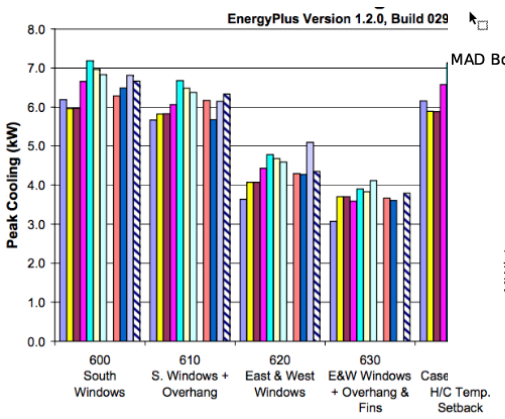
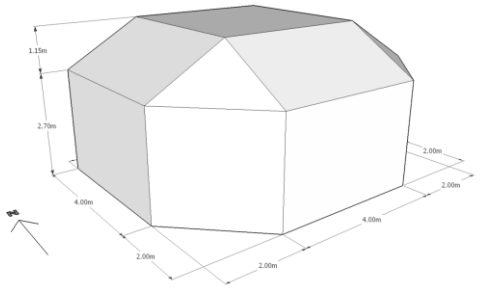
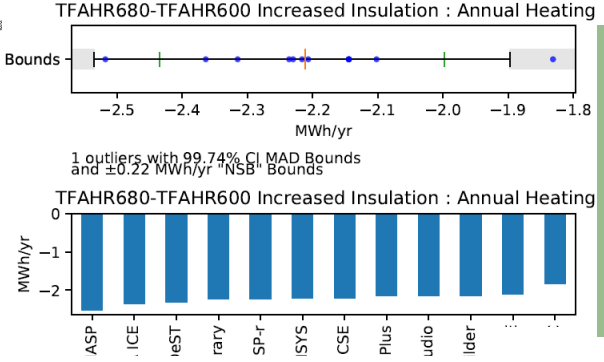
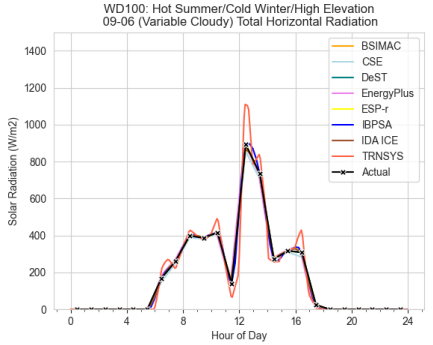
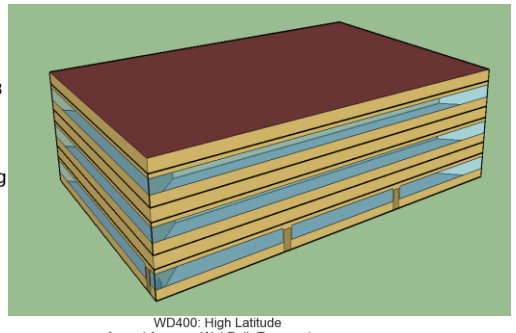
ASHRAE 140 Development and Maintenance

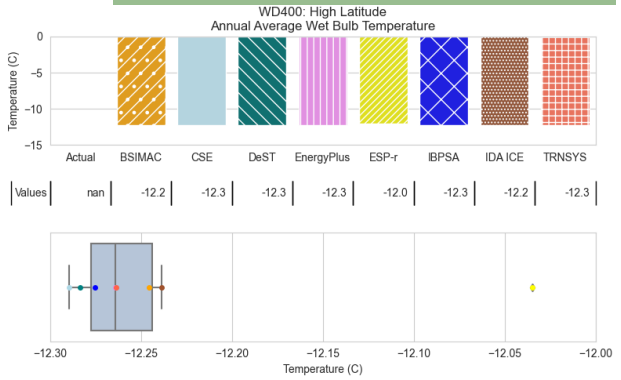












Argonne, Oak Ridge, Pacific Northwest National Laboratories
PI: Dr. Ralph T. Muehleisen
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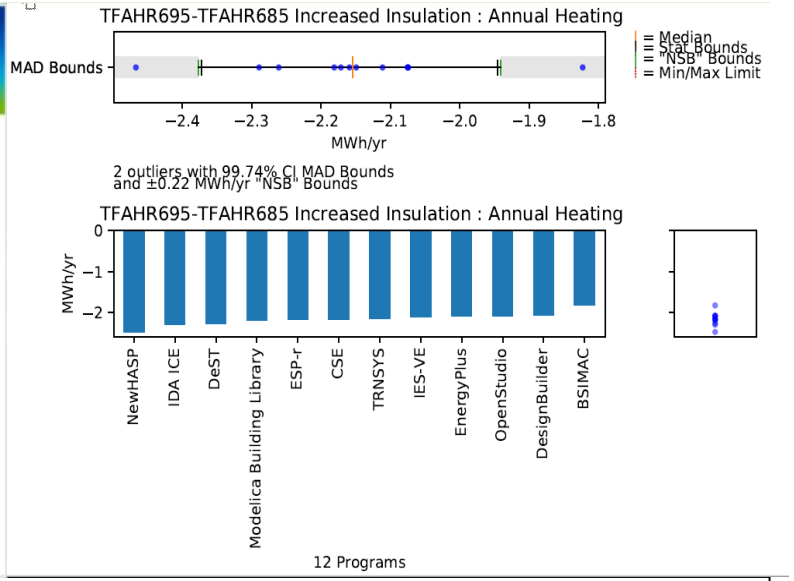
WBS 3.5.5.51

Project Summary

Objective and outcome

Continue development and maintenance of ASHRAE Standard 140 “Standard Method of Evaluating Building Performance Simulation Software” to improve BEM software, increase confidence in BEM software, improve consistency of code and above code calculations, increase investment in energy efficiency and decarbonization measures



Team and Partners

- **Argonne National Laboratory**
  - Big Ladder Software, GARD Analytics, J. Neymark & Associates, Thermal Energy System Specialists
- **Pacific Northwest National Laboratory**
  - Karpman Consulting
- **Oak Ridge National Laboratory**

Stats

Performance Period: 10/2022 – 9/2025

DOE budget: $3450k, Cost Share: $0k

Milestone 1: Acceptance Criteria

Milestone 2: Whole Building Test Suite

Milestone 3: Test Result Automation

Problem: Industry uses BEM and so BEM needs validation

Energy Codes, Ratings, Tax Incentives, and Rebates

- ASHRAE 90.x, IECC, CEC, NYC, Chi
- LEED, Passive House, WELL
- 179D, 45L, ZERH
- State and Utility Incentive Programs: NYSERDA, CEC, ComEd, PG&E, …

Designers and Engineers

- Understand performance differences in design tradeoffs
- Select and size HVAC equipment and storage
- Estimate, emissions, and LCC
- Demonstrate compliance

BTO/EERE/DOE

- Technology roadmapping
- Technical assistance (e.g., BPS)
- Pathway planning

All these users rely on the building energy modeling (BEM) software and so there needs to be a standard way to validate the accuracy of BEM software

- And for BEM software developers to improve BEM software

Solution: ASHRAE 140 “Method of Test for BEM Software”

- **A “framework” for BEM software test evolution**
  - Analytical: comparison to known closed form solutions
  - Comparative: comparison among software
  - Empirical: comparison to experimental data
  - Tests organized into suites of base cases + deltas
  - Detailed specifications
  - Testing reveals BEM discrepancies and need for additional tests
- **First published in 2001 thermal fabric heat transfer**
  - Now on 3-year continuing maintenance
  - Based upon DOE/IEA developed BESTEST Methods
- **From 2004-2020**
  - Thermal Fabric and Load, 2001 version updated 2020
  - Space Cooling and Heating Equipment
  - Airside HVAC Equipment
  - “Class II” limited testing for residential building software

Shortcomings of ASHRAE 140

Development of test suites was slow: only 5 new suites in 14 years	Test suites focused more on diagnosing software algorithm differences than establishing criteria for software accuracy	Many common systems and components in 90.1 designs are not in 140
Creating 140 models, extracting out results, and putting them in reporting spreadsheets was extremely manually intensive	No empirical validation test suite i.e. no “ground truth to measurement”	No pass/fail criteria, only comparison results between selected software
Limited guidance for “users” like codes and rating systems on how to use and cite 140	Stakeholder engagement typically limited to ASHRAE SSPC 140 committee meetings	140 test cases are dramatically simpler than typical designs modeled in 90.1 PRM

These three are all noted in Karpman et al “Building Performance Modeling Tools Physics and Sensitivity Testing in Support of Compliance Modeling” PNNL-33183, 2022.

Problems Identified in Compliance Modeling Sensitivity Report

- Karpman et al 2022 “Building Performance Modeling Tools Physics and Sensitivity Testing in Support of Compliance Modeling

Excerpt from Table 5: Space Cooling

Component	System/Component/ Controls Description	ASHRAE 140
Cooling Source	Chilled water	No
	DX	Yes
	Evaporative	No
Chiller Type	Centrifugal	No
	Positive displacement (reciprocating, scroll and screw)	No
	Absorption chiller	No
	Gas engine driven chiller	No
	Heat pump chiller	No
	Heat recovery chiller	No
Chilled Water Condenser Type	Air-cooled	No
	Water-cooled	No
Other	Cooling tower	No
	Fluid economizer	No

Excerpt from Table S1: Proposed New 140 Tests

Focus of the New Test	High Priority	Medium Priority
Representative Building Tests		
Multifamily, PRM baseline	x	
Multifamily, minimally code compliant design	x	
Multifamily, high-performance design		x
Medium office, PRM baseline	x	
Medium office, minimally code compliant design	x	
Medium office, high-performance design		x
Diagnostic Unit Tests		
Interior daylighting	x	
Exterior daylighting		
Comparative air-side HVAC tests (Air-side HVAC BESTEST Volume 2)	x	
Exhaust air energy recovery	x	
Air-side HVAC controls		
Optimal start	x	
Supply air temperature reset	x	
Variable speed drives	x	
Static pressure reset	x	
Demand-controlled ventilation	x	
Air-side HVAC systems		
Dedicated outdoor air system	x	
Perimeter radiation		x
Variable air volume with parallel fan power boxes		
Radiant panels and chilled/cooled beams		

Alignment and Impact

Improved and More Cited ASHRAE 140 Leads to Improved BEM and Increased Confidence in BEM

- More Use of BEM in Design
- Stricter Energy/Carbon Codes
- More Rigorous Compliance
- Expanded Utility Programs
- Better And More Trusted TA
- More and better BEM jobs

- More High Performance Bldgs
- Lower Costs For High Performance Bldgs (Especially Important For Disadvantaged Communities)
- Decreased Energy Use, Cost, and Emissions

Risks and Mitigation Strategy

Risk	Mitigation Strategy
140 not used/cited by codes and ratings because it lacks tests reflective of performance rating methods	• Develop more realistic whole building modeling test suite with a focus on tests that are reflective of modeling used in performance rating methods (PRM)
New Acceptance Criteria (AC) not actually used/cited by codes and ratings	• Work with codes and ratings groups to update references to 140 and help write changes to properly cite using AC • Develop User Manual with a section devoted to regulators and code officials for understanding and citing 140
Testing software with ASHRAE 140 is too cumbersome for software developer industry	• Develop automation tools and workflows to make it easier for vendors to run 140 test suites • Develop User Manual with a section devoted to developing 140 models and workflows

Approach

Acceptance Criteria

Develop Pass/Fail Acceptance Criteria

Develop clear pass/fail for software to allow for identification of weak software

Develop a clear target for software improvement

Update the criteria as new tests are added and as software improves

User Engagement

Organize and Host Stakeholder Meetings

Get direct input on development needs from stakeholders like Software Developers, AHJs, Regulators, Code Developers, Utility Program Managers, etc.

Rotate meetings between focus groups so meetings produce useful and in-depth dialog between participants

New Test Suites

Develop and Run Field Trials for New Test Suites

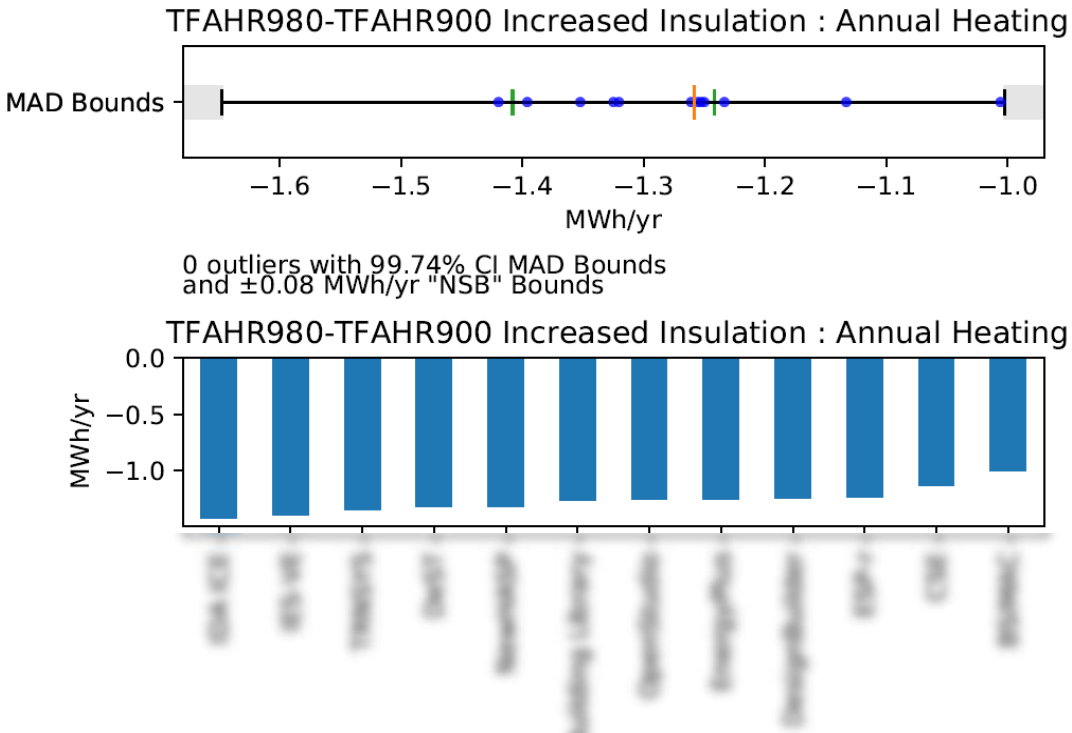
Speed development by streamlining approach, and modeling and reporting requirements

Expand physics and systems tested to improve software and better meet needs of codes and standards

Progress: Acceptance Criteria

- **Acceptance Criteria Published in Jan 2023**
  - Pass/Fail Criteria based, in part, on advanced statistics (median absolute deviation)
    - Purpose is to weed out really weak software
  - Currently Includes Thermal Fabric, and Airside, Cooling, and Heating Equipment Test Suites
- **Updating references by 90.1, 189.1, IECC, LEED, et al.**
  - Updates are necessary to ensure codes et al. require passing the new Acceptance Criteria
  - Found that ASHRAE 140 is cited more than we previously thought and cited inconsistently

Example of an Acceptance Criteria Test for Change in Heating Energy from Increased Insulation



Unofficial results → vendor names redacted (but they know who they are)

Progress: Acceptance Criteria

- **Passing AC Requires Passing 90% of Selected Tests in the Selected Test Suites**
  - Passing a Given Test Requires Being Within Bounds Determined from a Statistical Analysis of Reference Software Results and "Non-Statistical" Physics based Bounds

Thermal Fabric Low Mass Pass Results using MAD with 99.74% CI

index	Total_test							
Number Thermal Fabric Annual Heating Low Mass passed	10	10	10	10	10	8	10	10
Number Thermal Fabric Annual Cooling Low Mass passed	11	11	9	9	11	8	11	11
Total Passed	21	21	19	19	21	16	21	21
Met 90% Passing Threshold	18	Yes	Yes	Yes	Yes	No	Yes	Yes

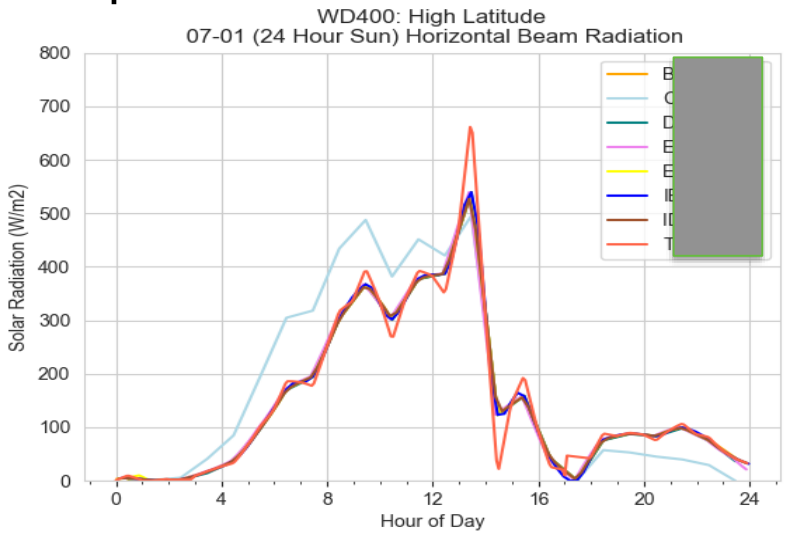
Thermal Fabric High Mass Pass Results using MAD with 99.74% CI

index	Total_test							
Number Thermal Fabric Annual Heating High Mass passed	9	8	7	9	9	6	9	9
Number Thermal Fabric Annual Cooling High Mass passed	10	9	9	9	10	4	10	10
Total Passed	19	17	16	18	19	10	19	19
Met 90% Passing Threshold	17	Yes	No	Yes	Yes	No	Yes	Yes

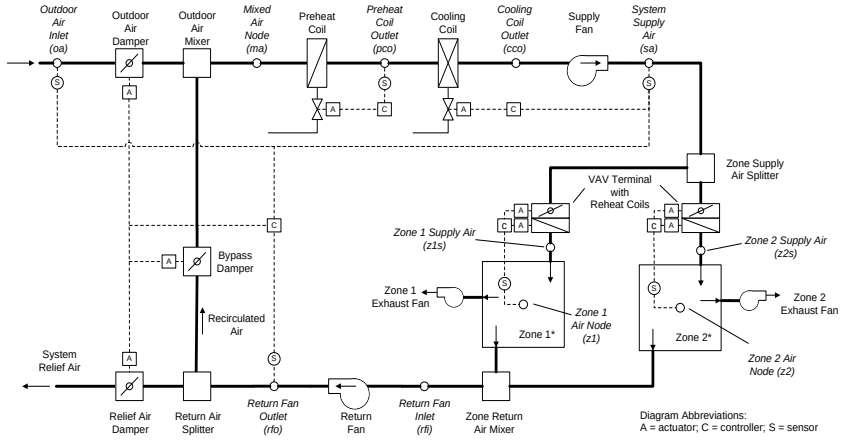
Progress: New Test Suites

- **Completed Weather Drivers Test Suite**
  - Published 2022 as 140-2020 Addendum A
  - Identifies software problems like improperly interpolating solar radiation into sub-hourly timesteps
- **Started Airside HVAC System Test Vol 2**
  - More realistic VAV system with reheat
  - Directly addresses need in PRM report
- **Developed recommendation document for reorganization of standard and suggestions for developing new test suites**
  - Facilitate easier new test suite additions
  - Current test procedures too manually intensive

Plot of variation of Horizontal Beam Radiation from Interpolation Differences

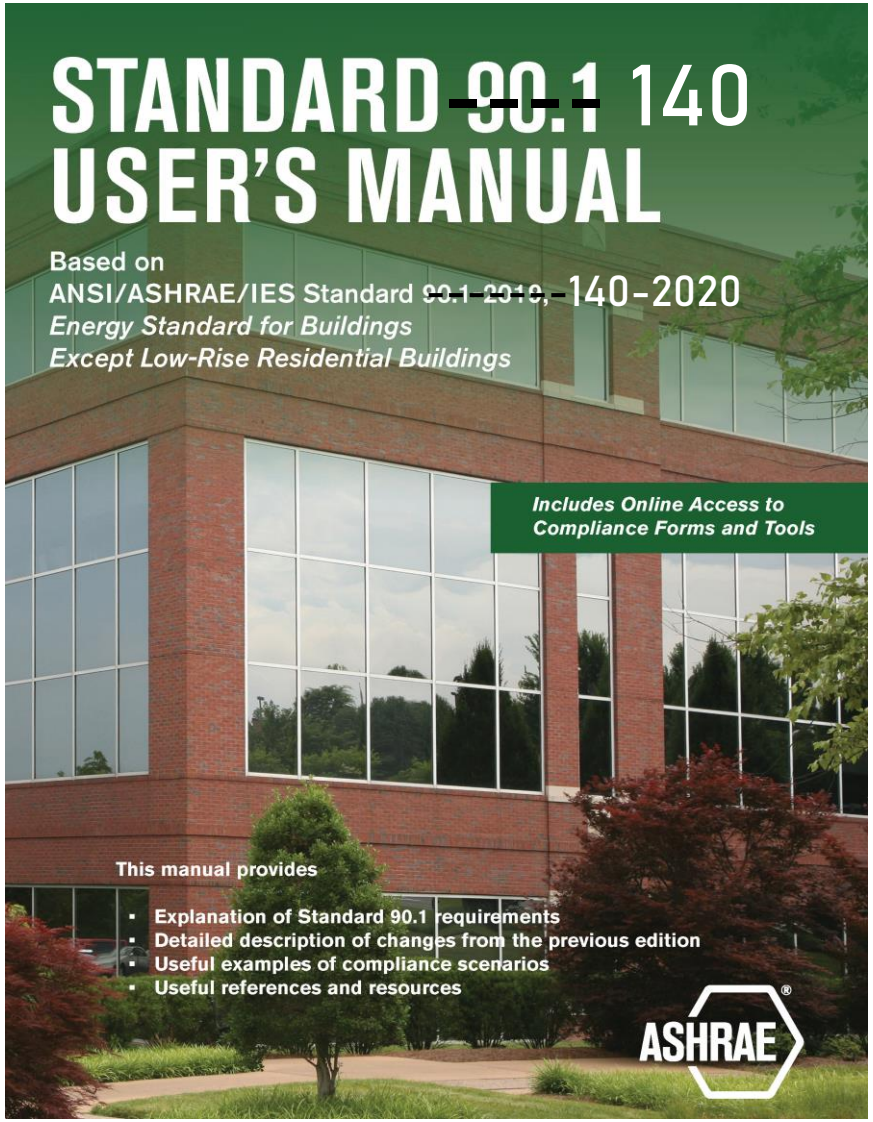


System Schematic for Airside Vol 2 Tests



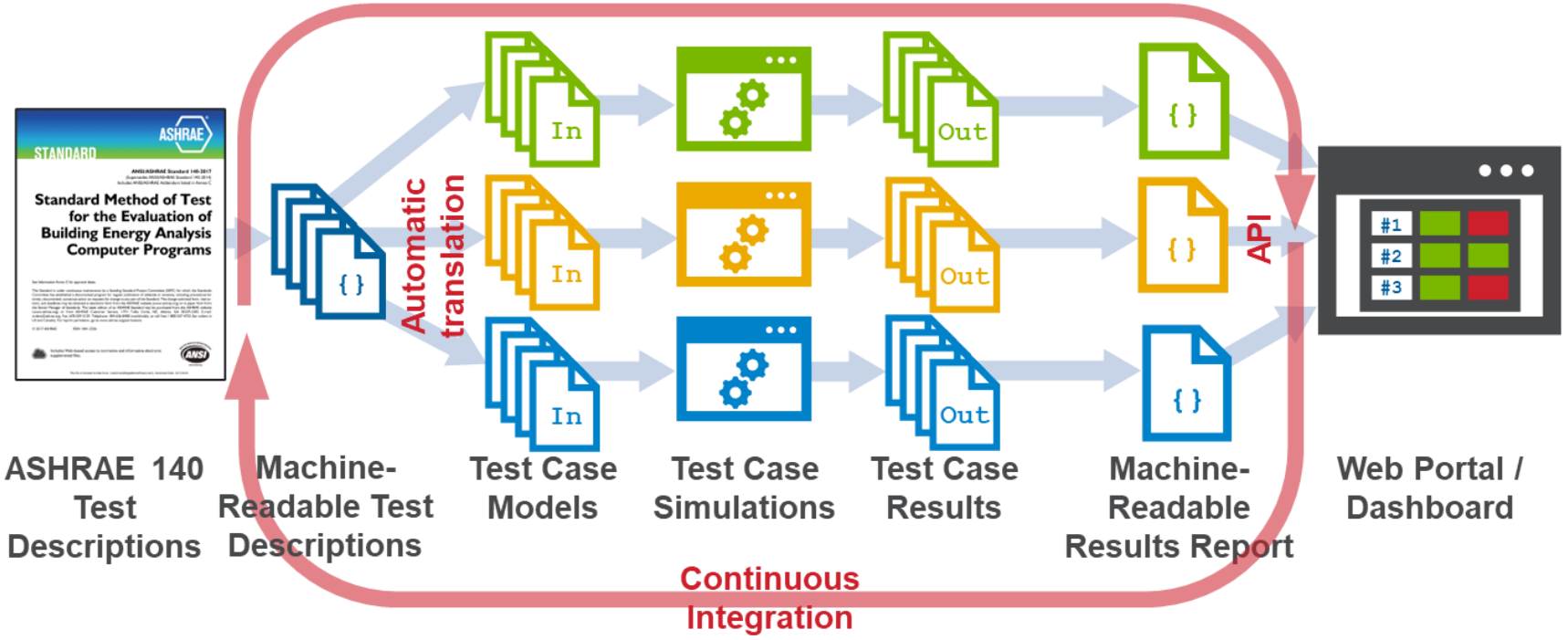
Progress: User Manual

- **Developing a User Manual for at least three distinct audiences**
  - Authorities Having Jurisdiction (AHJs) and regulators + other standards on why and how to cite ASHRAE 140
  - Software vendors who run 140 tests on how to create the test suite models and how to use them for diagnostics
  - Building Performance Modelers on how to create models to a specification and diagnose problems in models
- **Expected publication in Fall 2023 or Spring 2024**



Progress: ASHRAE 140 Automation

- **Develop workflows to help vendors perform and submit ASHRAE 140 testing**
  - More vendors wanting to be part of field trials
  - Improve timeliness of validating software against 140
- **Completed one stakeholder meeting**
- **Automating processing of test outputs to generate comparison reports and charts**



Eye to the Future: Empirical Validation

- **Other DOE Projects are completing experiments and analysis designed specifically for Empirical Validation**
  - These are some of the most accurate building energy experiments ever made and have been developed specifically for "**ground truth**" testing in 140
  - Projects finishing development of specifications ready for 140 field trials
  - 140 project team expected to take first specs to field trial in Fall 2023

ANL & JNA: ETNA

Single Zone Shoebox

NREL & JNA: iUnit

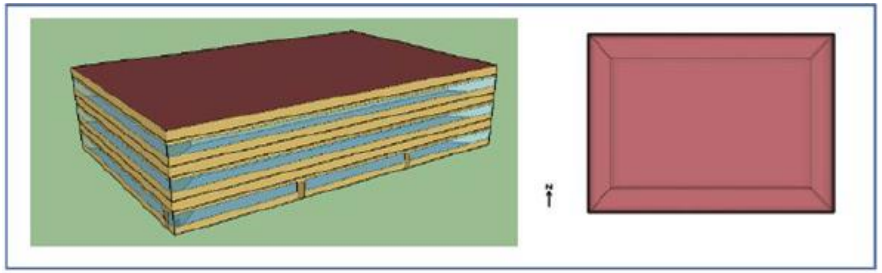
Single Zone Apt

ORNL & ANL: FRP

Multizone VAV

Eye to the Future: Whole Building Test Suite (WBM)

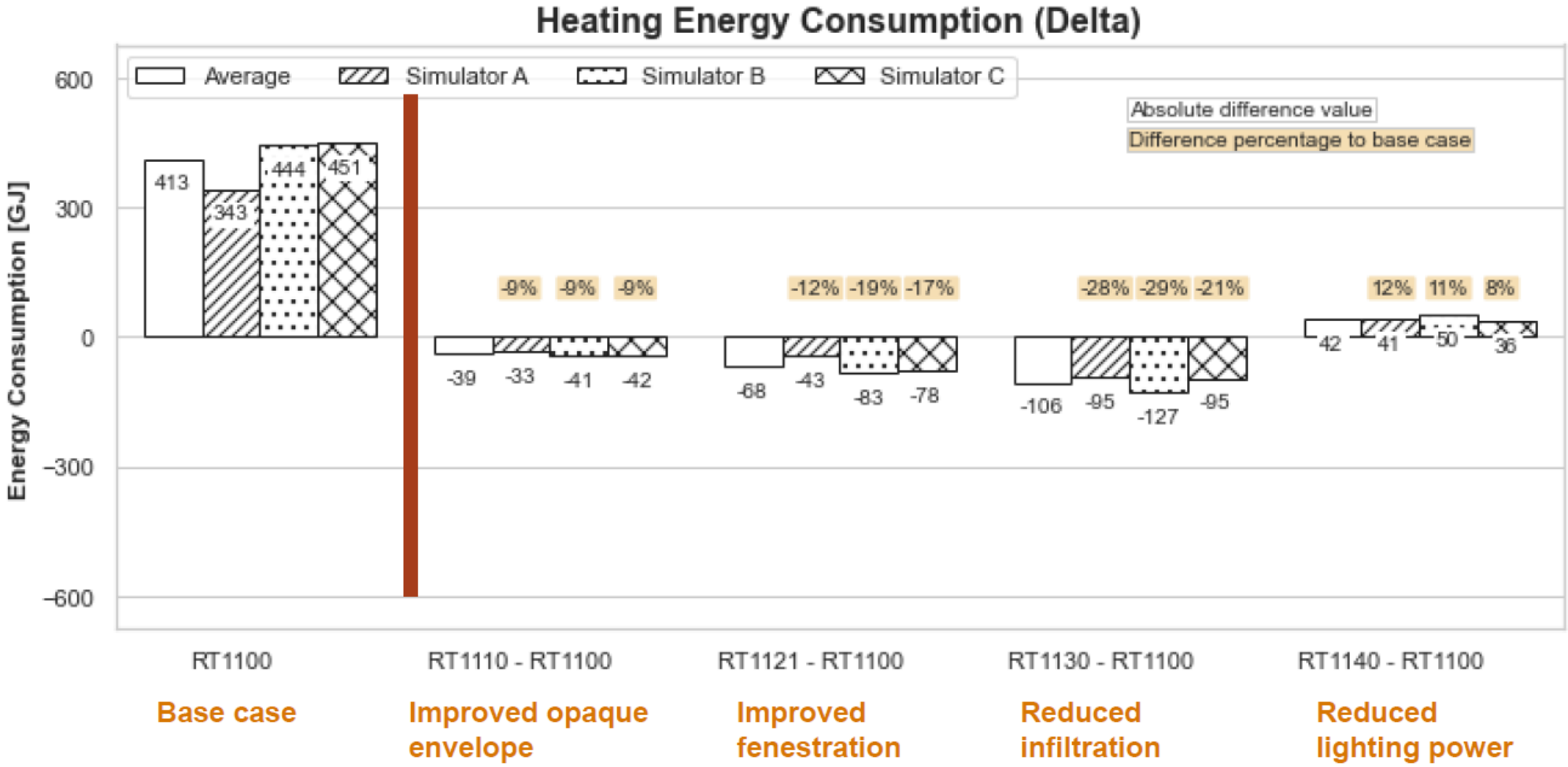
- **PNNL is leading a team from PNNL, ORNL, and ANL to develop a new whole building test suite for 140**
  - Current tests are diagnostic, use “shoebox” models
  - Test suite reflective of PRMs (e.g., 90.1 Appendix G)
  - More realistic buildings and HVAC systems
  - ECMs/sensitivity tests that mimic PRM methods
- **First suite uses medium office building type**
  - Adapted from 90.1 prototype model
- **Year 1 progress: Proved feasibility via internal trial using 3 most popular BEM programs (EnergyPlus, DOE-2, IES)**
- **Future**
  - Finalize spec and start field trials with several software vendors
  - Add delta tests to cover more equipment, ECMs, and diagnostics
  - Start work on 2nd WBM Test Suite: High-Rise Multifamily



Test ID	Section	Test Features
Section 5.6.1: Base Case		
RT1100	5.6.1	Base case
Section 5.6.2: Envelope and Loads Tests		
Section 5.6.2.1: Opaque Envelope Tests		
RT1110	5.6.2.1.1	Improved opaque envelope
RT1111	5.6.2.1.2	Improved opaque envelope with
Section 5.6.2.2: Fenestration Tests		
RT1120	5.6.2.2.1	Increased fenestration area
RT1121	5.6.2.2.2	Improved fenestration solar and t
RT1122	5.6.2.2.3	Improved fenestration solar and t fenestration area
Section 5.6.2.3: Infiltration Tests		
RT1130	5.6.2.3.1	Reduced infiltration rate
		Weather dependent infiltration al
		Reduced infiltration rate and wea
nal Load Tests		
		Reduced lighting power
		Reduced lighting power and runti
oved Envelope and Loads Test		
		Improved envelope and loads

Whole Building Test Suite Results So Far

Example Comparison of Heating Energy Savings from Various ECMs



ASHRAE 140: More Eye Toward the Future

Reorganize the Standard	• Make it easier to add test suites and addenda • Expect to publish reorg by Spring 2024
More Stakeholder Meetings	• AJH's / Regulators, Software Vendors
More Test Suites	• Multizone Diagnostics • Weather Driven Infiltration
Update Acceptance Criteria	• Add new test suites and output types to criteria • Update acceptance ranges as software improves
Complete User Manual	• Expect to publish Fall 2023 or Spring 2024
Implement First Automation	• Expect to release sometime in 2024

Thank You

Argonne, ORNL, PNNL
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REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: 140-2020 CM Revision Published	◆											
Q2 Milestone: Stakeholders Meeting		◆										
Q3 Milestone: Weather Drivers Published				◆								
Q4 Milestone: Acceptance Criteria Published					◆							
Q1 Milestone: Reorg and Roadmap Plan Deveveloped						◆						
Current/Future Work												
Q3 Milestone: Whole Building Suite Field Trials Start							◆					
Q4 Milestone: Stakeholder Meeting								◆				
Q4 Milestone: Users Manual Published								◆				

Team

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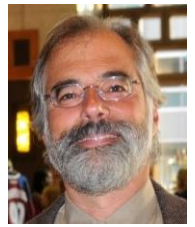

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EERE/BTO goals

The nation's ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO's vision for a net-zero U.S. building sector by 2050

Support rapid decarbonization of the U.S. building stock in line with economywide net-zero emissions by 2050 while centering equity and benefits to communities

Increase building energy efficiency

Reduce onsite energy use intensity in buildings 30% by 2035 and 45% by 2050, compared to 2005

Accelerate building electrification

Reduce onsite fossil -based CO_2 emissions in buildings 25% by 2035 and 75% by 2050, compared to 2005

Transform the grid edge at buildings

Increase building demand flexibility potential 3X by 2050, compared to 2020, to enable a net-zero grid, reduce grid edge infrastructure costs, and improve resilience.

Prioritize equity, affordability, and resilience

Ensure that 40% of the benefits of federal building decarbonization investments flow to disadvantaged communities

Reduce the cost of decarbonizing key building segments 50% by 2035 while also reducing consumer energy burdens

Increase the ability of communities to withstand stress from climate change, extreme weather, and grid disruptions