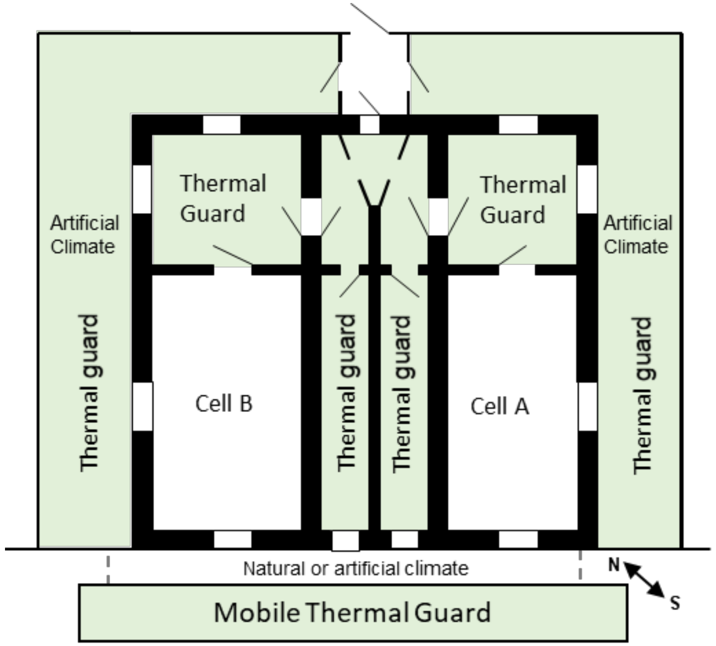
Empirical Validation using ETNA Data



Argonne National Laboratory, J. Neymark & Associates, Thermal Energy System Specialists
Dr. Ralph T. Muehleisen, Chief Building Scientist, Argonne
Tel: 630-252-2547, email: rmuehleisen@anl.gov

Project Summary

Timeline:

Start date: 10/1/2019

Planned end date: 9/30/2022

Key Milestones (insert 2-3 key milestones and dates)

1. First Steady State Data Analyzed; 7/2020
2. First Artificial Climate Data Analyzed; 10/2021
3. First Natural Climate Data Analyzed, 1/2022

Budget:

Total Project $ to Date:

- DOE: $500k
- Cost Share: $0

Total Project $:

- DOE: $996k
- Cost Share: $0

Key Partners:

J. Neymark & Associates
Thermal Energy System Specialists

Project Outcome:

This project will analyze data from the most detailed and controlled building thermal fabric energy transfer experiments done at the ETNA Facility in France in 2000-2001.

The analyzed data will be used to generate a suite of empirical validation tests and ASHRAE 140 format test specifications ready for field trials and adoption by ASHRAE SSPC 140

Team

Dr. R. Muehleisen, ANL, PI

ANL Chief Building Scientist

Expert in Uncertainty & Building Science

SSPC 140 NV Member

PI for ASHRAE 140/205 Maintenance Project

J. Neymark, JNA, Co-I

ETNA Research PI (1999-2004)

BESTEST Developer

SSPC 140 Chair

On ASHRAE 140/205 Maintenance Project Team

Dr. J. Kim, ANL

ANL Building Scientist

Expert in EnergyPlus, IESVE & Uncertainty

SSPC 140 NV Member

On ASHRAE 140/205 Maintenance Project Team

T. McDowell, TESS

TRNSYS Developer

Building Science Expert

SSPC 140 Vice Chair and VM

On ASHRAE 140/205 Maintenance Project Team

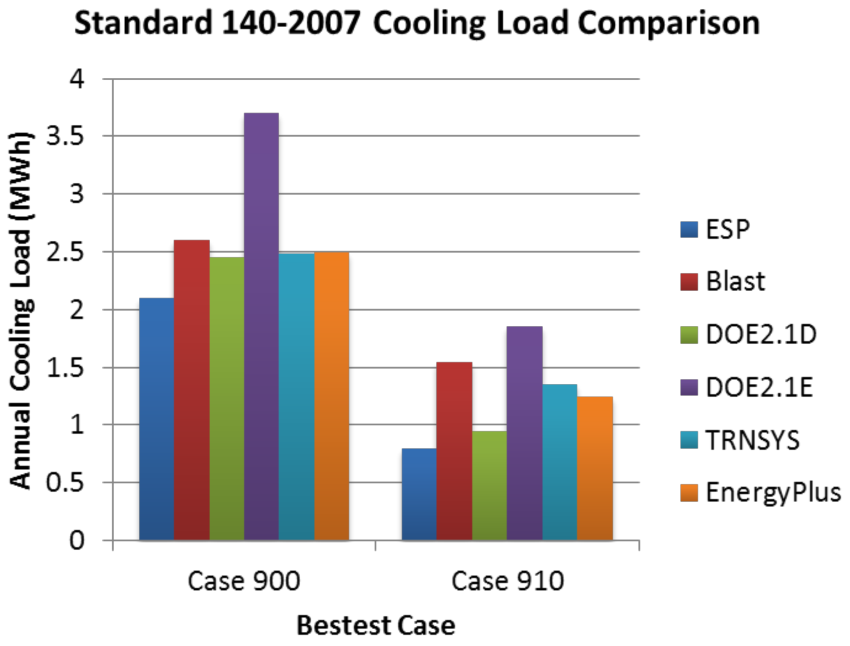
Unparalleled Expertise: ETNA, Validation, ASHRAE 140, and Statistics

Challenge

ASHRAE 140 Method of Test for Evaluating Building Performance Simulation Software is the standard for testing accuracy of software that models building physics.

- Referenced by ASHRAE 90.1, IECC, 179D Tax Code, CEC Title 24

But, ASHRAE 140 only has very simple tests with analytic solutions as ground truth. All more complicated tests are comparative (i.e. software to software). When software differ, who is right?



Empirical Validation can provide ground truth so we *know* which software is right

Challenge

Development of Empirical Validation tests of even a simple building is very, very, very, hard for many reasons including:

- Construction requires supports (studs, beams, columns, etc) that create 2/3D heat transfer, however, whole building software is ALL 1-D approximation
- Buildings are NEVER constructed as drawn/designed; rarely are drawings updated to “As Built”
- Eliminating all heat leak paths (thermal bridges, infiltration) is impossible and characterizing them is near impossible
- Measurement of surface phenomenon (boundary layers) is really, really hard in a real building
- Thermal/physical properties of all construction materials have high uncertainty

As a result, most previous attempts at empirical validation have failed.

Approach

- From 1999-2001 US and EdF (France) researchers conducted a set of experiments on the EdF ETNA facility specifically designed for development of an empirical validation data set
  - The ETNA experiments are considered the most complete, accurate, and controlled experiments of building thermal fabric physics ever made.
  - Researchers were able to repeat/extend experiments when data glitches arose

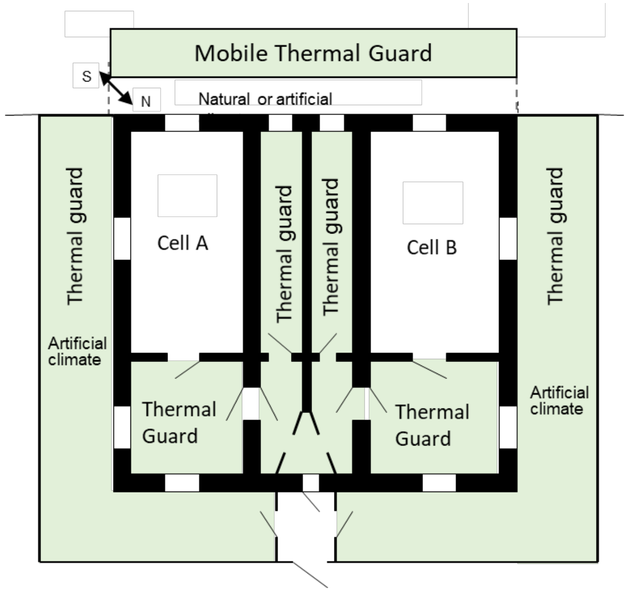
- EdF shifted funding after completion of experiments and so the data were never fully analyzed and turned into an empirical validation test set
  - BTO funding of empirical validation work is allowing these incredible data to be utilized

- The Argonne project team includes the original PI of the EdF project (J. Neymark) who led the experiments, supervised the data acquisition, and is the “keeper” of the data
  - Another of the original researchers, R. Judkoff, is on the project Technical Advisory Group (TAG)

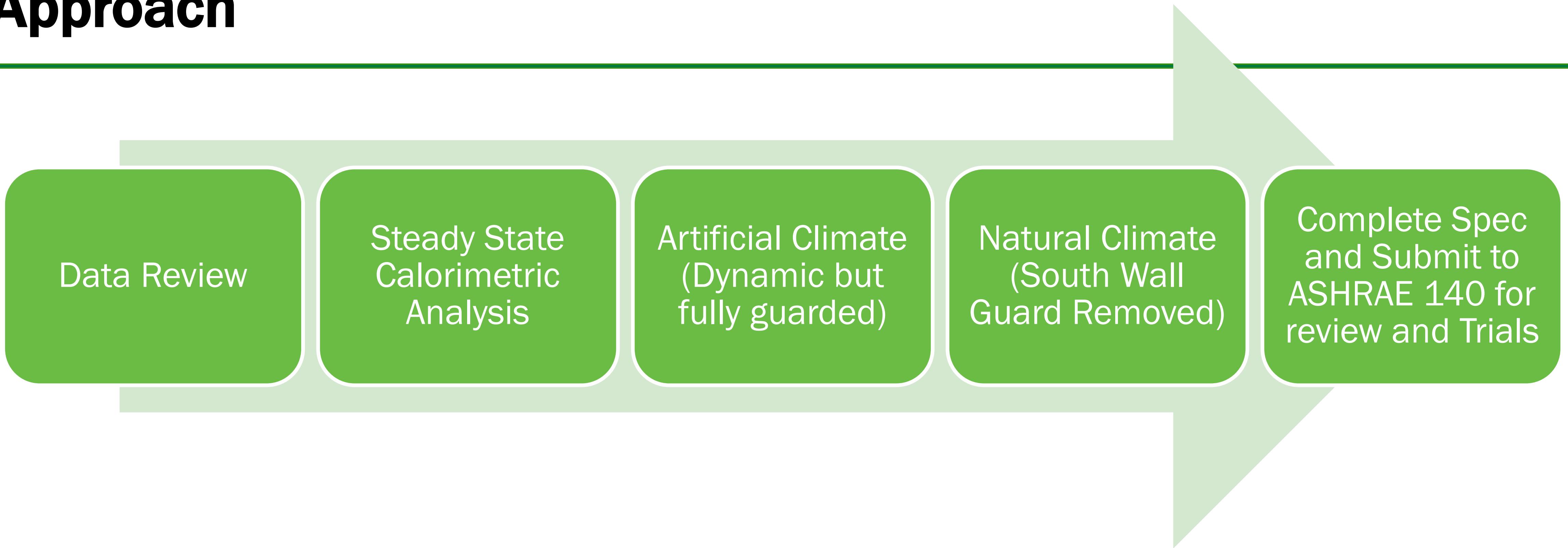



Approach

- Why ETNA is different, and why this project will succeed:
  - Side-by-side, twin test cells
  - Thermally guarded on all six sizes to allow calorimetric measurements
  - Individual temperature control on all six sides to allow for “artificial” climate tests
  - One guard removable to allow for natural climate tests
  - Specially designed heating source is nearly totally convective
  - Design of enclosure reduces thermal bridges allowing better characterization of 2D/3D heat transfer
  - Researchers were allowed enough time for cells to reach steady state for each test
  - Test procedure designed to follow BESTEST methodology



Approach



- Because there is no access to the facility or to do no experiments, careful analysis of data and quantification of uncertainty is key
  - With respect to the data “***When in doubt, throw it out***”
  - Using multiple analysis methods to ensure data consistency and as a double check
  - Using two different software (EnergyPlus and TRNSYS) to check spec for interpretability and ability to model measured physics

Impact

ETNA (and other EV&U) will play a key role in expanding the use of simulation in design and code compliance which will

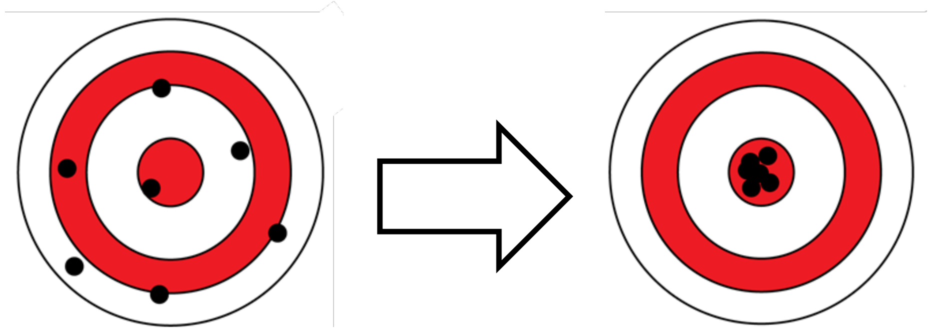
- **Increase decarbonization**
- **Increase resilience**

It does this by increasing the confidence in simulation by

- **Ensuring physics modeling is correct**
- **Identifying bad software**

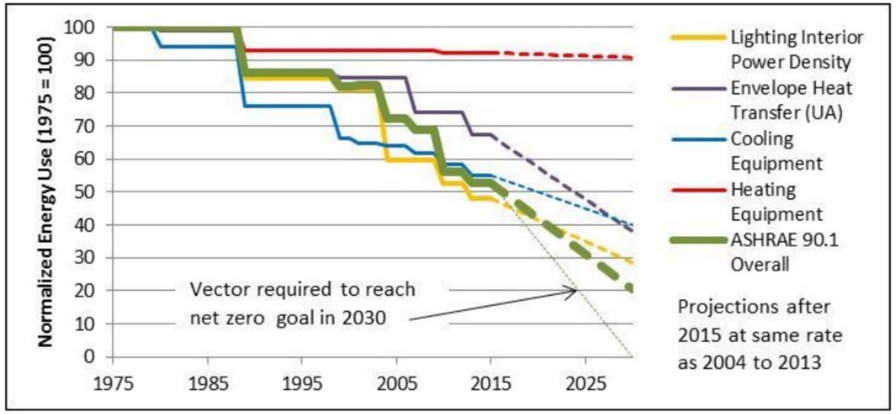
This allows for

- **More stringent energy codes**
- **More compliant designs**



Modeling Software Today

Modeling Software Tomorrow



Impact

ETNA does not replace the other DOE funded EV&U projects

- ETNA is focused on thermal fabric
- Heating only (no cooling conditions)
- Single Zone

This project essentially provides *empirical* testing to augment the 600/900 series thermal fabric *comparative* tests in ASHRAE 140

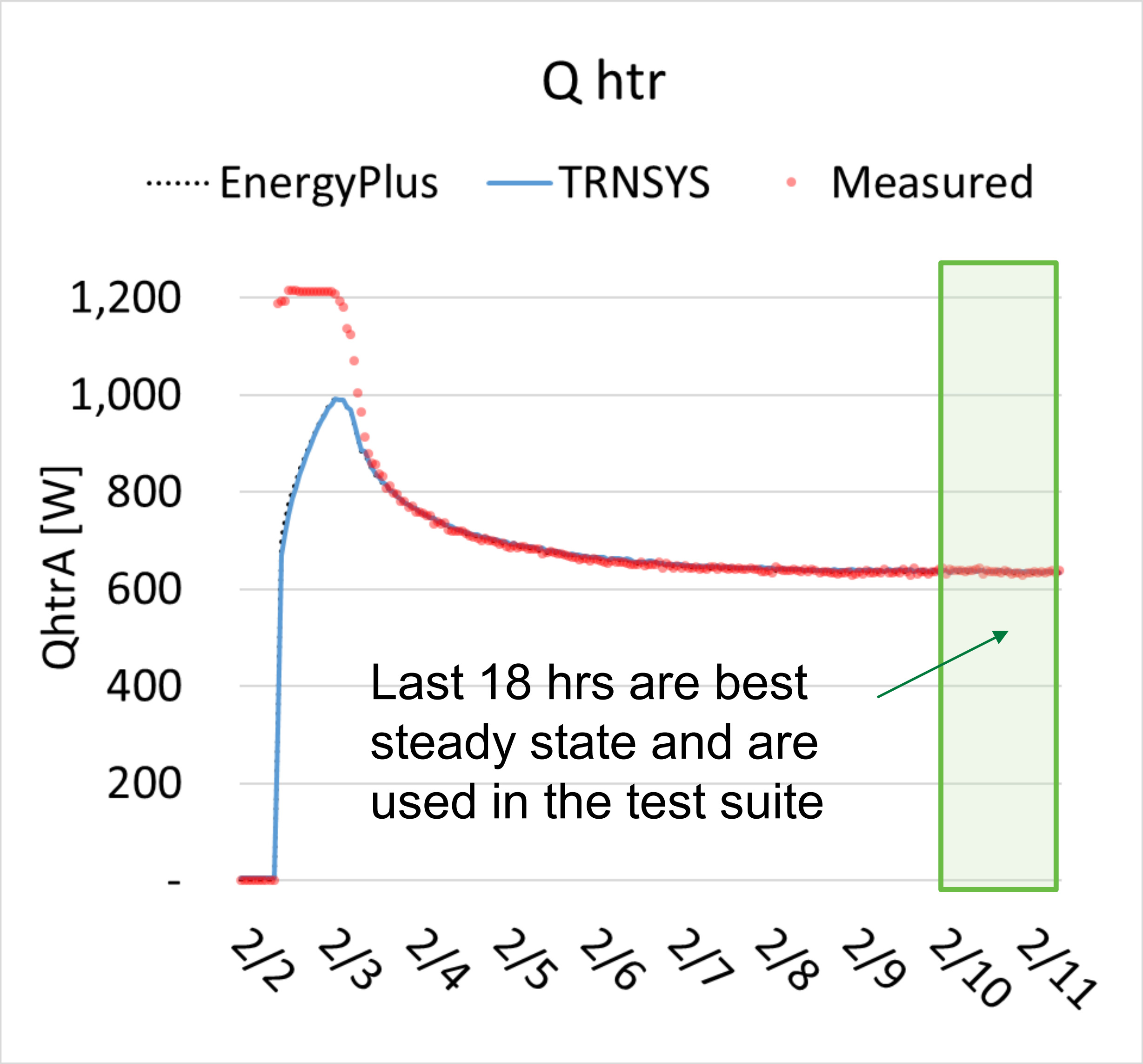
- The other EV&U will provide validation for other or new test suites

ETNA's data quality and low uncertainty will provide the benchmark for all EV&U projects and allow the test suites from those projects to focus physics not tested by ETNA

Progress

- Original data, notes, and preliminary spec, retrieved from old computers and converted to modern formats (Excel, Word, PPT, JPGs) for analysis
- Steady State Baseline Case Selected, Data Analyzed, and Spec Developed
- Tested spec with models in EnergyPlus and TRNSYS
  - Soon to start checking with IESVE
- Started calculating 2/3D effects to see how much they explain the difference between measured data and:
  - 1D models using "listed" material properties
  - 1D models using empirically determined 1-D equivalent material properties

Steady State Base Case Results



- Meas. Uncertainty:

  < 0.5% standard error

- Model vs Measured Diff (with empirical 1-D equivalent material properties):

  < 0.3% for EnergyPlus and TRNSYS

  Two software, with independent models and modelers, have matched model to measurement within small uncertainties!

- This is incredibly low uncertainty - the ETNA data and its spec are looking good and reliable!

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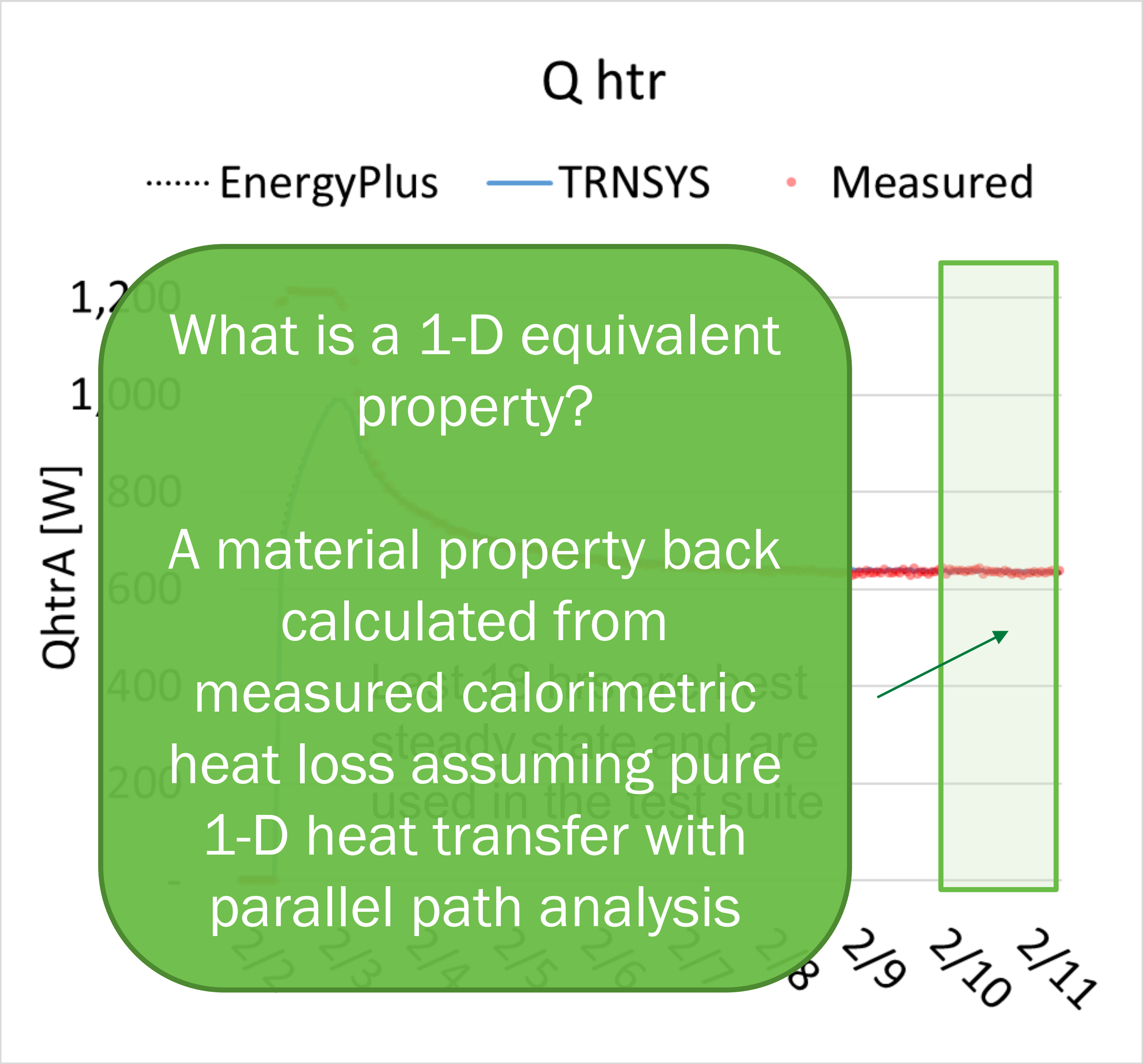

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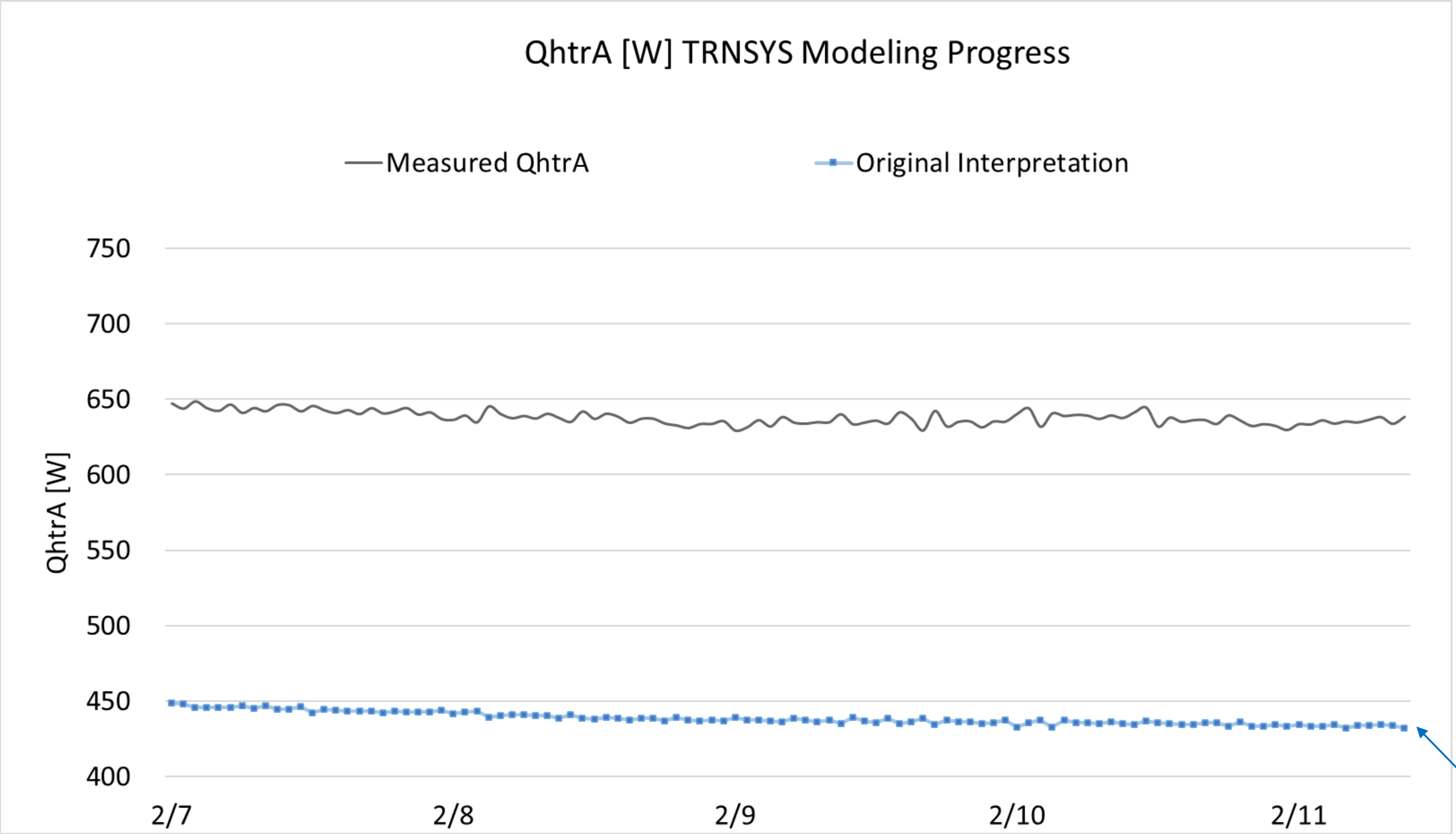
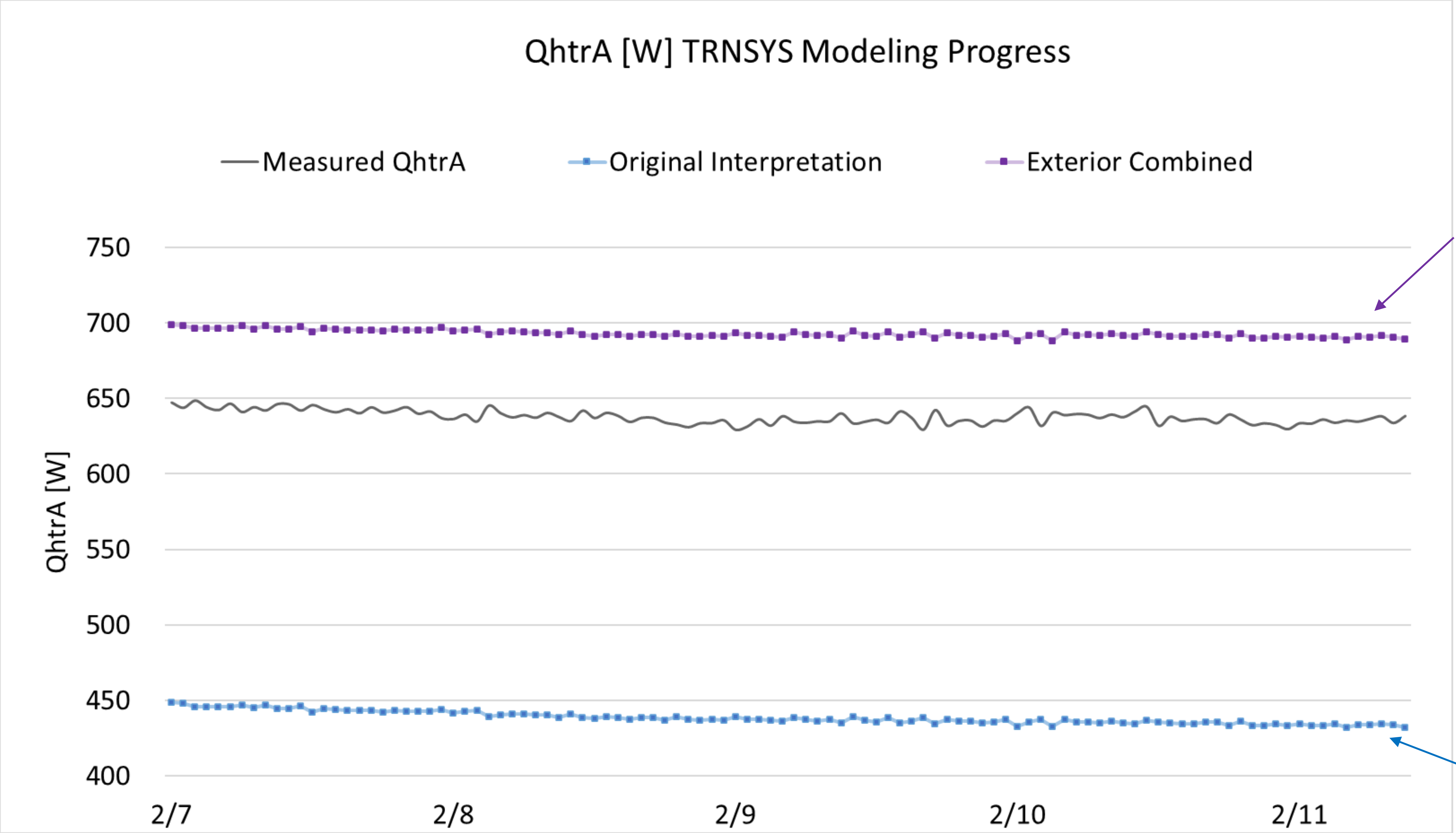
Step through QA/QC process with one software



1. Initial interpretation low by 32%

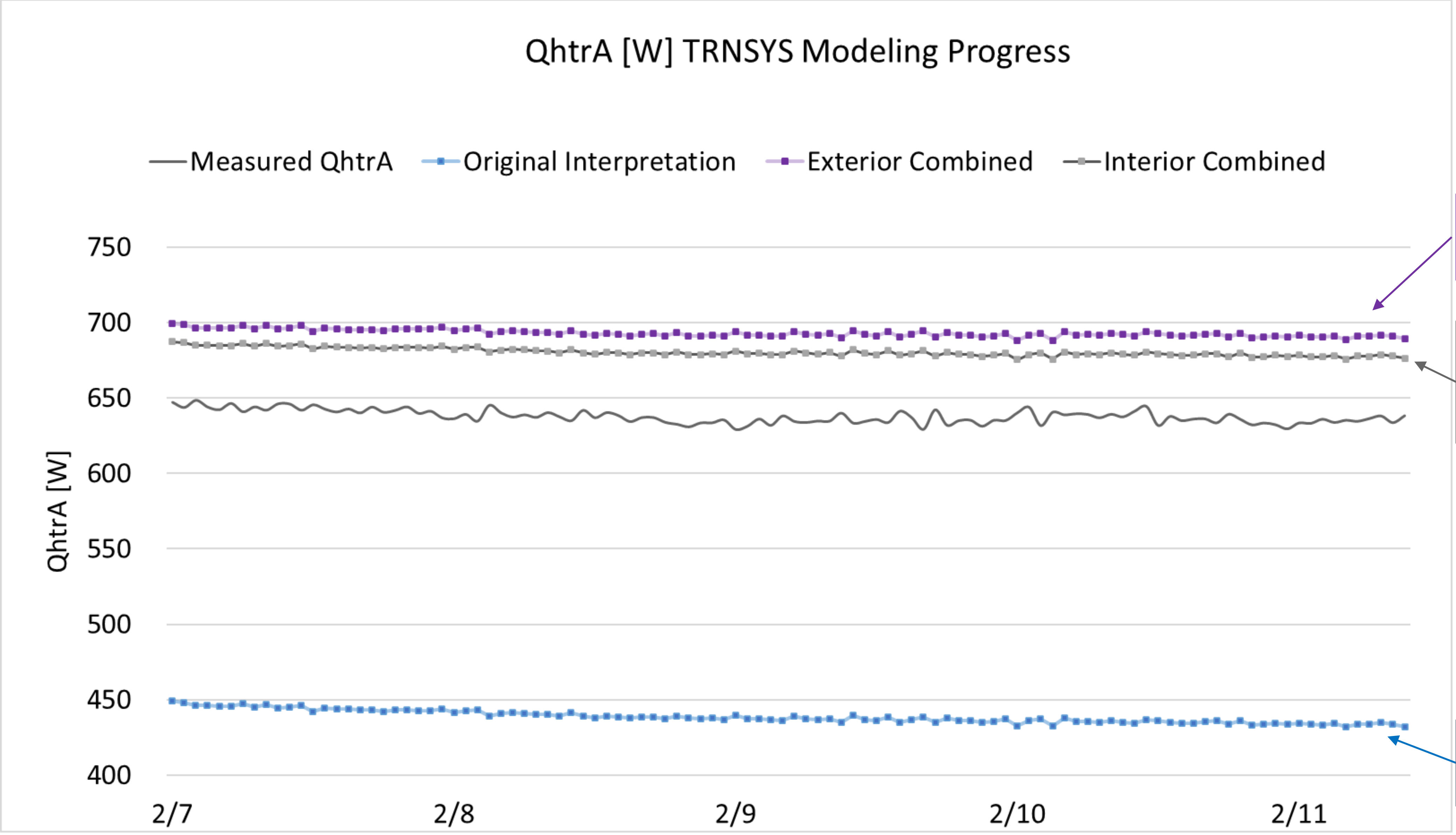
Step through QA/QC process with one software



2. Updated hx coeff went high by 9%

1. Initial interpretation low by 32%

Step through QA/QC process with one software

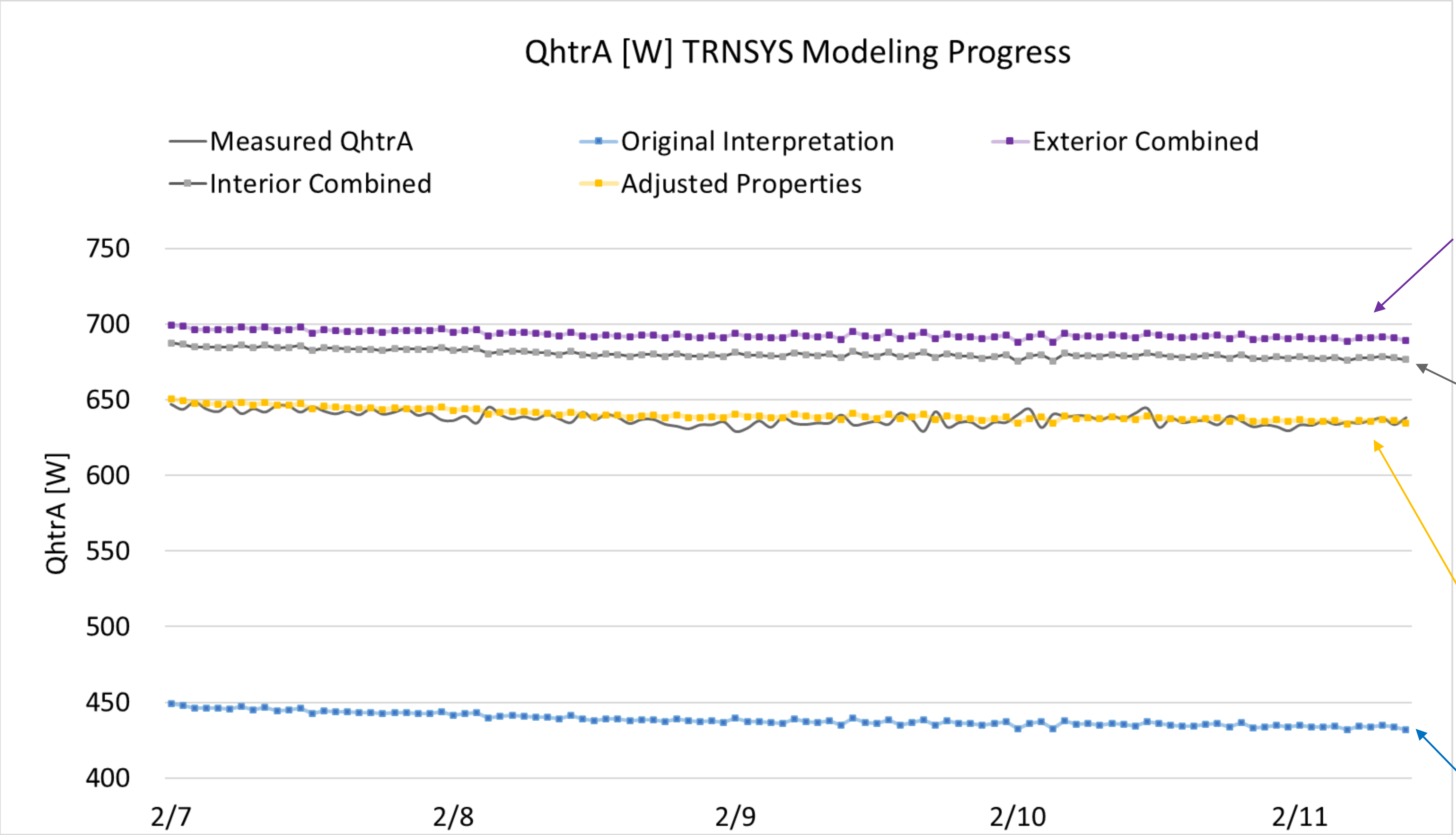


2. Updated hx coeff went high by 9%

3. Modified radiation calculation still high by 7%

1. Initial interpretation low by 32%

Step through QA/QC process with one software



2. Updated hx coeff went high by 9%

3. Modified radiation calculation still high by 7%

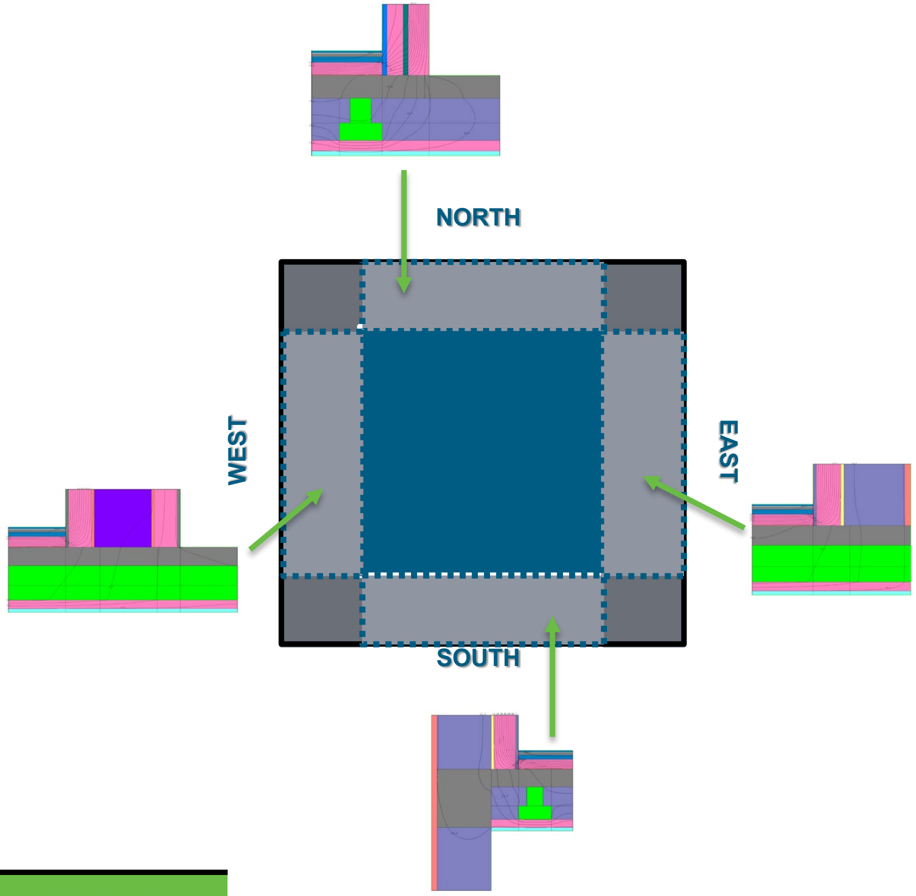
4. Corrected thermal conductivity, , Difference reduced to 0.23%

1. Initial interpretation low by 32%

2/3D Effect Modeling

- Break wall into center, edges, and corners
- Use Therm (2D FEM) to estimate heat transfer at edges
- Use 3D adjustments to estimate corners from Therm models of edges

We will be comparing the differences between proper 2/3D analysis and using empirically determined 1-D equivalent properties



Floor UA Estimate with 2/3D Therm Analysis

	Measured	1-D Model with Listed Properties	2/3D augmented Model with Listed Properties
U * A	5.67 W/K	3.5 W/K	5.53 W/K
Δ	-	38.3%	2.5%

Progress

	FY20 Q1	FY20 Q2	FY20 Q3	FY20 Q4	FY21 Q1	FY21 Q2	FY21 Q3	FY21 Q4	FY22 Q1	FY22 Q2	FY22 Q3	FY23 Q4
1. Verify Data			* *									
2. Steady State Base					* *							
3. Steady State Sensitivity Tests								*				
4. Artificial Climate (Dynamic)										* *		
5. Natural Climate (S. Guard Removed)											*	
6. Final Report and 140 Submission												*

	Completed Work
	Work in Progress

* Milestones

* Go/No-gos

Stakeholder Engagement

Primary Stakeholder Engagement has been through a Technical Advisory Group (TAG)

- Meetings in July 2020, March 2021, with three more meetings planned.
- TAG has feedback has been outstanding
- Feedback from TAG has led the team to focus more on understanding 2/3D effects

Secondary Stakeholder Engagement is through bi-annual updates of ASHRAE 140 constituents in the SSPC 140 committee meetings.

- DOE funded EV&U projects meet prior to ASHRAE to share best practices

Tertiary Stakeholder Engagement is through bi-annual ASHRAE 140/205 Maintenance and Development Project stakeholder engagement meetings

- Muehleisen is PI of that project too and all team members on ASHRAE project too

Further outreach will be through IBPSA and ASHRAE Conference papers and presentations:

Remaining Project Work

	FY20 Q1	FY20 Q2	FY20 Q3	FY20 Q4	FY21 Q1	FY21 Q2	FY21 Q3	FY21 Q4	FY22 Q1	FY22 Q2	FY22 Q3	FY23 Q4
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5. Natural Climate (S. Guard Removed)											*	
6. Final Report and 140 Submission												*

	Completed Work
	Work in Progress

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Remaining Project Work

- Complete Steady-State cases and move onto Artificial and Natural Climate
  - Steady state cases are the foundation of the spec and ensuring the overall test procedure is right and repeatable in multiple software

- Complete writing test spec in a 140 ready format
  - Spec will be fully written and vetted with at least 3 software programs and 3 modelers, speeding field trials and inclusion into ASHRAE 140

Changes from original project plan in response to Stakeholder Feedback:

- More emphasis on analyzing 2/3D effects
  - TAG is interested in seeing if we can write the test spec so people could:
    - Use 2/3D modeling without applying empirically characterized 1-D equivalent material properties (i.e., using only the originally listed material properties)
    - Compare such models with 1-D only models applying the empirically characterized 1-D equivalent material properties

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: $996k, about $330K/yr
Variances: FY20 funding did not arrive until Q2 FY20, project started 1 quarter late
Cost to Date: Identify what portion of the project budget has been expended to date.
Additional Funding: None

Budget History					
10/1/2019– FY 2020 (past)		FY 2021 (current)		FY 2022 – 9/30/2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
329k	0	330k	0	332k	0

Project Plan and Schedule

	FY20 Q1	FY20 Q2	FY20 Q3	FY20 Q4	FY21 Q1	FY21 Q2	FY21 Q3	FY21 Q4	FY22 Q1	FY22 Q2	FY22 Q3	FY23 Q4
1. Verify Data		*	*									
2. Steady State Base				*	*							
3. Steady State Sensitivity Tests							*	*				
4. Artificial Climate (Dynamic)									*	*		
5. Natural Climate (S. Guard Removed)											*	
6. Final Report and 140 Submission												*

	Completed Work
	Work in Progress

* Updated Milestones

* Original Planned – Delay because of 1 quarter funding delay at beginning of project