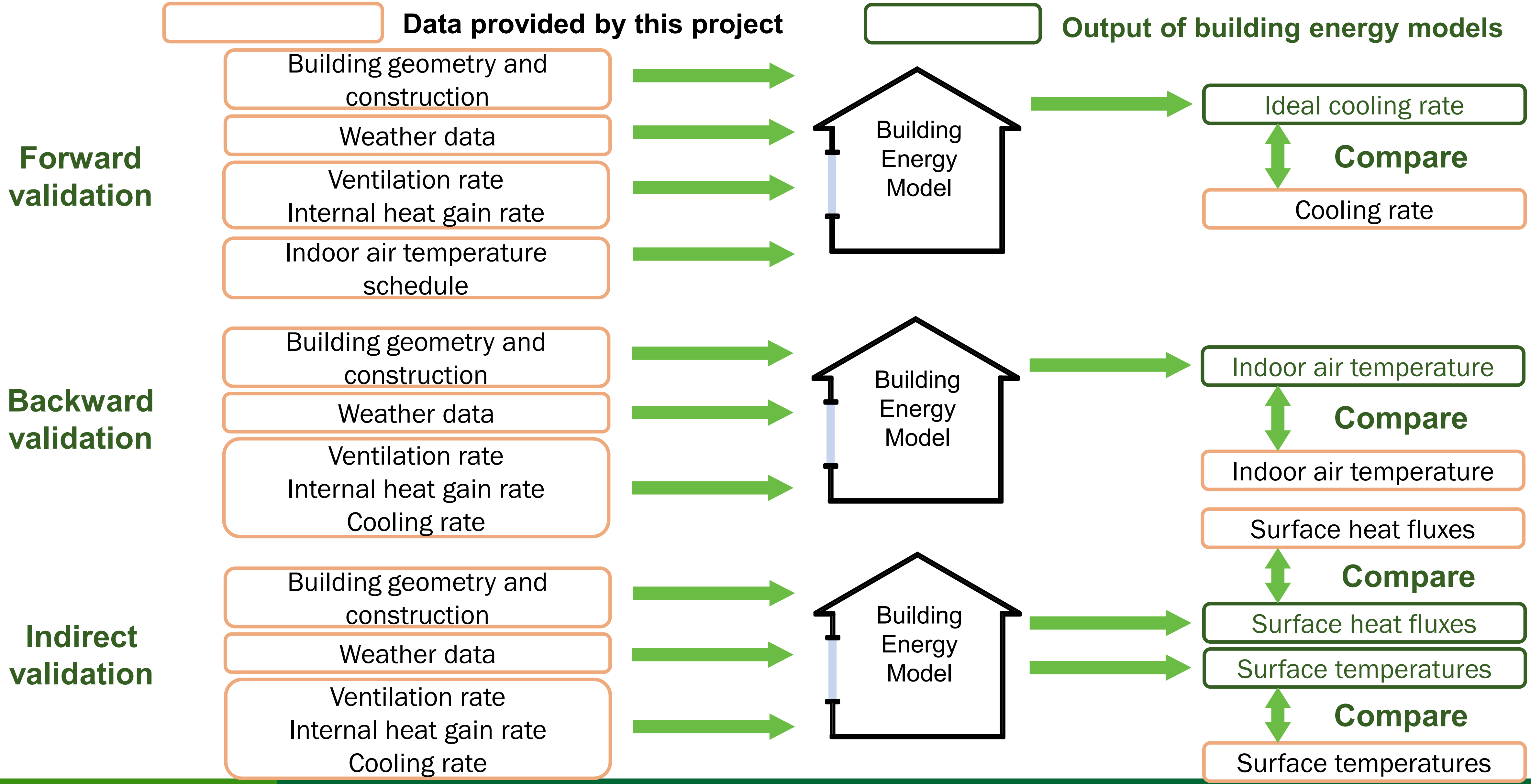
Approach - FLEXLAB

- What is unique about FLEXLAB?
  - Single zone, configurable as south facing exterior zone or as an interior zone
  - Control volume is the room (excluded air handler, ducts etc.)
  - Well instrumented hydronic heating and cooling system
- What calculations are we trying to validate?
  - Sensible heating and cooling load




Temperature Stratification Trees
Heat-flux Sensors
IR Camera
Temperature Sensors
Fan Coil Units
Hydronic Supply
Space Heater
Oscillating Fans

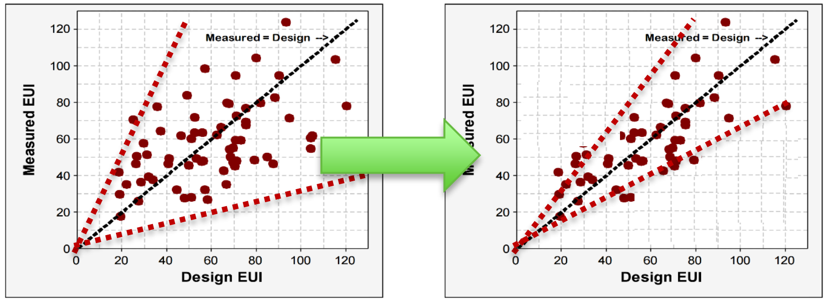
Approach – how will data be used

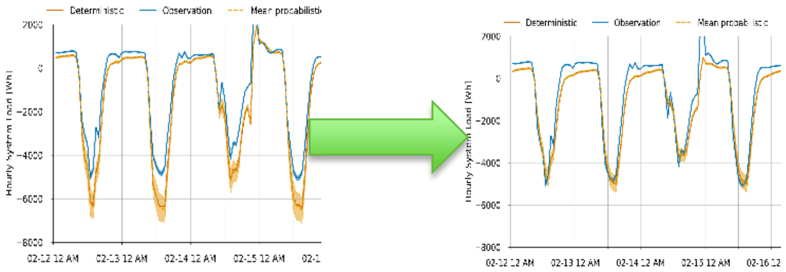


Impacts

- This project helps doubters to overcome the perception that models are inaccurate and therefore useless
  - Tests predict energy use in real, but controlled, buildings
- This project helps vendors improve the quality of their software
  - “Ground truth” for vendors to improve / debug code
- More trust and better tools can result in building design based on modeling science instead of conservative rule-of-thumb.

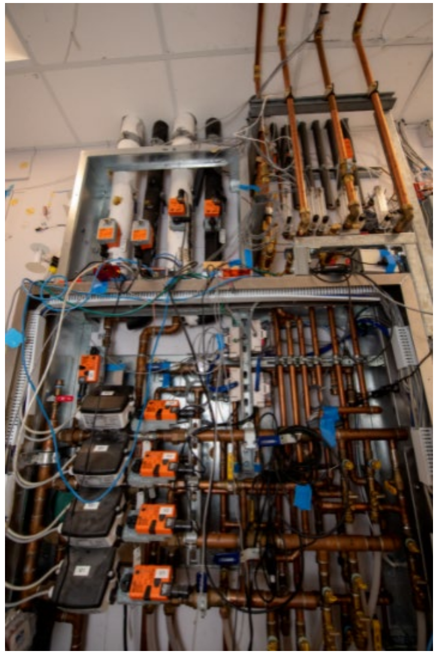
- ASHRAE 140 Stakeholders have *continually* placed Empirical Validation Tests near the top of the priority list for new tests to add to the standard





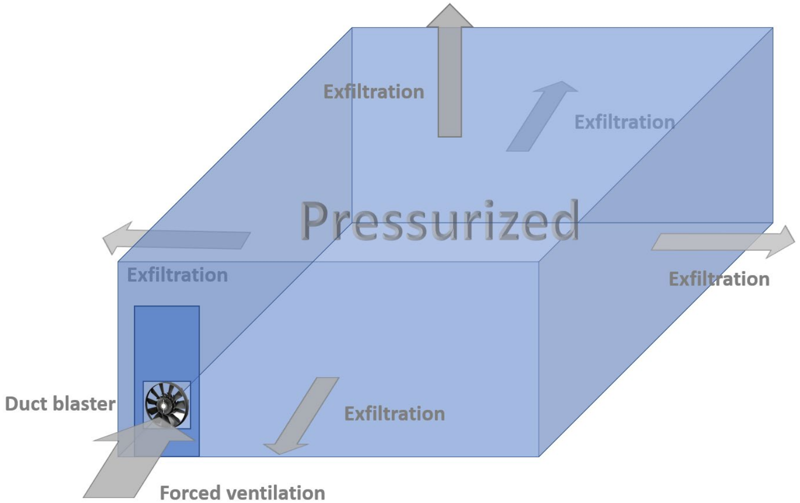
Progress

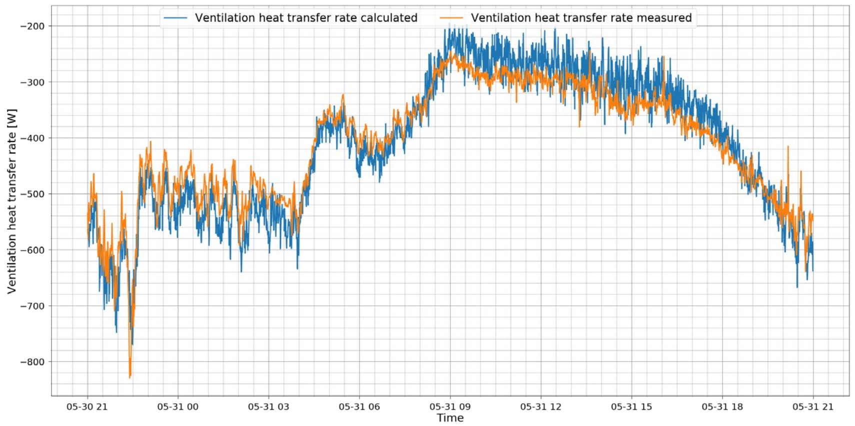
- Generated detailed dataset of measured conditions in FLEXLAB
  - Measured and controlled **infiltration**
  - Performed detailed **heat-flux** measurements through all surfaces
  - Controlled temperature with custom **fan-coil** with very accurate measurements
  - Achieved **Energy Balance**



Progress – Infiltration

- Developed a 3-zone CO_2 measurement and analysis method to determine infiltration
- Controlled infiltration using constant pressurization of the test cell (validated with CO_2 measurements)

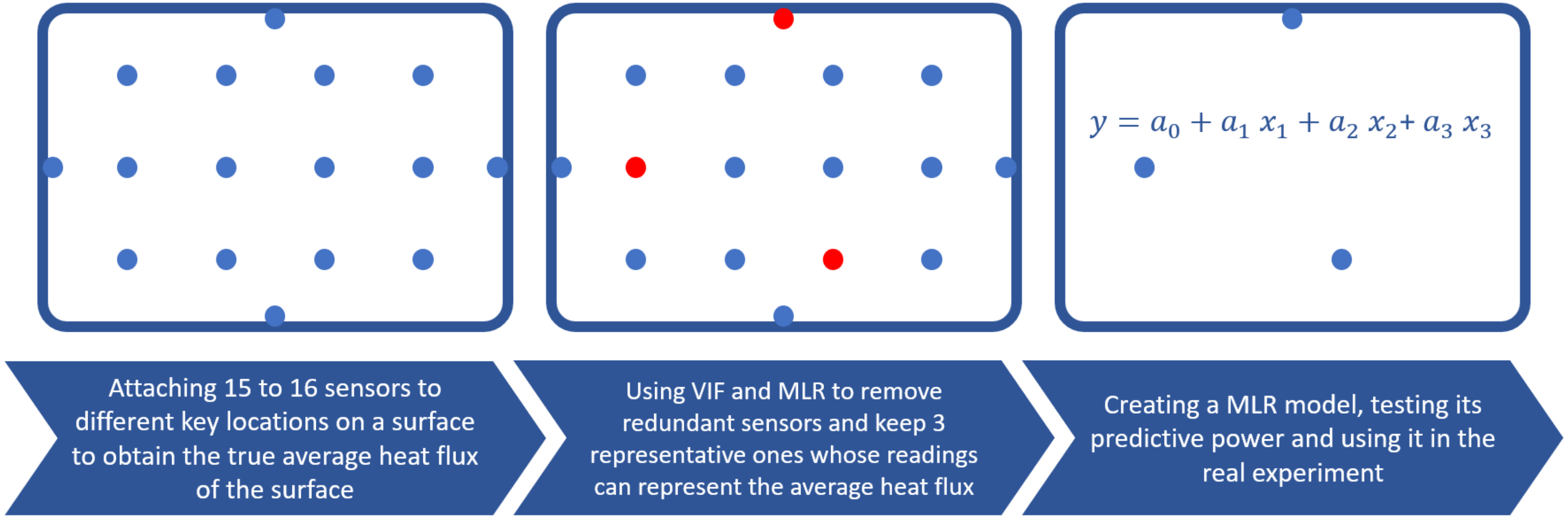




CO2 based vs blower door flow rates

Progress – Heat-flux measurements

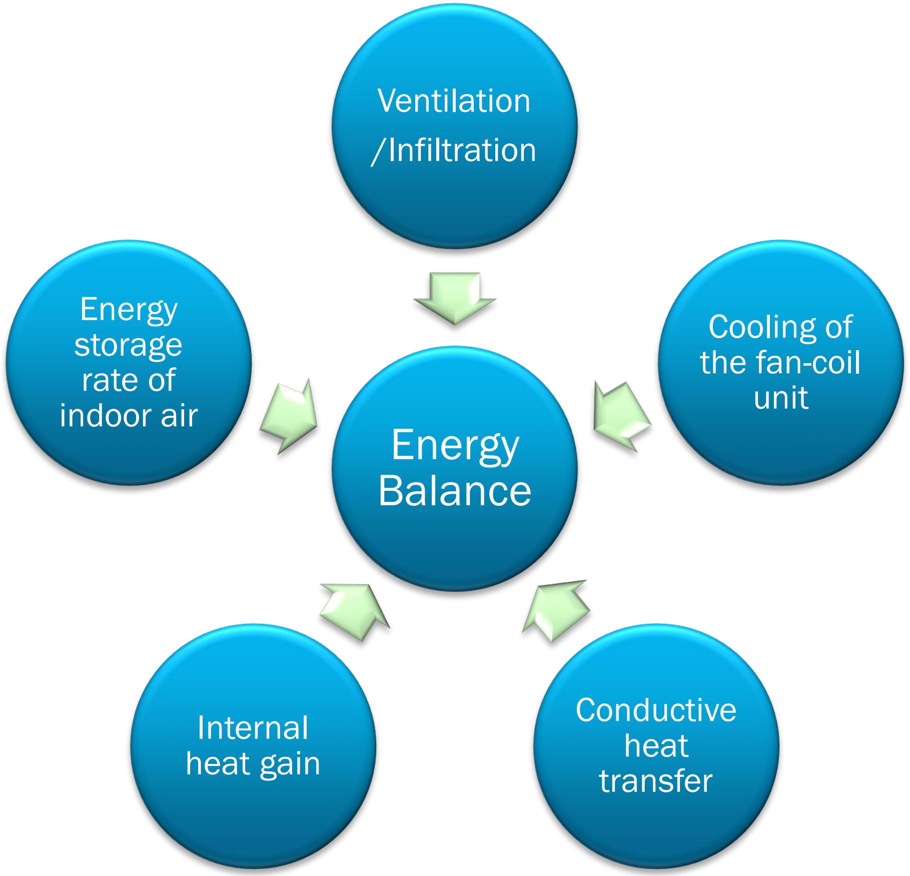
- Performed detailed heat-flux measurements per surface (16 sensors temporarily per surface)



VIF= Variable Inflation Factor
MLR= Multiple Linear Regression

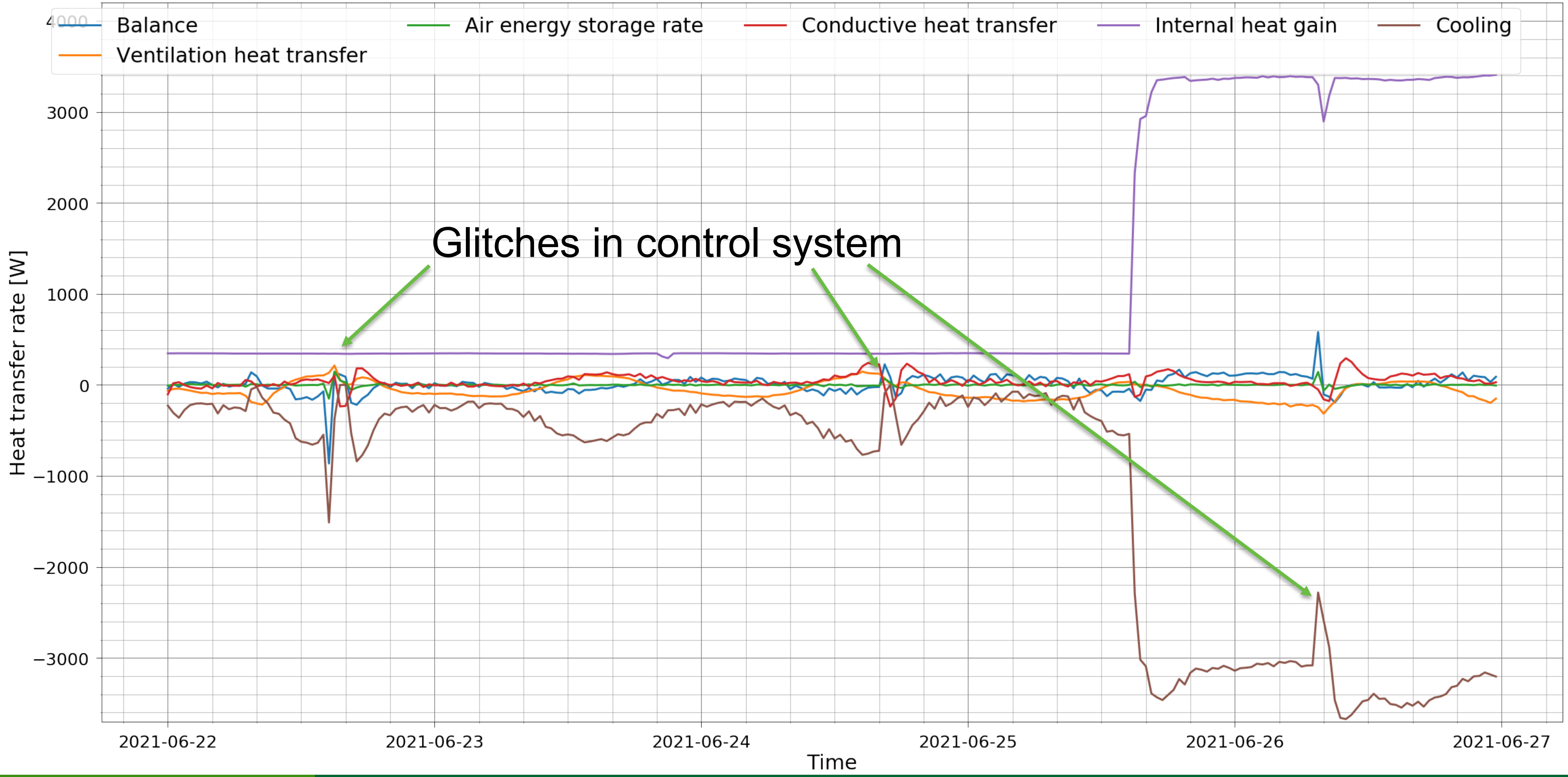
Very small heat-fluxes (<5 W/m2) due to well insulated walls and relatively small South facade

Progress – Energy Balance

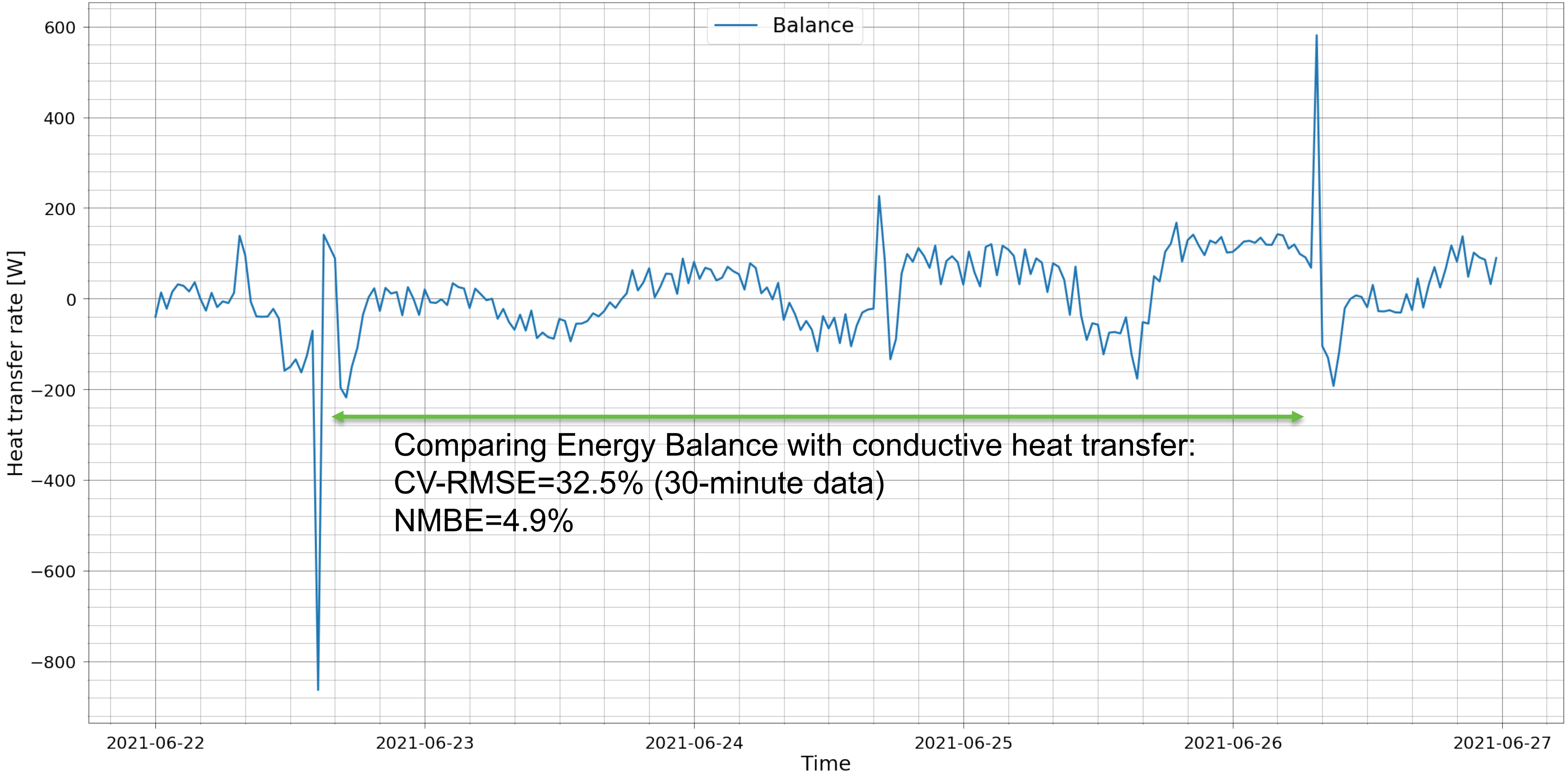


If the Energy Balance is ~0W over a time period, we have confidence that we properly measured all the components.

Progress – Energy Balance

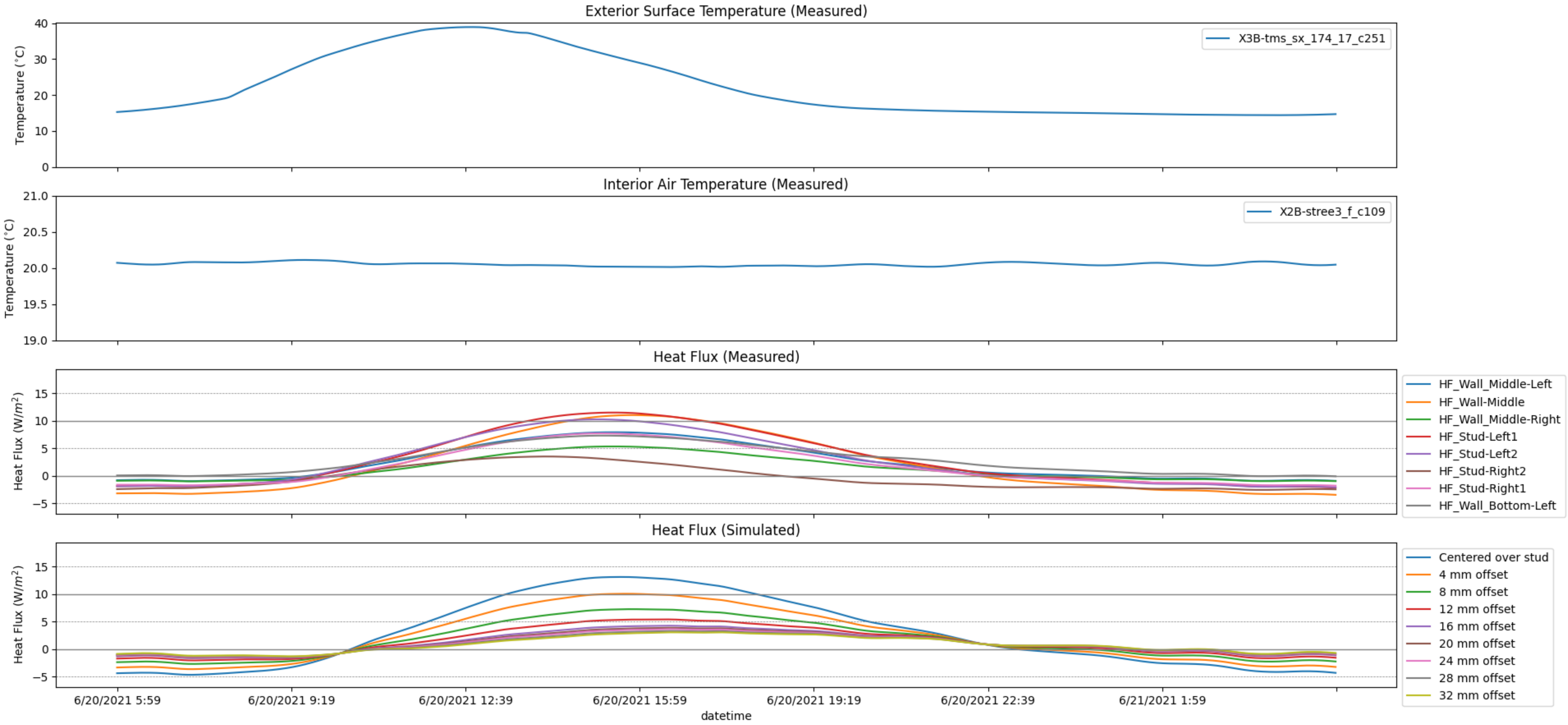


Progress – Energy Balance



Mean: 12 W over 5 days, standard deviation: 103 W (due to glitches).
Energy Balance Achieved!

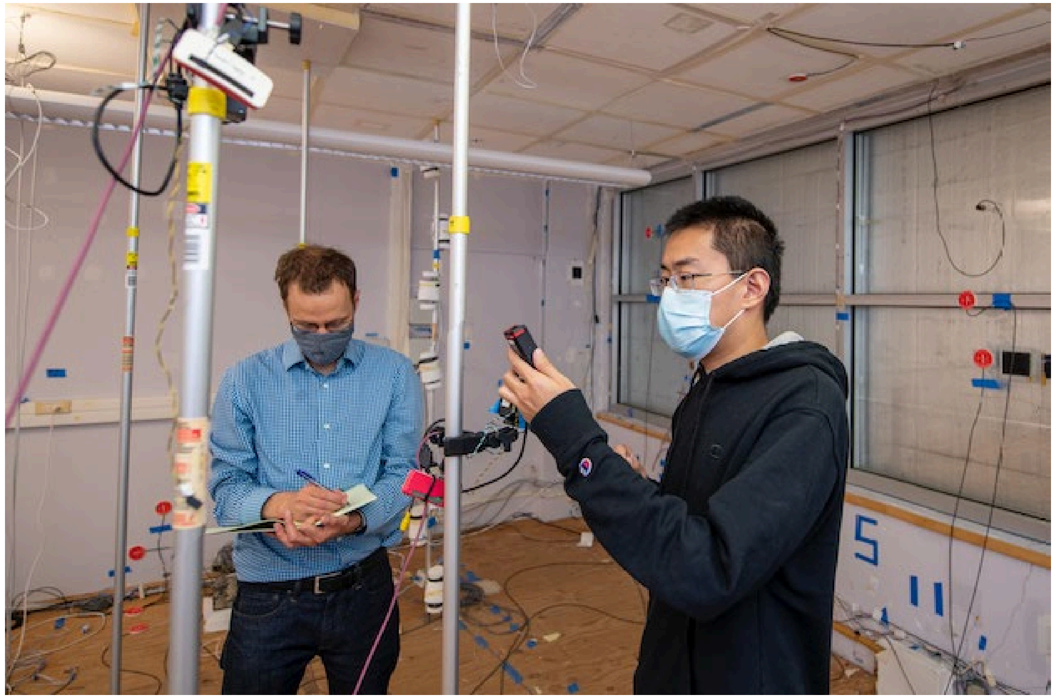
Progress – THERM Validation



Measured and simulated heat-flux on South wall, showing strong sensitivity to sensor placement.
Moving the sensor 8 mm away from the center of the stud, changes heat-flux by 42% (7.5W/m2 instead of 13 W/m2)

Progress – COVID impacts

- 75% of this project occurred during COVID
- Limited on-site access (researchers and technicians)
- This project is measuring data in a physical facility, so reduced access has a large impact



Stakeholder Engagement

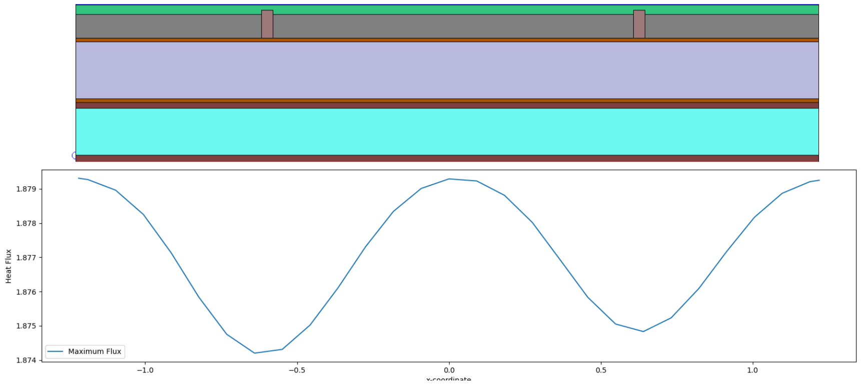
- Quarterly calls with Argonne National Laboratory
- ASHRAE SSPC 140, working group meeting each 6 months, summary of multi-lab results to whole committee

Remaining Project Work

- Creating data packet with:
  - Architectural drawings
  - Weather data
  - Temperatures, heat-fluxes, internal gains etc.
- Working with ANL to identify best data and physics to develop ASHRAE 140 test suite or validation tests for other software not covered by ASHRAE 140 (i.e. 2/3D heat transfer programs like THERM, Heat2 / Heat3, COMSOL)
- ANL to complete uncertainty characterization of the selected data
- ANL to create final spec for an ASHRAE 140 test suite and develop independent simulation models in EnergyPlus and IESVE to ensure spec is ready for handoff to ASHRAE 140 for further test trials.

Conclusion

- We were able to acquire a good data set, but further experiments would have diminishing returns, we therefore propose to stop the experiment.
- Measuring an overall energy balance requires a calorimeter-like setup
- While not designed as a calorimeter (500 ft^2 is very large for this), FLEXLAB was able to provide useful data. Side-by-side experiments are more common use case.
- Data is valuable both as an ASHRAE 140 dataset as well validation of dynamic thermal bridges for THERM
- Component validation of EnergyPlus models is valuable in addition to whole zone validation



Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: The original budget was $550k/year for three years (FY20, FY21, FY22)
Variances: Based on conversations between the TDM and the project team it was decided to end the experimental work in FY21. The carry-over funding into FY22 will be used for engagement with the ASHRAE 140 committee and to return the FLEXLAB test cell to its original state.
Cost to Date: Cost to date is $847k or 77% of the total budget. In FY21, $434k was spent YTD and $86K will be spent in the remaining months for a total of $522k.
Additional Funding: None.

Budget History					
10/1/2019– FY 2020 (past)		FY 2021 (current)		FY 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$414k	$0	$522k	$0	$164k	$0

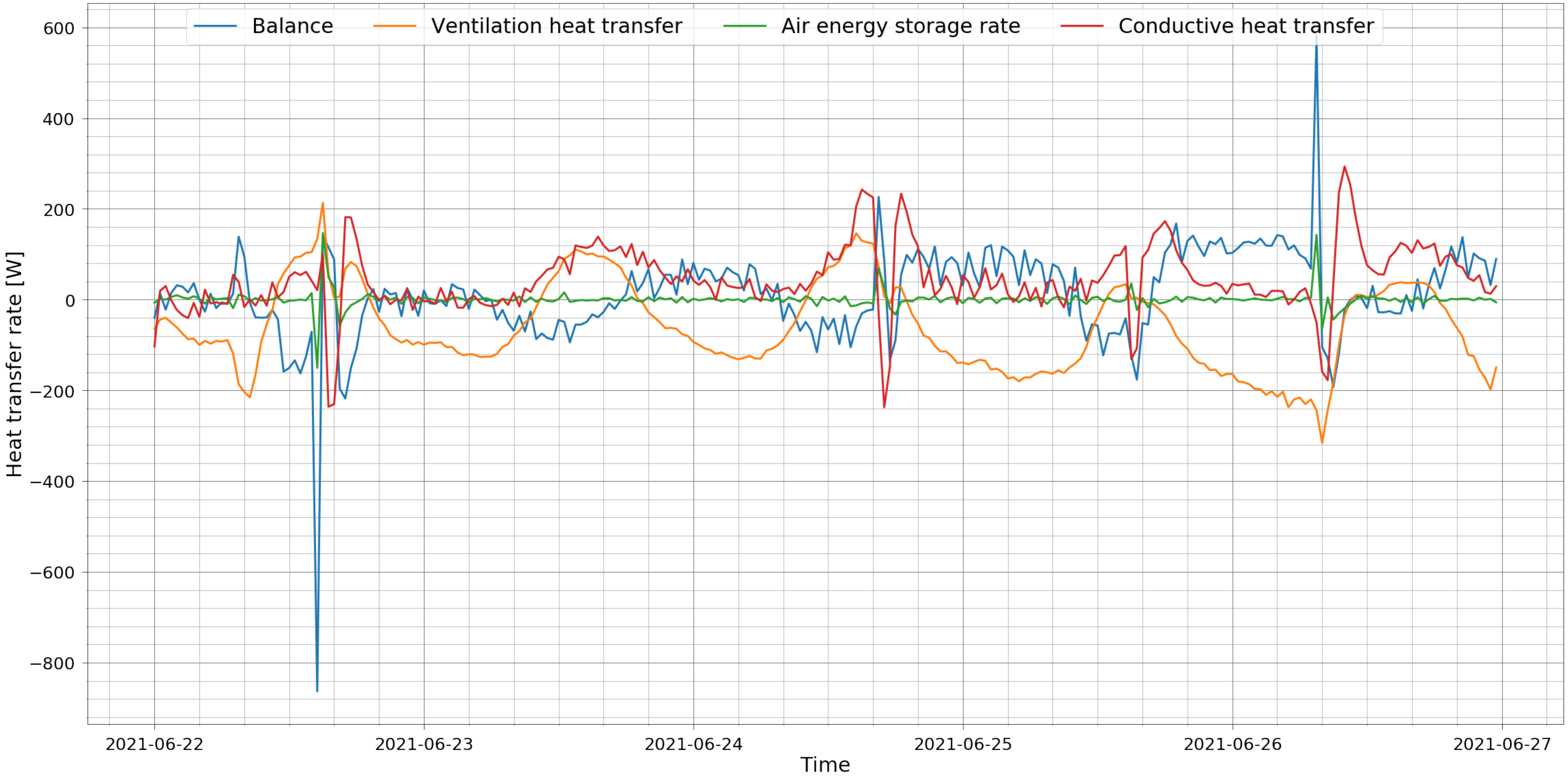
Project Plan and Schedule

- Project original initiation date: 10/1/2019 & Project planned completion date: 9/30/2022
- EnergyPlus validation will be performed by ANL after Task 3 which was recently completed.
- Measurement delays due to limit access to the facility during COVID (75% of this project was during COVID).
- Final deliverable will be datasets for 2 experiments.

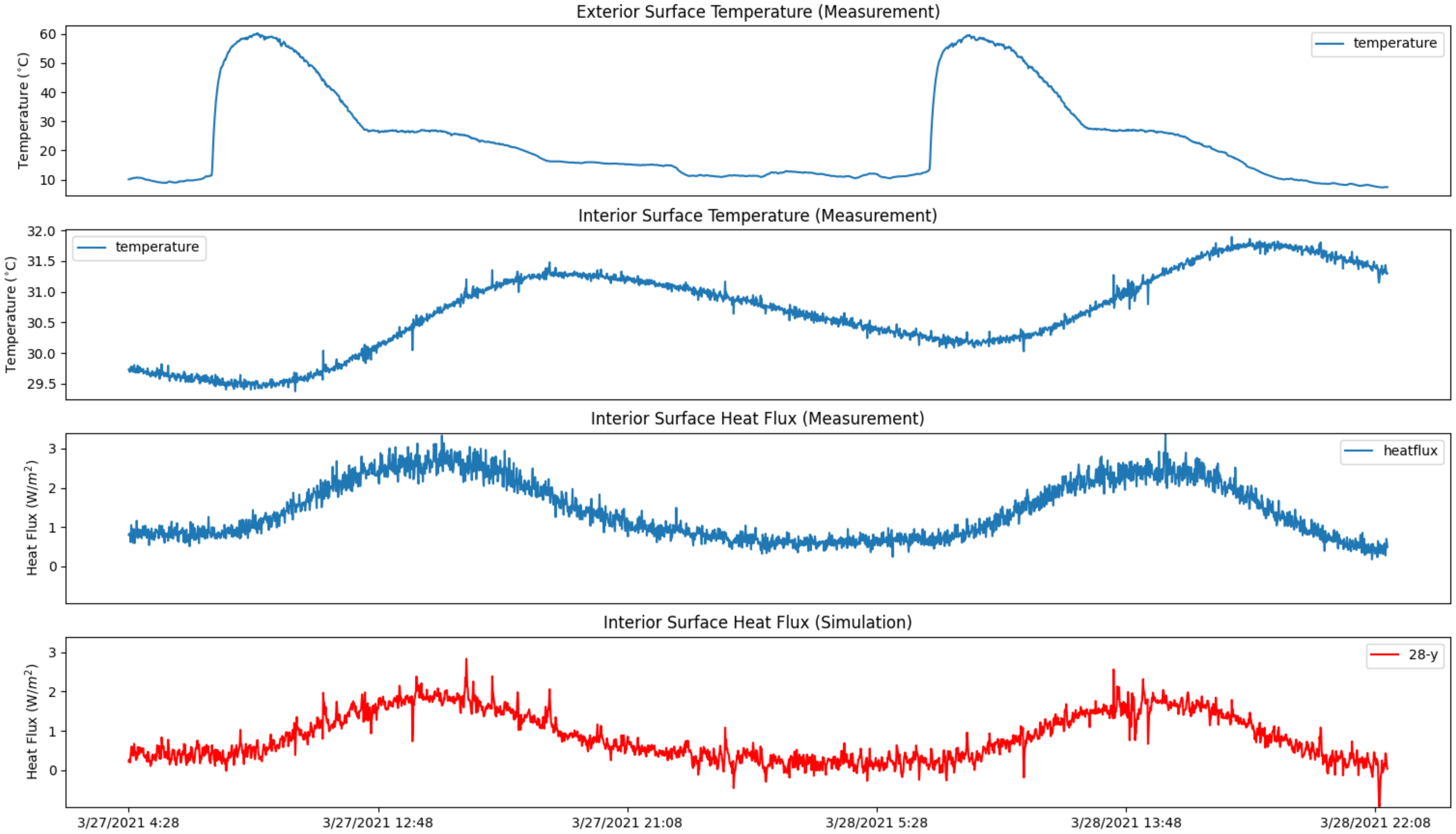
	◆ (red)	Milestone/Deliverable (Originally						
	◆ (black)	Milestone/Deliverable (Actual)						
	FY2020				FY2021			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work								
Project plan for Years 1–3 and detailed plan for Year 1 experiments	◆							
Progress report describing experimental progress			◆					
First EnergyPlus validation with FLEXLAB data								◆ (red)
Task 1: Report documenting infiltration heat/gain loss from tracer gas measurements.					◆			
Task 2: Report on test facility characterization						◆		
Task 3: Datasets for two experiments complete							◆	
Current/Future Work								
Task 4: Packaged dataset for SSPC 140 for four experiments								◆

Backup slides

Progress – Energy Balance - details



Progress – THERM Validation



Measured and simulated heat-flux on East wall, show good agreement for time delays

Note: 1 W/m2 is 60 μV output from heat-flux sensors, which is challenging to measure

Ventilation/Infiltration heat transfer

Decay Technique

Disadvantages:
- Requiring multi-day continuous measurement;
- Sensitive to environmental conditions;
- Unable to quantify the impact of environmental conditions on the results.

Constant Injection Technique

Advantages:
- Data of different tests can be concatenated for calculation.

Disadvantages:
- Sensitive to environmental conditions;
- Requiring a large number of tests in different environmental conditions.

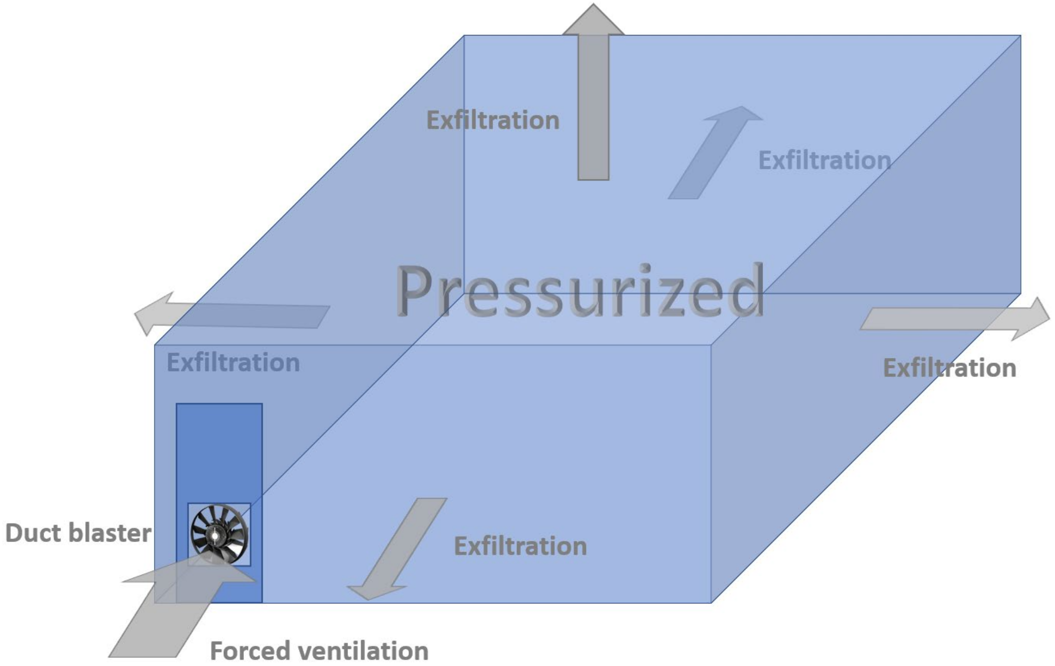
Blower-Door Technique

Advantages:
- The air flow rate is measured with high accuracy regardless of environmental conditions.

Disadvantages:
- A large air flow rate is required to maintain a positive pressure in 3B which may be different from everyday situations.

Ventilation/Infiltration heat transfer

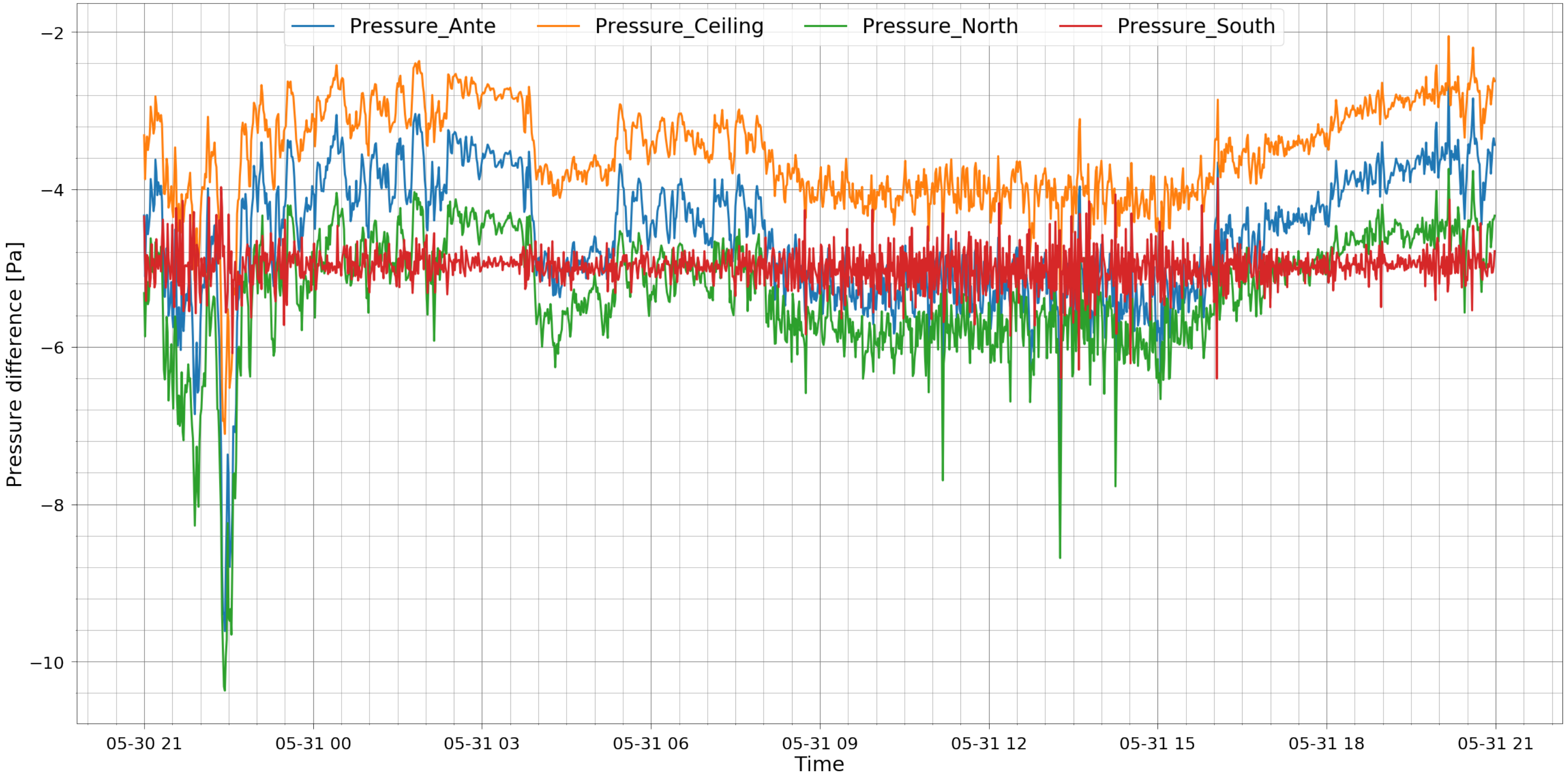
Blower-door technique



Advantages:

- A positive pressure is maintained in 3B by a duct blaster, so tha all infiltrations are prevented;
- We only need to measure the temperature and flow rate of the air going into 3B.

Ventilation/Infiltration heat transfer



A constant positive pressure is maintained in 3B

Energy balance model

Total conductive heat transfer rate through each surface: