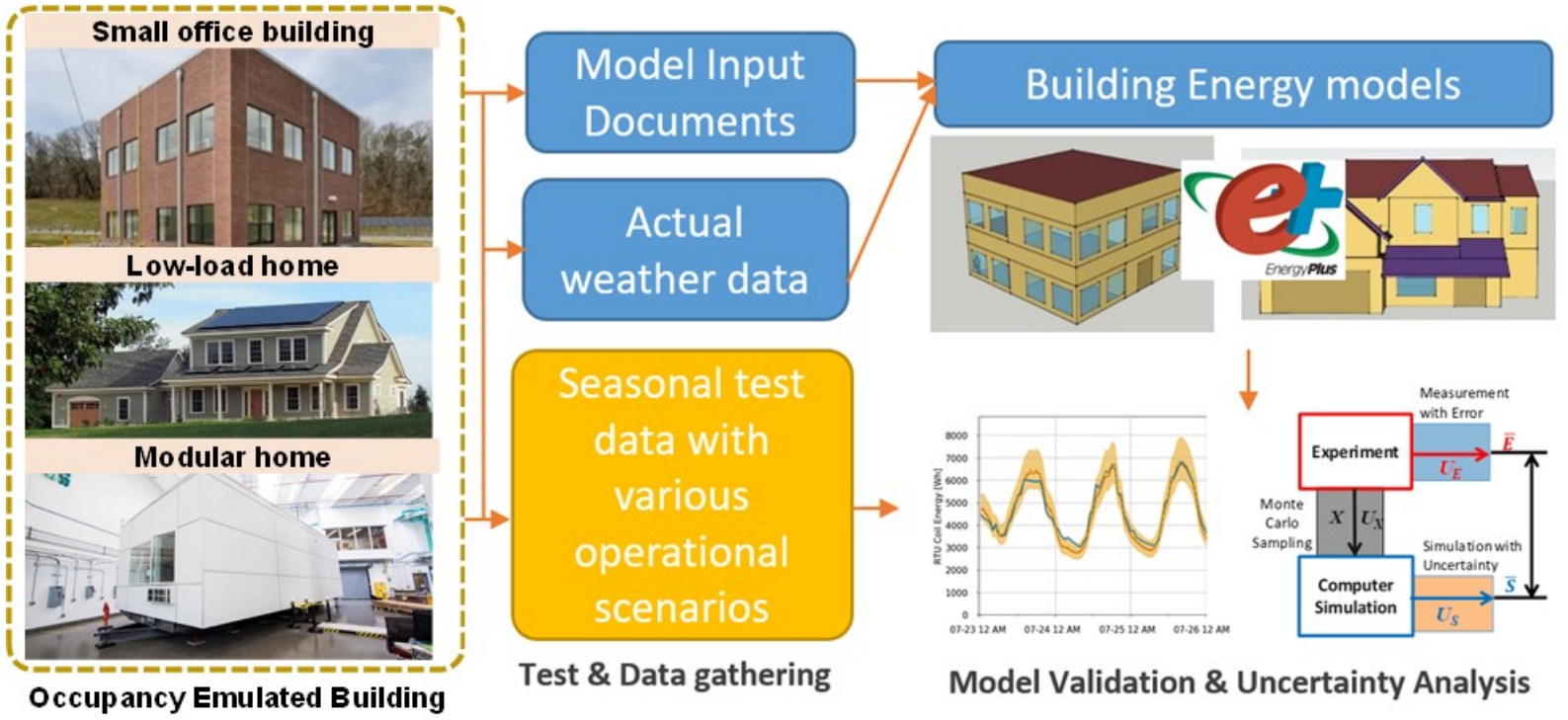
Empirical Validation of Building Energy Simulation: FRP, iUnit, and NZERTF



Oak Ridge National Lab (ORNL), National Renewable Energy Lab (NREL), and Argonne National Lab (ANL)
Piljae Im, PhD. R&D Staff
865-241-2312, imp1@ornl.gov

Project Summary

Timeline:

Start date: 10/1/2019

Planned end date: 9/30/2022

Key Milestones

1. Present improved EnergyPlus models for the FRP. The level of improvement will be evaluated with improved CVRMSE values for room air temperatures.; 6/30/2021
2. Updated Independent EnergyPlus model for FRP; 6/30/2021

Budget:

Total Project $ to Date:

- DOE: $1,508K
- Cost Share: $0

Total Project $:

- DOE: $3,030K
- Cost Share: $0

Key Partners:

ASHRAE SSPC 140
New Jersey Institute of Technology (NJIT)
National Institute of Standards and Technology (NIST)

Project Outcome:

Provide empirical data for ASHRAE Standard 140 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs to promote

- Improved accuracy of BEM engines
- Improved characterization of their accuracy
- Confidence in all BEM tools with greater adoption of the tools and greater influence on design decisions

→ All of which means more efficient and higher performing buildings and decarbonization from building sector

Team


Piljae Im (PI)


Sungkyun Jung


Prateek Shrestha


Mikael Salonvaara


Mahabir Bhandari

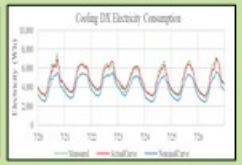

Tony Gehl


Matt Leach


Liang Zhang

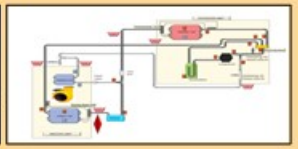
ORNL

- Lead Lab
- Overall Project management
- Test facility: FRP



NIST & NJIT

- Test facility:
the Net-Zero Energy Residential Test Facility (NZERTF)




Hyojin Kim (NJIT)


Lisa Ng (NIST)


Brian Dougherty (NIST)

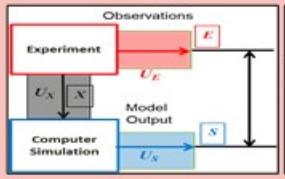
ASHRAE SSPC140 Committee

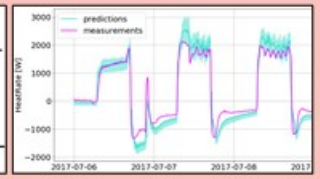
NREL

- Test facility:
Modular Apartment Unit

ANL

- Uncertainty Quantification Analysis
- Independent modeling



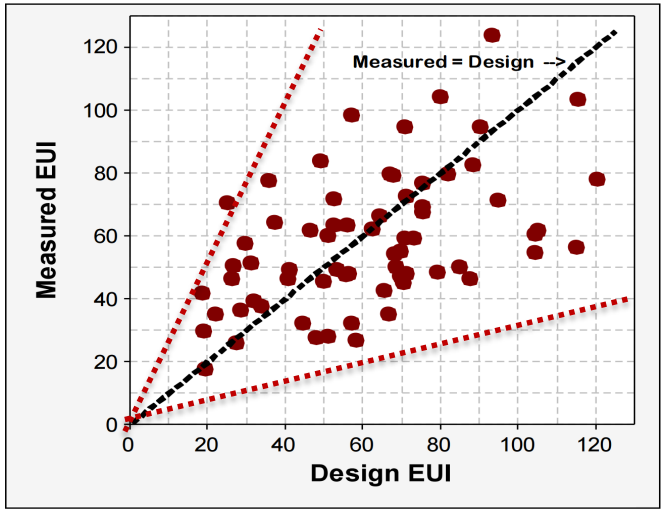



Ralph Muehleisen


Ji-Hyun Kim

Project Overview: Background and Challenges

- **Use of building energy modeling (BEM)**
  - Design new and existing buildings for energy efficiency
  - Code compliance
  - Green building certification
  - Real time building control
- **Problem**
  - Energy simulation cannot reliably predict actual energy performance (i.e., performance gap): "the measured energy use can be as much as 2.5 times the predicted energy use"
  - Sources of the gap: mostly model input parameters (occupant behavior, weather, building/HVAC properties), and modelers' decisions, and model algorithms.
- **Validation of BEM**
  - Comparative studies, analytical verification, and empirical validation
- **The ASHRAE Standard 140 framework accommodates empirical tests but does not yet include any dataset**



* EUI: Energy Use Intensity

Impact

- **ASHRAE Standard 140**
  - Generate sets of measured data to enable empirical validation → will be incorporated in an extended version of ANSI/ASHRAE Standard 140.
  - This research will feed the process of developing standard methods of test, specifically ANSI/ASHRAE Standard 140 - Method of Test for the Evaluation of Building Energy Analysis Computer Programs.
- **Validation of energy modeling simulations:**
  - The data sets will be used to evaluate both new and existing energy simulation software, including DOE's EnergyPlus. The data sets will be equally applicable to validation of other simulation engines as well.
- **Promoting the use of energy modeling:**
  - Increasing the accuracy of energy simulations → significant impact on expediting the use of energy modeling in the building planning, design, and retrofit process, and thus on realizing the maximum energy and cost savings potential for new and existing buildings.

ORNL: Multizone HVAC System Validation using ORNL's Flexible Research Platform

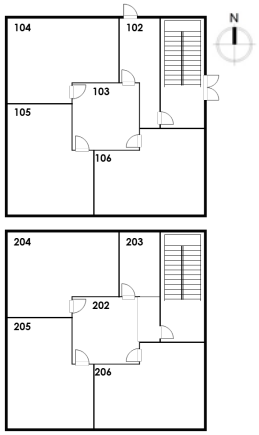
Flexible Research Platform (FRP)

- 2 story small **office building** with 10 thermal zones
- Multizone HVAC - Rooftop Packaged Unit (DX cooling) with Variable Air Volume (VAV) Reheating
- Onsite Weather Station (Temp, RH, Solar (global, direct normal, diffuse, wind)

Outcomes (Progress)

- 3 cooling and 3 heating season tests with limited uncertainties
  - *Heating/cooling baseline, Heating/cooling free floating, Heating/cooling setback*
- Documentation: Modeling input specifications
- Validated models: EnergyPlus & DOE-2.2
- Data sets:
  - Test data sets: 1 min and 60 min resolution per test
  - Weather data: 1min resolution

Flexible Research Platform (FRP)



Multi-zone HVAC - RTU with VAV Reheating

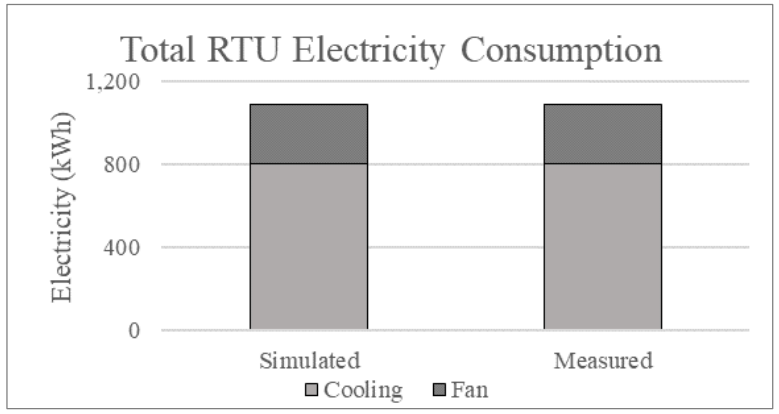
Weather Station

#	Parameters	Sub-parameters	Unit
1 - 3	RTU energy use	DX cooling	Wh
		Evaporative fan	Wh
		VAV box (electric reheat)	Wh
4	RTU discharge temperature		F
5	RTU return air temperature		F
6	RTU supply air flow		CFM
8	Room temp for each zone		F

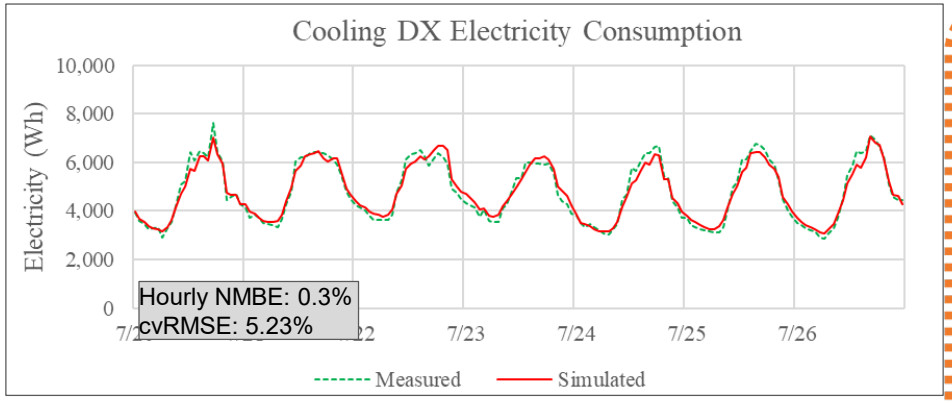
Validation : Cooling Baseline (FY20)

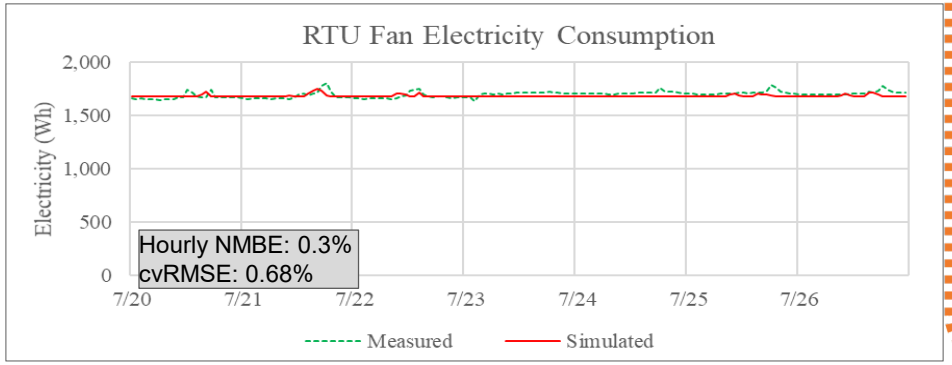
Test 1: Cooling Baseline :

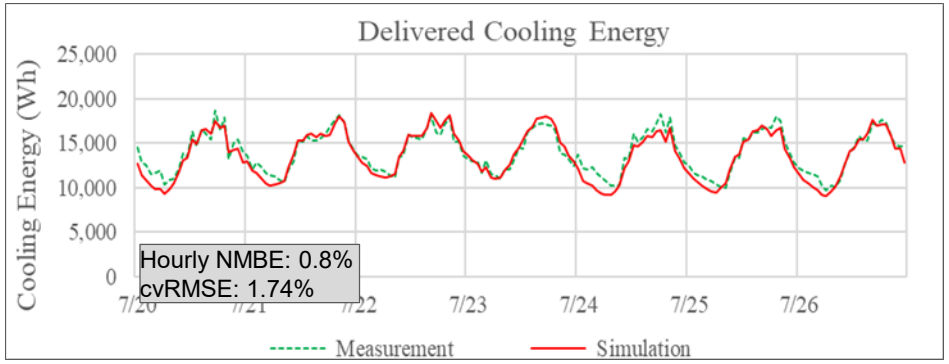
- No occupancy emulation
- All internal lights are turned off; no internal loads
- Fixed discharge temperature of 55°F and no Outdoor air ventilation or exhaust air
- No humidity control and no heating (including no reheating)
- Fixed zone set point temp of 72°F

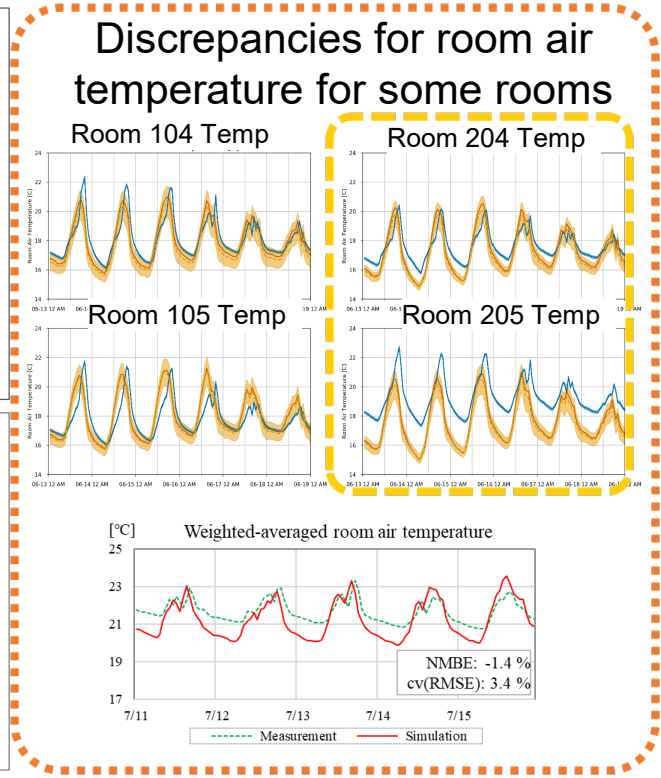


Less than 1% difference





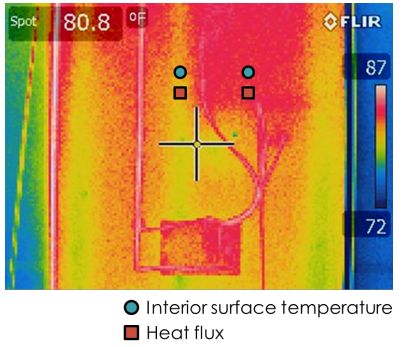


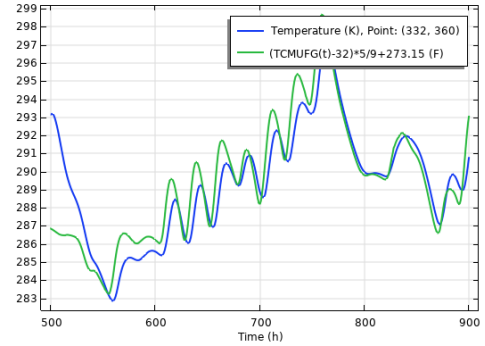


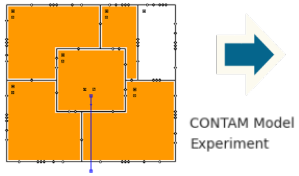
→ Focusing on validating envelope-related input parameters (e.g., wall, windows thermal properties, whole building and zonal infiltration)

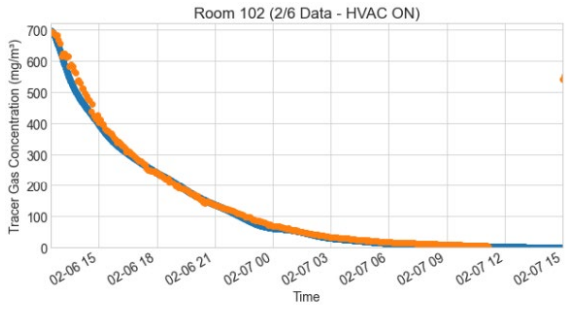
Progress Update (FY20 – 21)

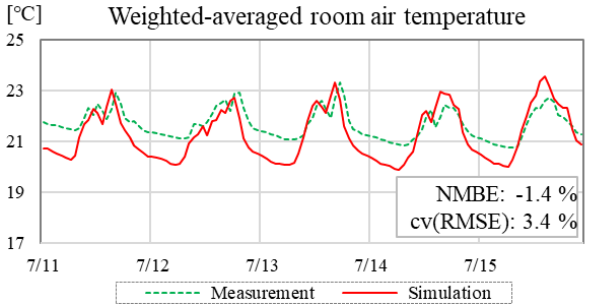
- **Validation of building envelope (Wall, Windows) performance with additional sensors**
  - Simulated and measured heat flux comparison
  - Comparing glazing solar transmittance
  - Updated building thermal properties values
- **Tracer gas test and CONTAM model calibration for infiltration modeling**
- **FRP EPlus model – Zone-part validation by decoupling zone and system models**
- **Updated zone model results as of August 2021.**

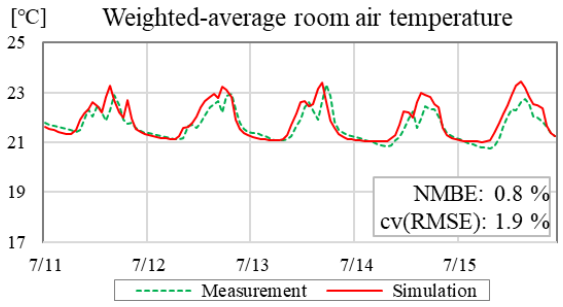


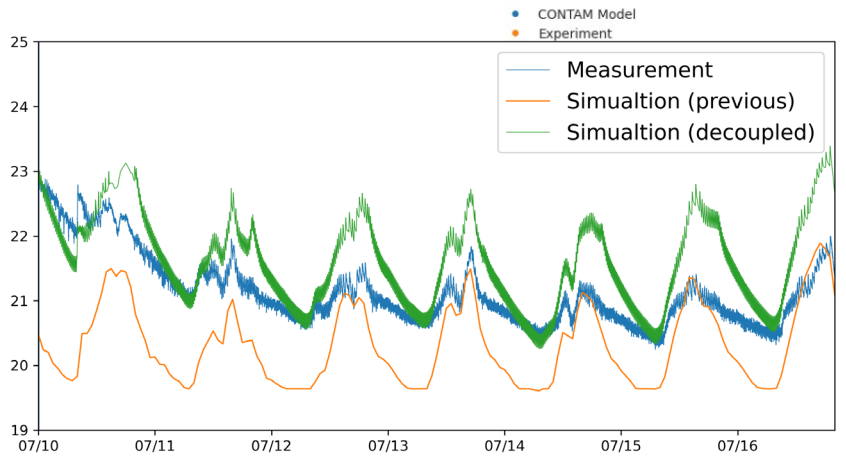












NIST/NJIT: Residential HP System Validation using NIST's NZERTF

NIST Net-Zero Energy Residential Test Facility (NZERTF)

- Floor area = 252 m^2 (2,709 ft^2) (4BR+3BA)
- EUI = 33.8 kWh/m^2 (23.5% of the average home in the U.S.)
- Residential HP with a two-stage compressor and a variable-speed indoor blower
- Onsite weather station collecting temp/RH/solar (GHI, DNI, DHI)/wind

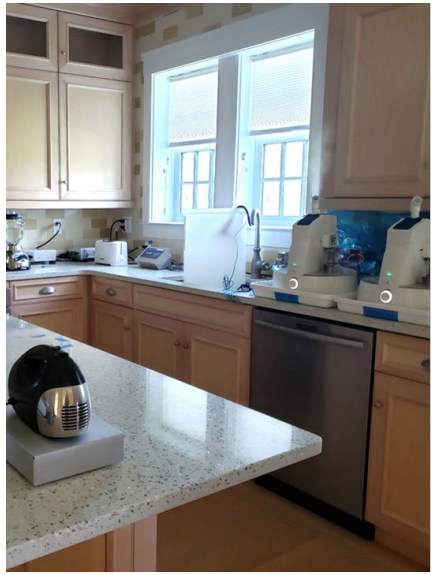
Outcomes (Progress)

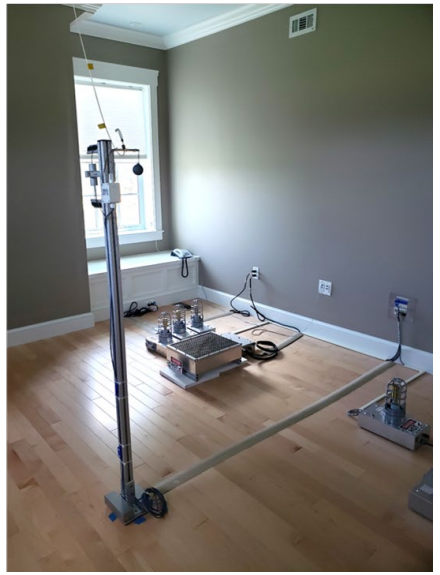
- [FY20] 6 tests with ± 0.4 heating/cooling differential
  - Heating/cooling baseline
  - Heating/cooling scheduled internal heat gains
  - Heating/cooling DR-enabled thermostat
- [FY21] 2 heating season tests with ±0.1°C heating differential
  - Heating baseline
  - Heating free floating
- Validated models: EPlus
- Data sets:
  - Test/weather data sets: 1-min and 60-min resolution per test

What's Next (Plan)

- [FY21/22] 2 cooling season tests with ±0.1°C cooling differential
  - Cooling baseline and Cooling free floating


NIST Net-Zero Energy Residential Test Facility (NZERTF)





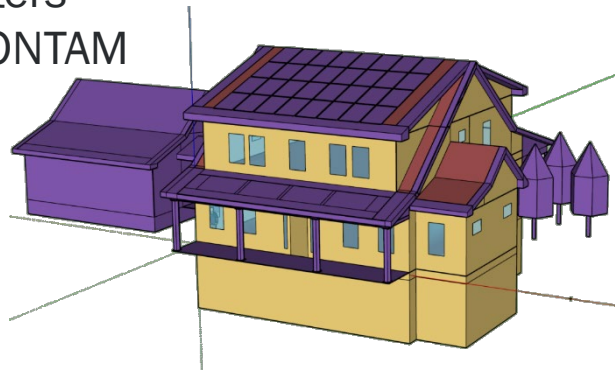
NIST/NJIT: Residential HP System Validation using NIST's NZERTF

Heating Free Floating

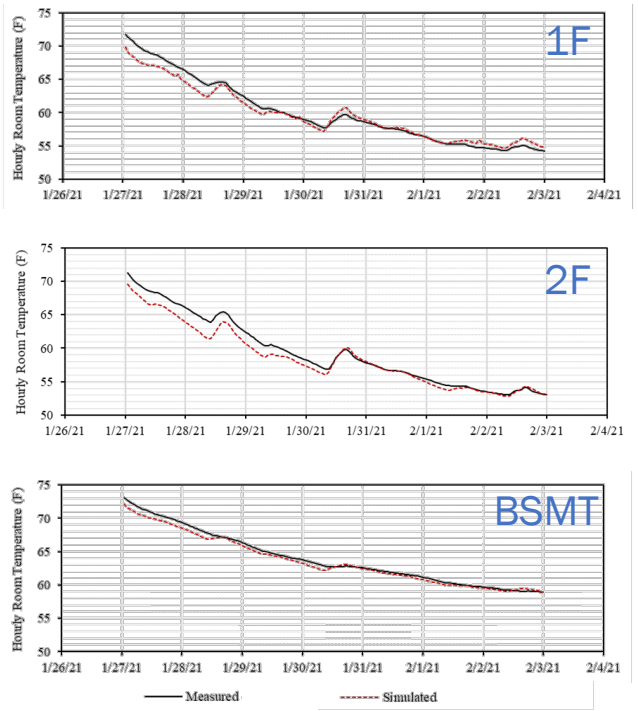
- Validated envelope-related input parameters
- Comparison of different ground heat transfer models
- Advanced air flow calculations using CONTAM
  - Floor-by-floor infiltration calculations (AVG. 0.05 ACH)
  - Floor-to-floor air flow calculations

Heating Baseline with ±0.1°C heating differential

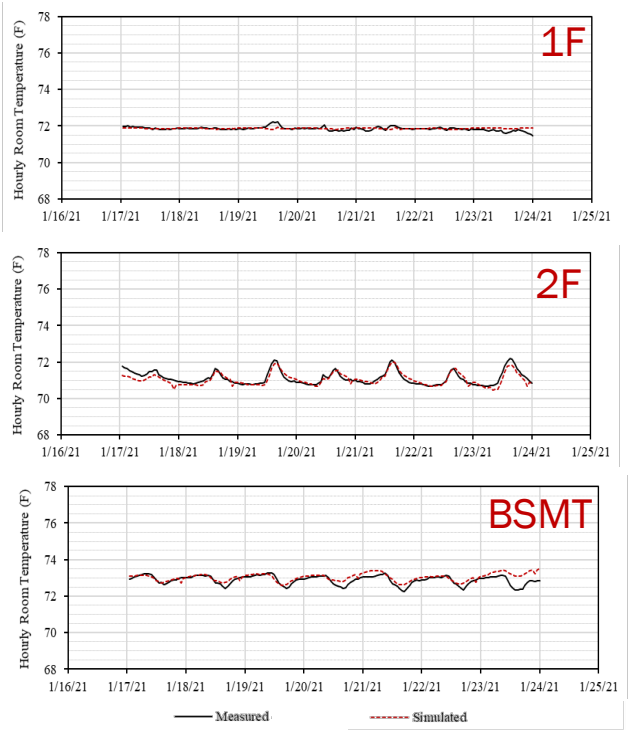
- Validated system-related input parameters
- Advanced air flow calculations using CONTAM with actual HP cycling
- Improvement Plan
  - Validation of SA flow to each floor



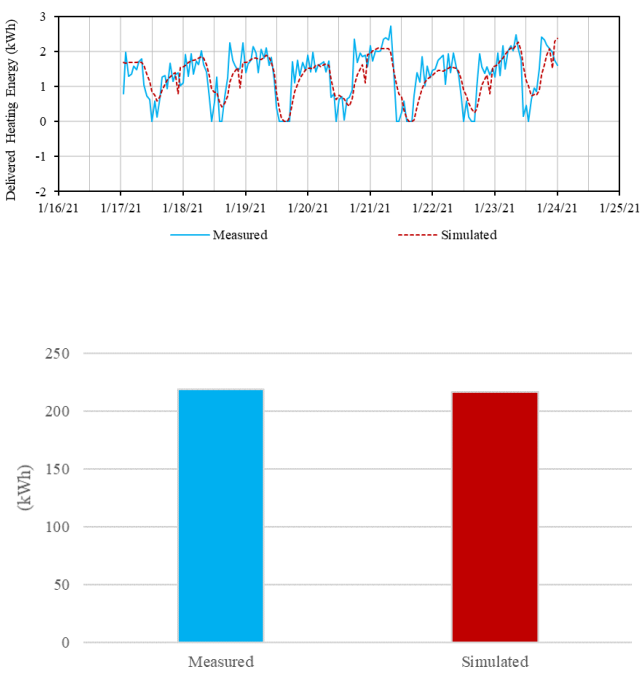
Zone Temperatures



Zone Temperatures



Delivered Heating Energy (kWh)



Progress: NREL Data Collection and Specification Approach

Data Collection

- iUnit indoor/outdoor test building during both heating and floating operation
- Focus on controlled indoor states (steady state and temperature decay) and continuous outdoor data collection (to capture a wide range of weather drivers)
- North-facing orientation from Q1 FY20 through Q2 FY21; south-facing orientation starting in Q3 FY21

Specification Approach

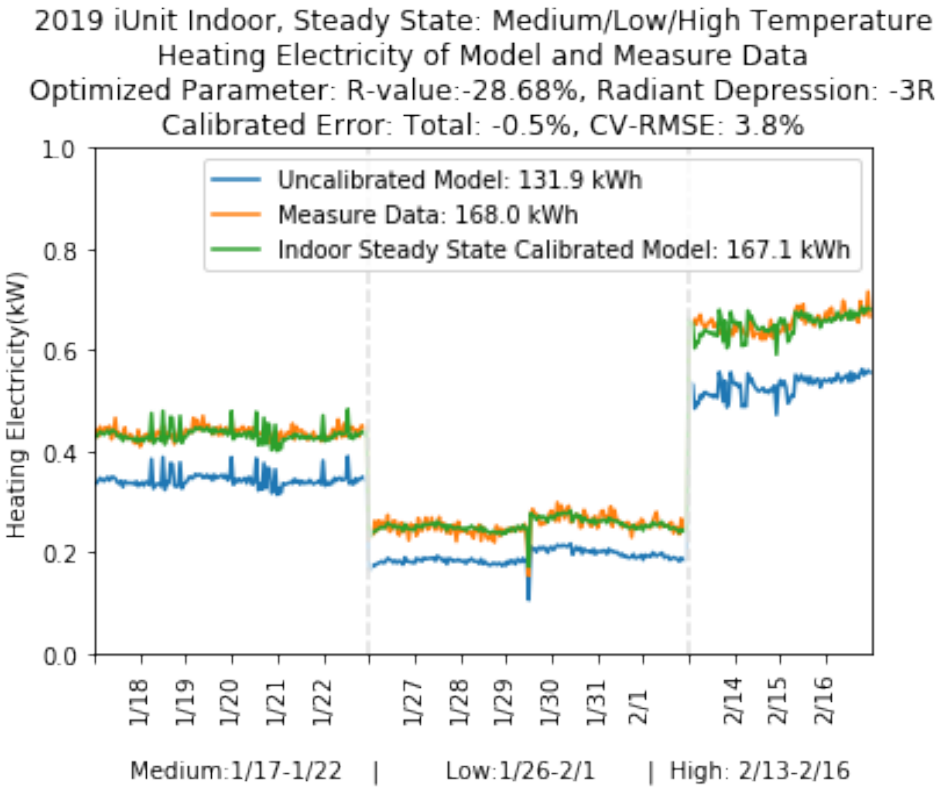
1. **Analysis of indoor data set**
   - Specifying modeling inputs directly from measured data and/or construction details is preferable
2. **Indoor steady state calibration**
   - Quasi steady state conditions and well-known infiltration (minimal wind) enable isolation of thermal conductivity
3. **Indoor temperature decay**
   - Focus solely on tuning thermal mass
4. **Outdoor calibration**
   - Focus on parameters sensitive to variability in outdoor conditions (wind-driven infiltration, solar absorptance, envelope thermal mass)

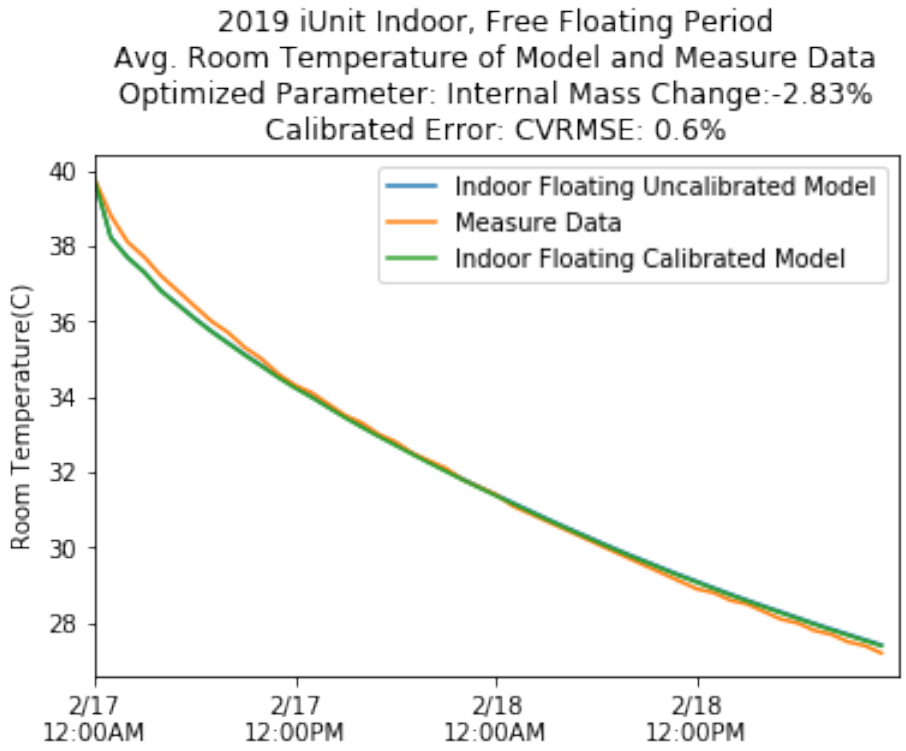
iUnit in south-facing configuration

Progress: NREL Indoor Calibration Results

Parameter Tuning

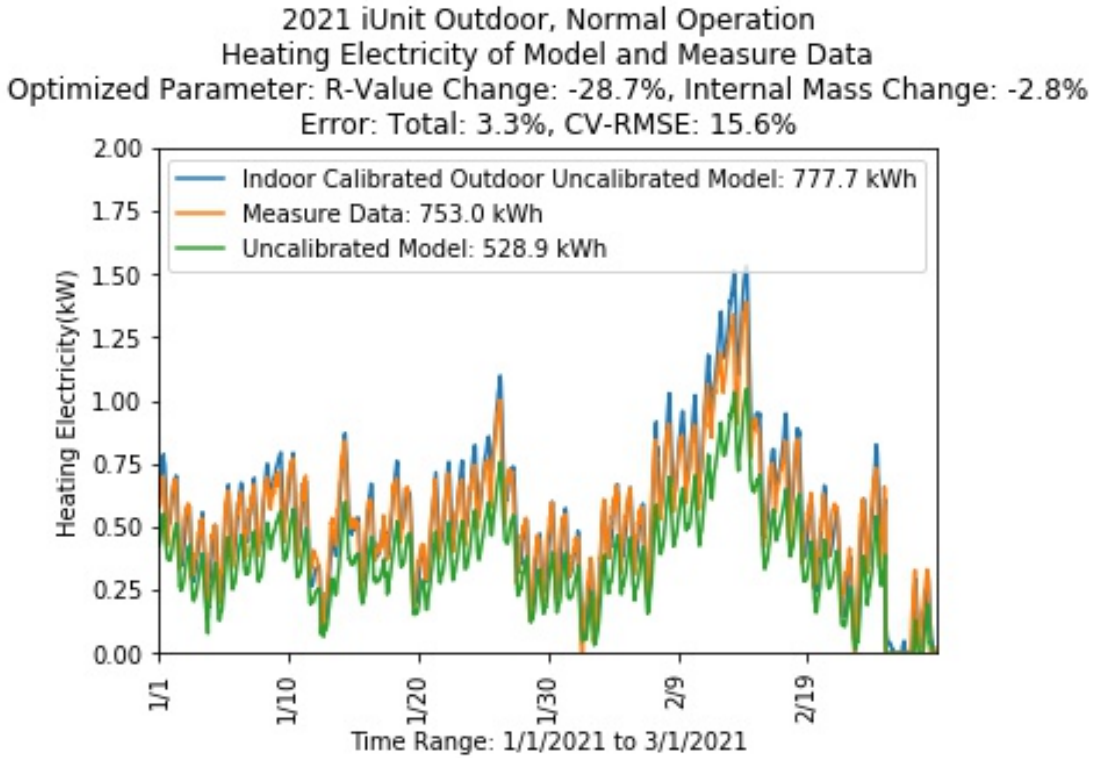
- Envelope R-value reduced by 29% to account for thermal bridging, construction imperfections, and 2D/3D heat transfer effects
- Internal mass reduced by 2.8% to match measured temperature decay
- Global radiant depression parameter used to tune impact of indoor radiant environment (not measured)

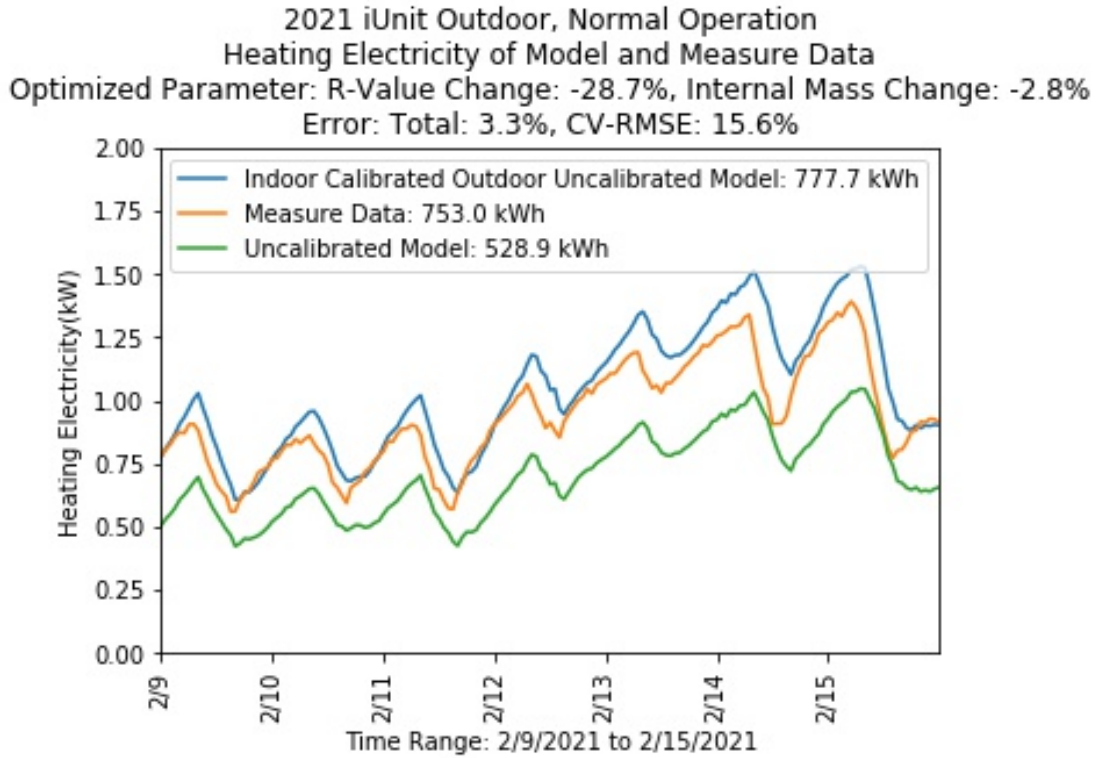




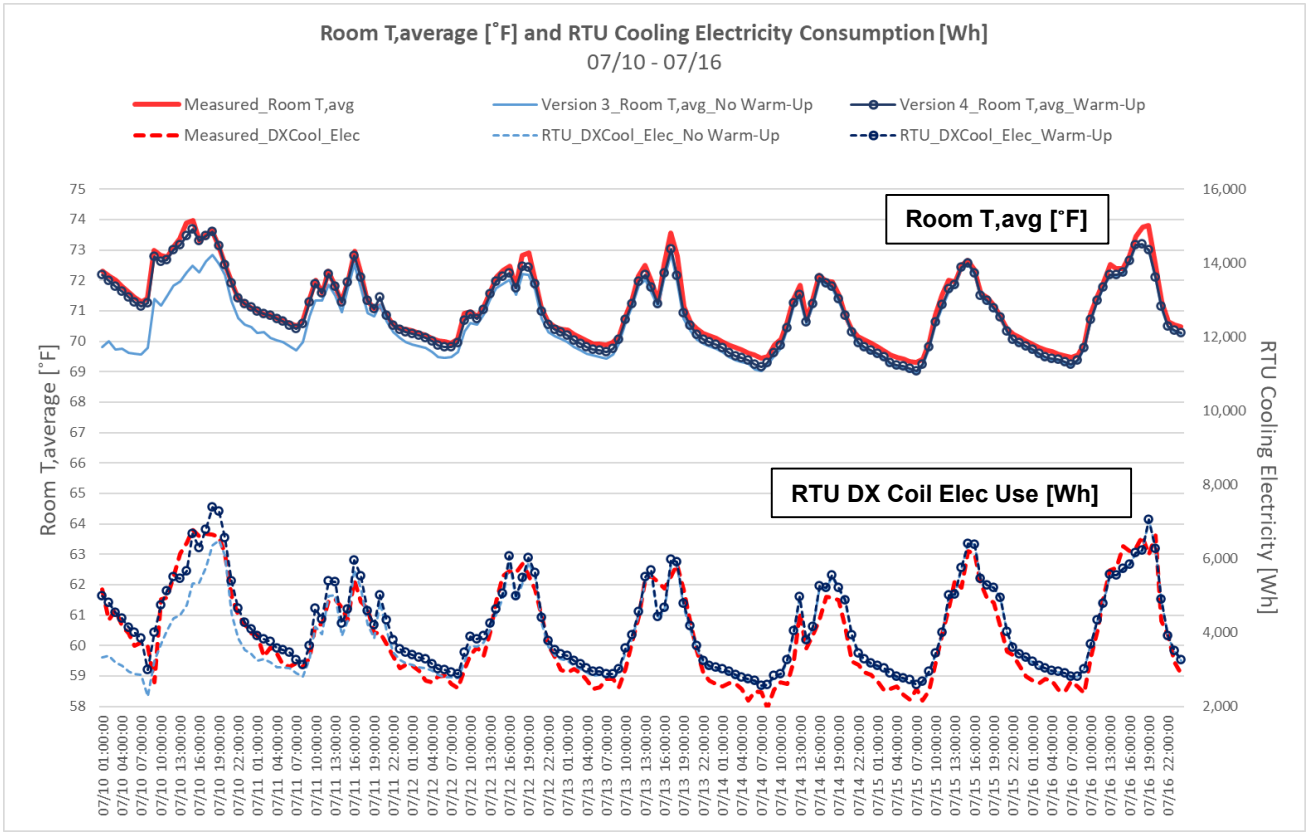
Progress: NREL Outdoor Results

- Indoor calibrated model aligns well with outdoor experimental data (winter scenario)
- Total heating energy error = 3.3%
- Total heating energy CV-RMSE = 15.6%
- We expect that error can further be reduced through additional parameter tuning to address time shift





ANL Testing of ORNL FRP Model Input Specification



- **Cooling Season Baseline** (version of Sept 2020) prepared by ORNL
- **Two Rounds of "Blind" Modeling** (EnergyPlus) conducted by Argonne
  1) With the specification only – suggestions for facilitating inputs
  2) With the measurement data – suggestions for using measured data

- **Next Steps**
  - Modeling iterations and Review for improved results and data quality
  - Identify where the test spec needed further clarifications

Stakeholder Engagement

- **Formed a Validation & Uncertainty (V&U) working group for ASHRAE Standing Standard Project Committee 140 - Standard Method Of Test For The Evaluation Of Building Energy Analysis Computer Programs”**
  - Provided project guidance and feedback
  - Combination of scientists, engineers, developers from labs, academia, & industry
- **Bi-annual working group meetings**
  - Dedicated working group meeting (2 to 3 hours) to review the project progress, issues and results
  - Feedbacks and comments have been incorporated to improve the test and modeling
  - Review the model input specification document
  - Perform independent modeling using major BEM software (planned)
  - Work together to include the dataset and model input specification to the ASRHAE 140

Achievement

- **2 Journal Papers, 3 Conference Papers (with 1 Best Paper Award), 2 Technical Reports**
  - Im, P., J. Joe, Y. Bae, J.R. New (2019) Empirical Validation of Building Energy Modeling for Commercial Buildings, *Applied Energy 261, 114374.*
  - Joe, J., P. Im, J. Dong (2020) Empirical Modeling of Direct Expansion (DX) Cooling System for Multiple Research Use Cases, *Sustainability*, 12, 8738
  - Li, Q, R. Muehleisen, Im, P., and Joe, J. (2020) Empirical Validation of Multi-Zone Building and HVAC System Models under Uncertainty, Proceedings of 2020 ASHRAE Building Performance Analysis Conference and SimBuild (Best Paper Award)
  - Im, P., J.R. New, and J. Joe (2019). Empirical Validation of Building Energy Modeling using Flexible Research Platform. 16th International Building Performance Simulation Association's (IBPSA) Building Simulation Conference, Rome, Italy, September 2-4, 2019.
  - Bae, Y., J. Joe, S. Lee, P. Im, L. NG (2021) Evaluation of existing infiltration models used in building energy simulation 17th International Building Performance Simulation Association's (IBPSA) Building Simulation Conference (accepted for the presentation and publication)
  - Im, P., Y. Bae, S. Lee, J. New (2020) Empirical Validation of Multi-Zone HVAC System Model: Evaluation of Existing Infiltration Models used in Building Energy Simulation, Technical Report, ORNL/TM-2020/1637
  - Ng, L., P. Im, Y. Bae (2020) Tracer gas decay test in Net-Zero Energy Residential Test Facility, Technical Report, ORNL/LTR-2020/1641

Remaining Project Work

ORNL/NIST/NJIT future work will focus on:

- Additional cooling and heating season tests and data collection for FRP and NZE RTF
- Further investigation for whole building infiltration and interzonal air flow
- Work with SSPC140 to update the model input specifications to be consistent with the SSPC140 format spec
- Model validation with additional BEM engine (e.g., DOE-2)

NREL future work will focus on:

- Continued data collection, including altering envelope to create “delta” scenario(s)
- Uncertainty analysis to assign parameter ranges based on measurement accuracy and experimental uncertainty
- Formalizing specification language for third-party application of test scenarios and corresponding empirical data sets.

ANL future work will focus on:

- Estimate input and output uncertainties for updated models
- Create independent model in IESVE for comparison
- Work with ORNL to begin selecting best data and converting tests to a 140 format spec

Thank you

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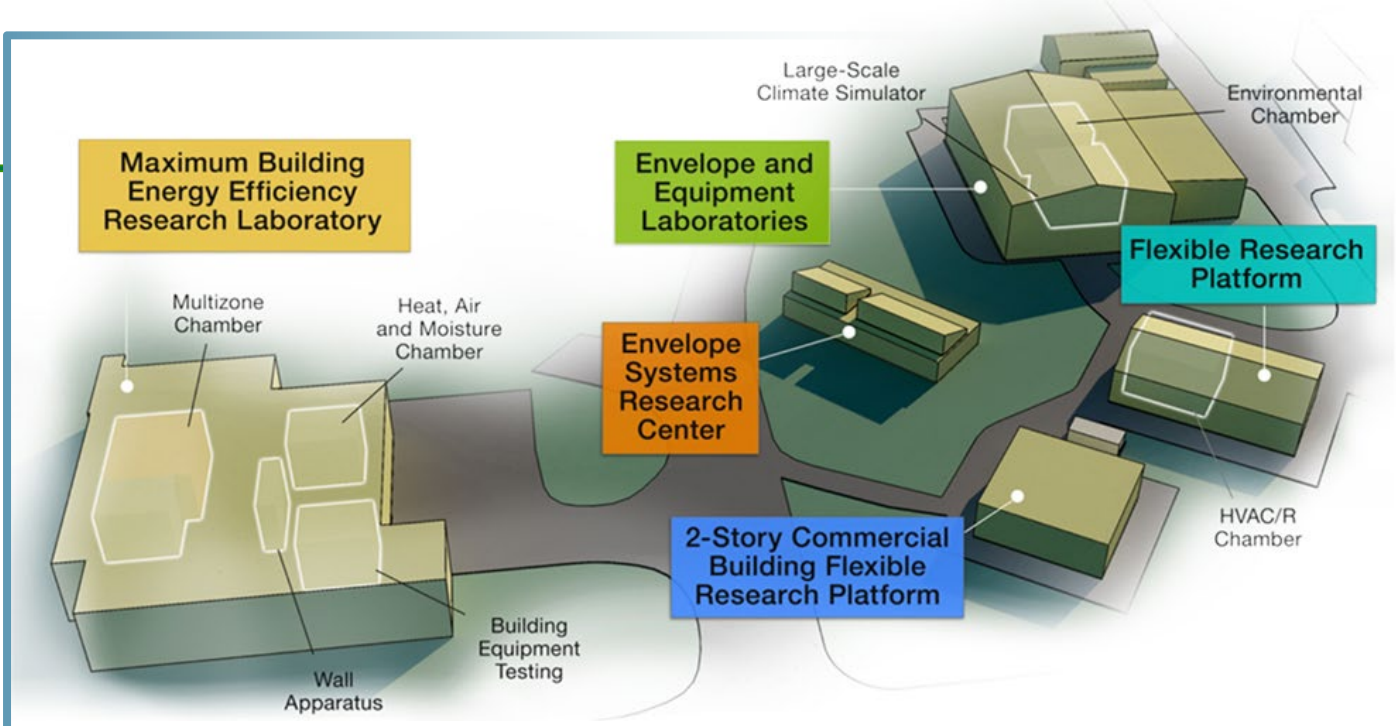

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: Total: $3,030,000, **ORNL: $1,665,000, NREL: $1,170,000, ANL: $195,000**
Variances: N/A
Cost to Date: 50% **of the project budget has been expended to date.**
Additional Funding: N/A

Budget History					
10/1/2019– FY 2020 (past)		FY 2021 (current)		FY 2022 – 9/30/2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,000,000	$0	$1,030,000	$0	$1,000,000	$0

Project Plan and Schedule

Project Schedule	FY2020				FY2021				FY2022			
Project Start: 10/1/2019	Completed Work											
Projected End: 9/30/2022	Active Task (in progress work)											
	Milestone/Deliverable (Actual)											
Task	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Past Work												
Q1 ORNL Milestone: Draft multiyear test plan for FRP and NIST NZERTF house												
Q1 NREL Milestone: Complete preparation for north-facing winter testing												
Q2 ORNL Milestone: Initial EnergyPlus model for NIST NZERTF												
Q2 ANL Milestone: Uncertainty Characterization of FRP experiments												
Q2 NREL Milestone: Complete analysis of indoor test results												
Q3 ORNL Milestone: Blower door test/Tracer gas test for FRP and NIST NZERTF												
Q3 NREL Milestone: Complete preparation for north-facing summer testing												
Q4 ORNl Milestone: Perform first set of tests on FRP and NIST NZERTF												
Q4 NREL Milestone: Draft modeling specification												
Q1 ORNL Milestone: Validation Analysis for NIST NZERTF House												
Q1 NREL Milestone: Complete preparation for north-facing winter testing												
Q2 ORNL Milestone: Installation of additional sensors												
Q2 NREL Milestone: Deliver initial model calibration results												
Q3: ANL Milestone: New independent model of FRP												
Q3 ORNL Milestone: Model improvements												
Q3 NREL Milestone: Complete preparation for south-facing summer												
Current/Future Work												
Q4 ORNL Milestone: Begin SSPC 140 Validation Package												
Q4 NREL Milestone: Update draft modeling specification based on calibration analysis												
FY22 ORNL Milestone: Perform rest of the tests, Improve the model results, Finalize SSPC140 Valiation Package												
FY22 ANL Milestones: Independent IESVE Model of FRP, Assist in SSPC140 Spec Development												
FY22 NREL Milestones: Complete data collection and subsequent analysis; finalize SSPC140 Validation Package												