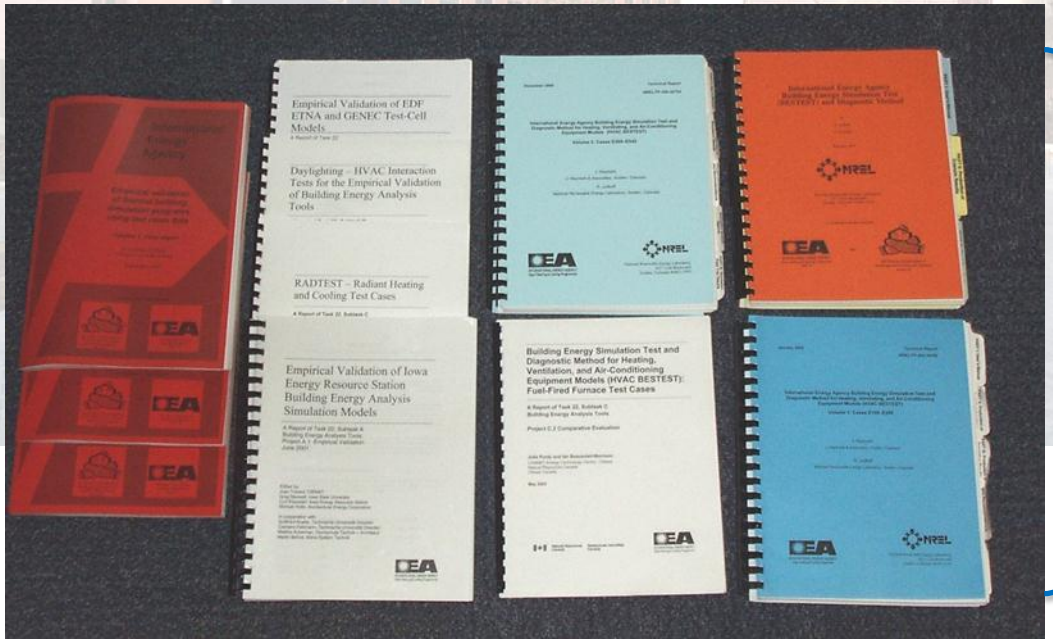
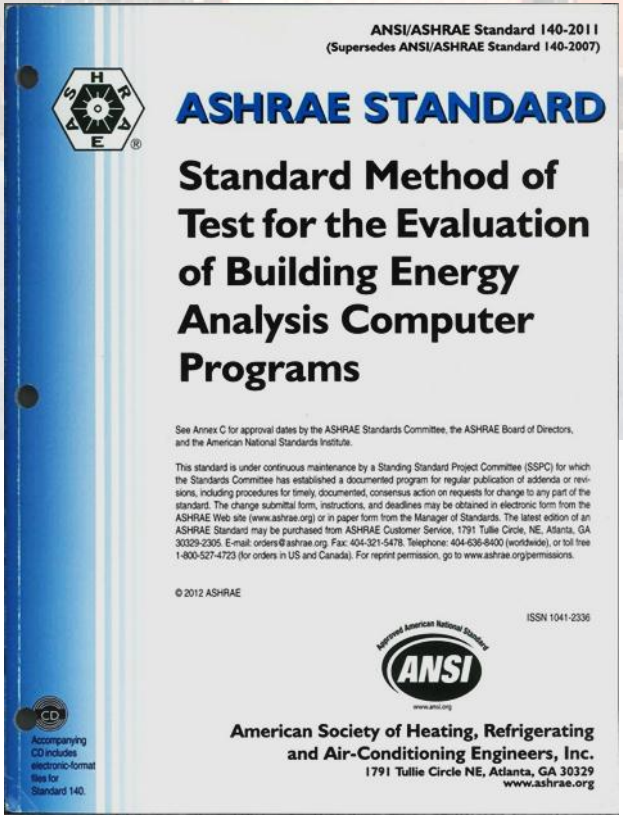
BESTEST: Test Procedures "Building Energy Simulation" Tools

2014 Building Technologies Office Peer Review

Pre-normative work by Labs, IEA, ASHRAE etc. becomes…



Normative ANSI/ASHRAE Standard 140



Software Testing & Diagnostic Method: Finding needles in haystacks

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

Ron.Judkoff@nrel.gov

Project Summary

Timeline:

Start date: Oct 2013*

Planned end date: Mar 2017*

Key Milestones FY14

1. Draft final report for Airside HVAC Tests
2. Draft updated BESTEST Thermal Fabric Tests
3. Addition of Ground Coupling tests to 140

Budget:

Total DOE $ to date: $580K

Cost Share to date: $600k

Total future DOE $: $972K

Target Market/Audience:

- Software developers/vendors/practitioners
- Codes & Standards bodies (E.g., IRS 179D)
- University professors and students

*Validation themed projects started prior to 1981 and will need to continue as long as software continues to be developed.

Key Partners (Partial Listing)

ASHRAE SSPC-140	Bentley Systems
RESNET	NRCan
TRANE	IES, UK
Carrier	TESS
AAON	GARD Analytics
Tsinghua U, China	De Montfort U, UK
U Strathclyde, Scotland	Tech U Dresden
TNO/VABI, Neth.	Sendai U, Japan

Project Goals:

-Develop methods for validating, diagnosing and improving building energy simulation tools and associated documentation.

-Increase confidence in the tools by developing standard methods of test that can be cited by regulatory bodies for software certification.

Purpose and Objectives

Problem Statement: Improve accuracy of building energy simulation programs; test capabilities; and identify strengths, weaknesses, and gaps.
Target Audience: Software developers, vendors, users, and regulatory bodies.
Energy Savings: New buildings market primary savings potential = 4.4 E+15 Btu/yr. by 2030*. Retrofit market = 12 E+15 Btu/yr. by 2030*.
Impact of Project:

- ANSI/ASHRAE Std-140 (based on BESTEST) is cited by many regulatory bodies needing to certify software in US and worldwide.
- Std-140 is 7th most purchased document out of 130 ASHRAE Standards and Guidelines.
- 96 Code citations in US.
- Referenced by: ASHRAE 90.1 Commercial Building Standard, IECC, IGCC, RESNET, ASHRAE Modeler Certification Exam, European Performance Directive, and energy codes of many nations world-wide.
- 18,000 BESTEST Reports downloads since 2011.
- IRS 179D Com Bldg Tax Credit cites 140 for approving software. Many other Federal, State and Local programs reference the IRS qualified software list.

IRS & RESNET Qualified Software BESTESTed with Standard 140

179D Commercial Building Tax Credits (13 Simulation Tools)

RESNET (HERS, IECC, Tax Credits)(6 Tools)

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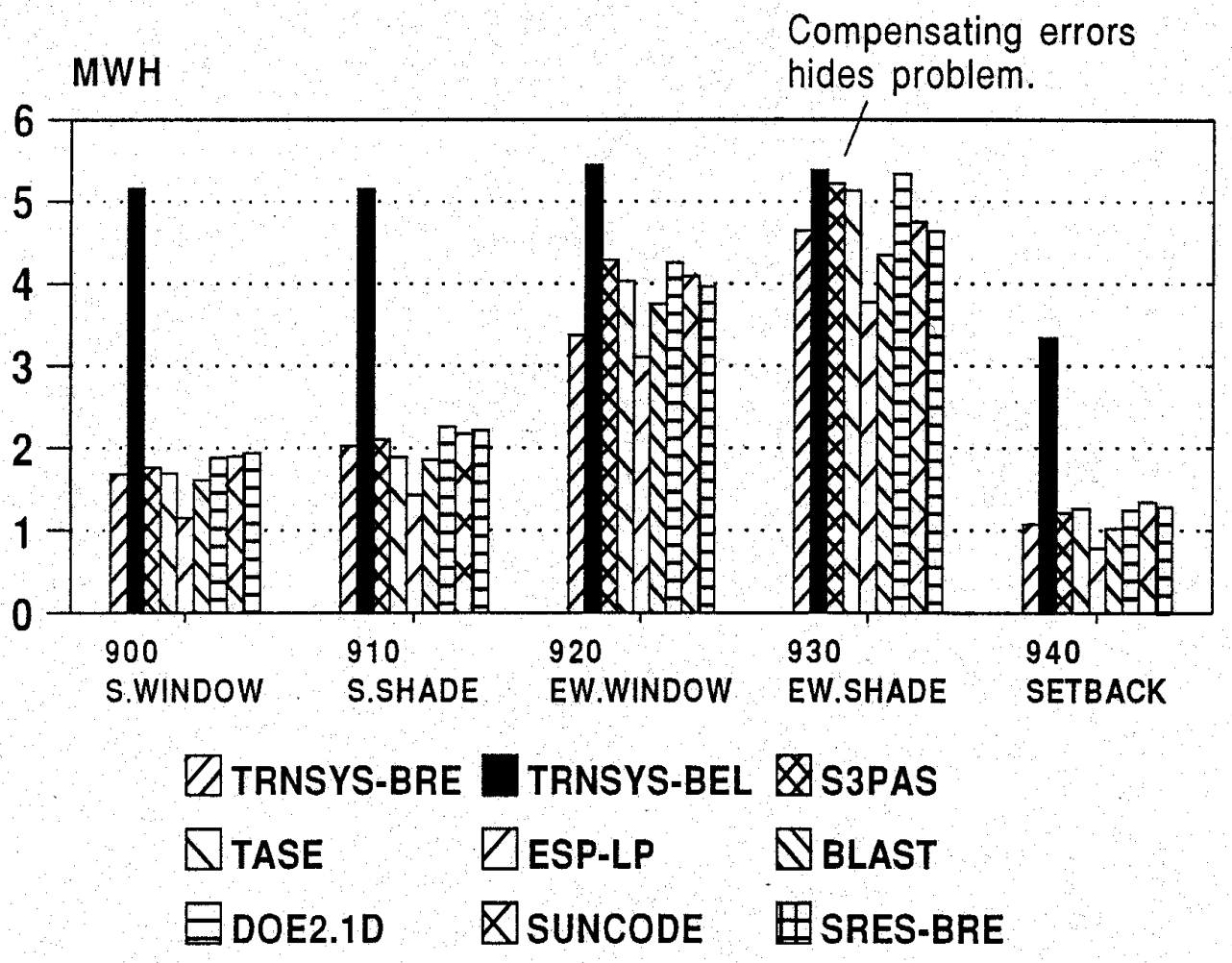
Validation Methods Pros/Cons

Technique	Pros	Cons
EMPIRICAL (tests model & solution)	Approximate truth standard. Any level of complexity.	Input uncertainty. Experiment uncertainty. Expensive. Limited sample of param-space. Compensating errors?
ANALYTICAL (tests solution only)	No input uncertainty. Exact truth standard within constraints. Inexpensive.	No test of model. Limited to highly constrained cases.
COMPARATIVE (relative test of model & solution)	No input uncertainty. Any level of complexity. Inexpensive. Diagnostic Power.	No truth standard.

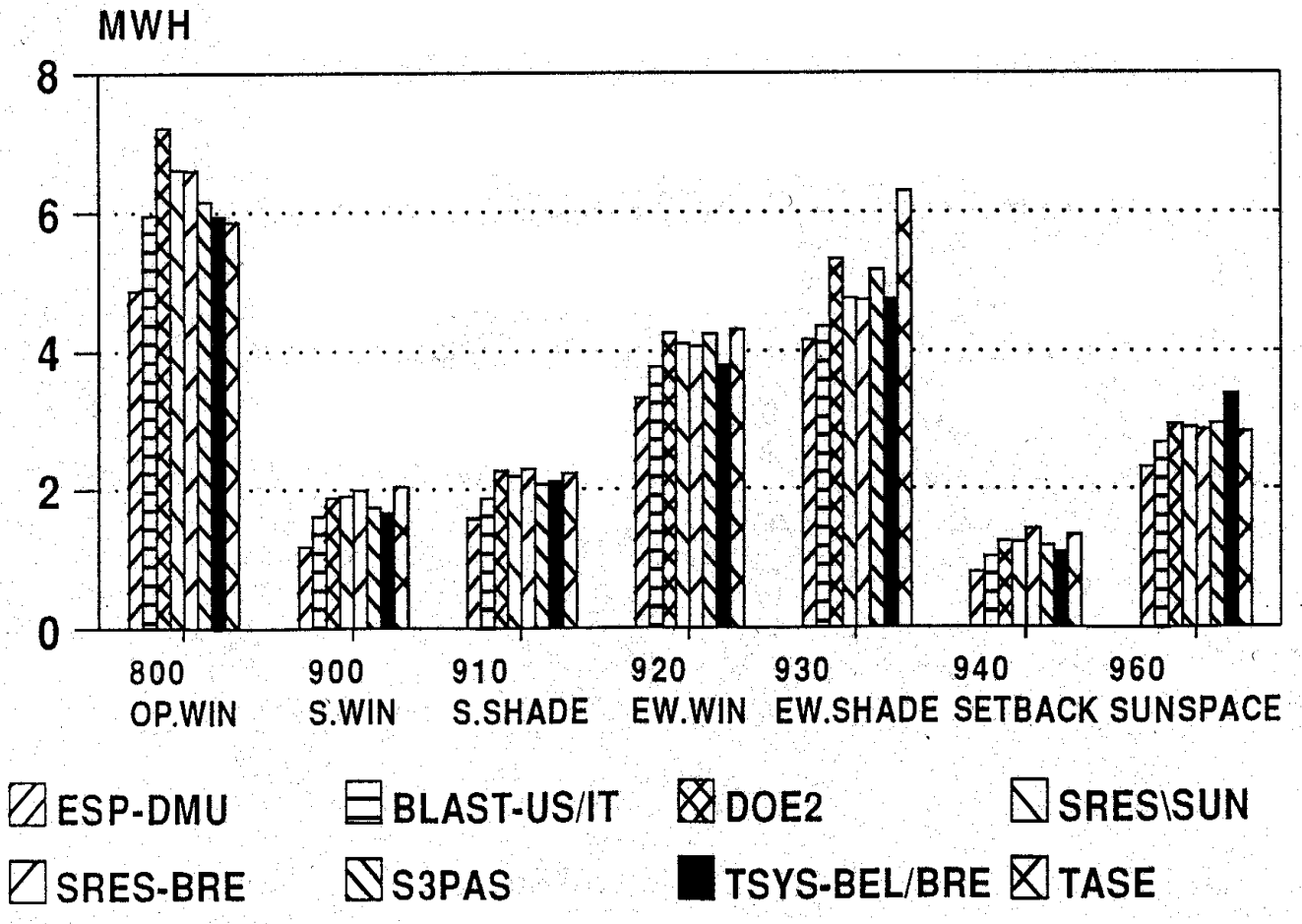
IEA BESTEST - TRNSYS DEBUG
HIGH MASS ANNUAL HEATING

RJ's Archive of Simulation Bloopers



TRNSYS BEFORE DEBUG (Transposed transfer function coefficient)

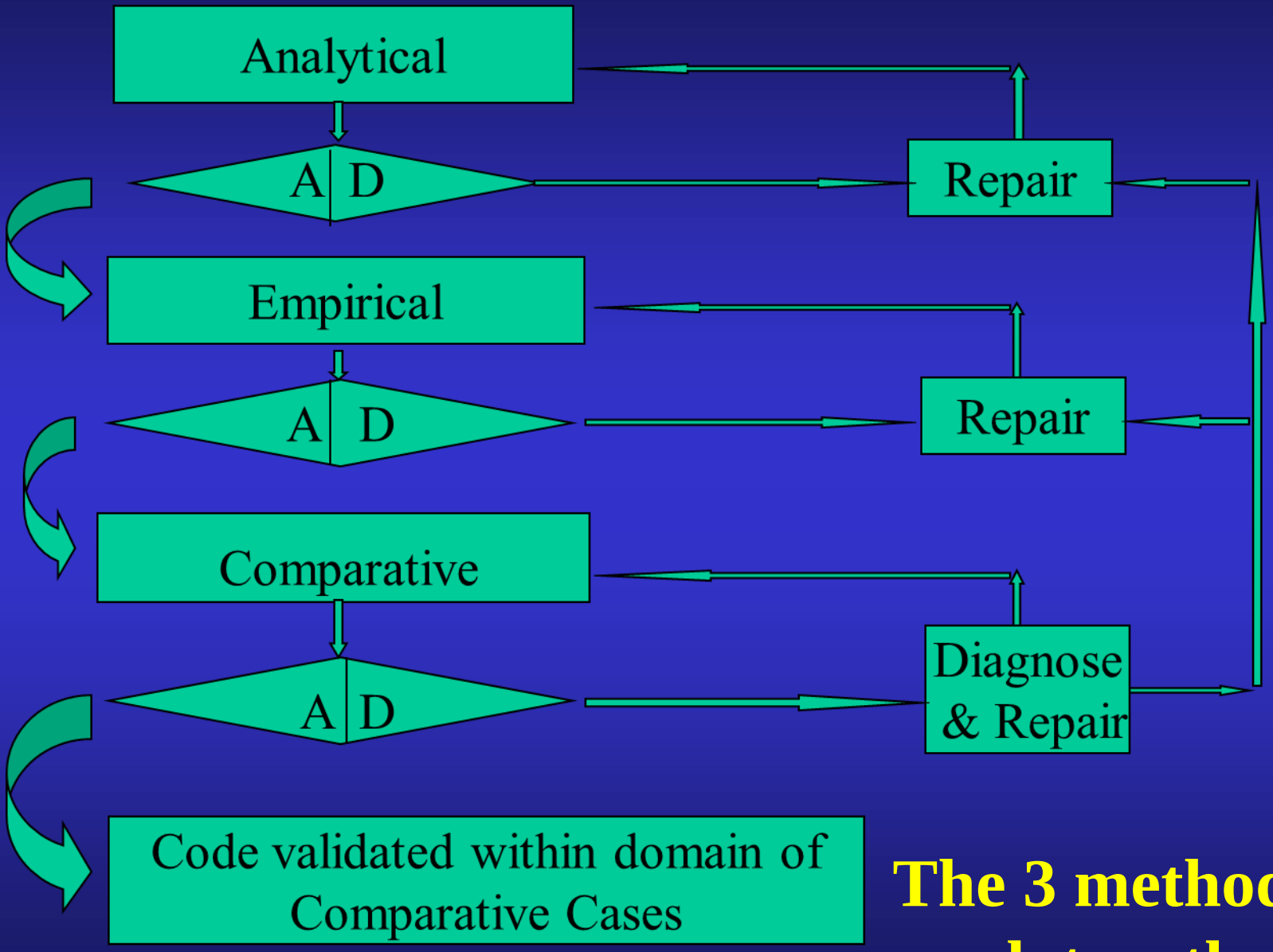
BESTEST QUALIFICATION
HIGH MASS ANNUAL HEATING



TRNSYS AFTER DEBUG

Transposed columns of transfer function coefficients (c to a)

VALIDATION METHOD: One of several useful flow paths



The 3 methods work together

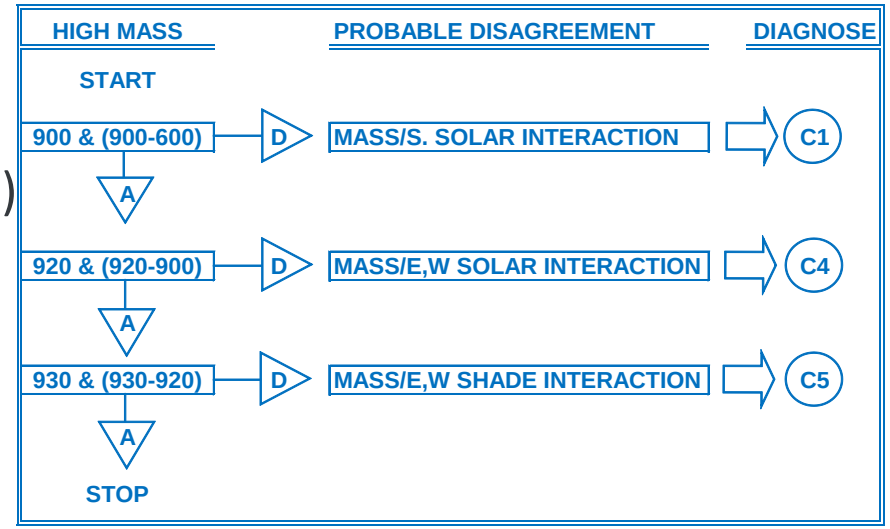
Approach

- Define test cases that provide a robust signal to noise ratio for the most important and fundamental simulation capabilities
- Construct and order the cases with diagnostic logic that progress one parameter at a time from simple to realistic (use analytical solutions as a starting point where possible)(use **good*** empirical validations where possible)
- Provide clear test specs (to minimize input errors) with equivalent inputs for many different types of building simulation programs (numerical, response, weighting factors, etc.)
- Refine test cases and example results by conducting iterative field trials with industry partners to test the simulation programs and to "test the test"
- Adhere to the principle of parsimony

Key Issues: BESTEST approach vs defined algorithm approach (ASHRAE v. ISO, CA T-24)

Distinctive Characteristics:

- Does not constrain evolution of tools
- Diagnostic logic



Validation Test Matrix

Test Type	Building Envelope	Mechanical Equipment	On-site Gen Eq.
Analytical	•Ground Coupling (NREL) •Multizone Non-air (NREL) •Working Doc of IEA Task 22 (Finland) •ASHRAE RP 1052 (OkSU) •Multizone Air (Japan)	•HVAC BESTEST vol 1 (NREL) •HVAC BESTEST Fuel-Fired Furnace (NRCan) •ASHRAE RP 865 (Penn St/ TAMU/NREL) Airside HVAC	
Comparative	•Fabric BESTEST (NREL) •Fabric BESTEST update •HERS BESTEST (NREL) •Ground Coupling (NREL 7/14) •Multizone non-air (NREL) •Multizone Airflow (Japan) •Double-Skin Facade (Denmark)	•HVAC BESTEST vol 2 (NREL) •RADTEST Radiant Htg (Switz.) •E+ Plant Tests (GARD) •Hydronic Systems (Germany) •RESNET/IECC Equipment Tests	•Fuel Cell IEA Task (NRCan)
Empirical	•ETNA BESTEST (NREL/EDF) •ETNA/GENEC Tests (EDF-Fr) •BRE/DMU Tests (BRE-UK) •EMPA:Daylite/shade/cool (Sw) •ERS – Daylighting (US/Iowa) •Double-Skin Façade (Denmark)	•Iowa ERS: VAV •Iowa ERS: Economizer Control •Iowa ERS: Daylite/HVAC •Iowa ERS: Daylite/HVAC2 •Hydronic Systems (Germany)	
Calibration	•BESTEST-EX (NREL)	•Hydronic Systems (Germany)	

Progress and Accomplishments

Lessons Learned:

- **Good** empirical validation studies are very difficult and expensive to do (but would be very valuable)(FLEXLAB may be of help)
- Iterative simulation trials are essential

Accomplishments Fy13 & 14:

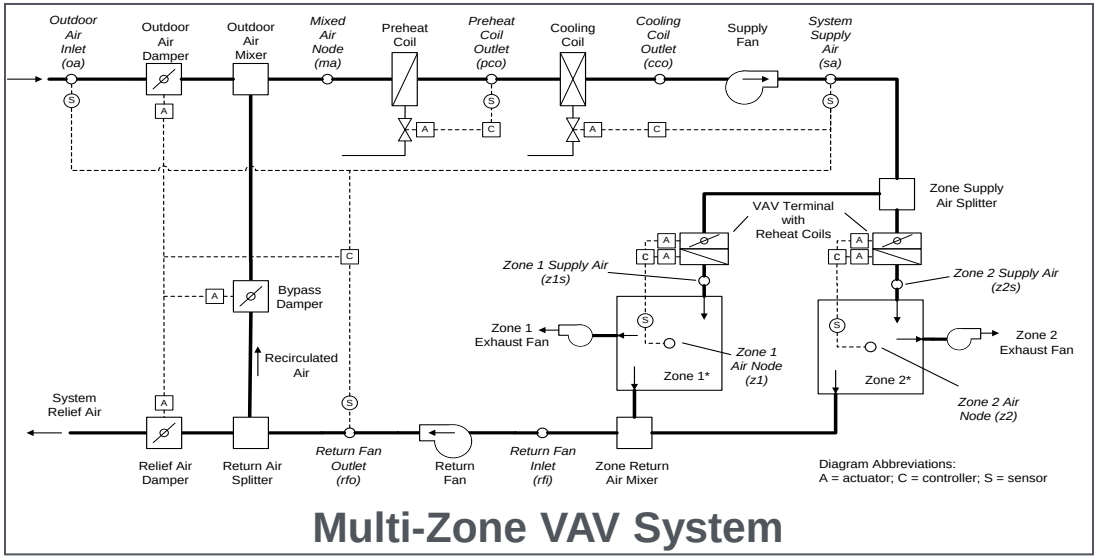
- 3 iterations of air-side HVAC tests resulting in improved agreement of example results, and unambiguous test specs good for a variety of model types
- Fabric tests: Spec update in progress, identified key updates with industry
- Completion of ASHRAE galley proofs for Ground Coupling tests
- Technical support to ASHRAE for Continuous Maintenance of 140-2014

Awards/Recognition:

- New validation section in ASHRAE Handbook by Judkoff and Neymark
- Translated into Chinese, Dutch, German, Japanese, Portuguese, and others
- Fabric BESTEST selected by the IEA as one of the 10 most significant reports in the history of the IEA
- 96 Code Agency citations in U.S.

Projects in Progress – Airside HVAC Model Tests

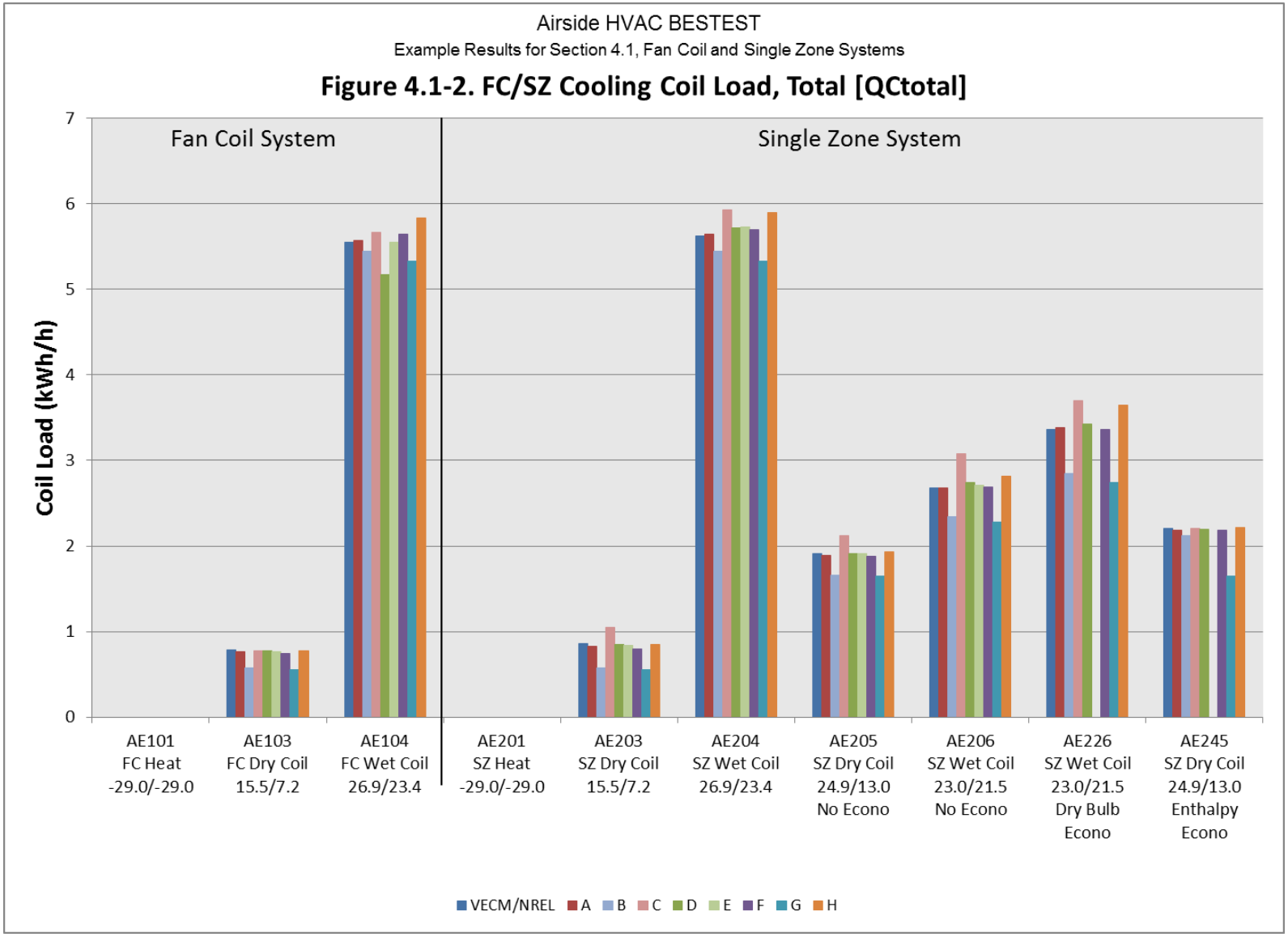
- System air energy balance
- Based on ASHRAE RP 865
- Analytical verification tests
- 4 systems: FC, SZ, CV, VAV
- 7 steady state cases per system
- Simulation trials and spec revisions *for standardization*
- 3rd simulation trial completed



Simulation Trial Participants (7 models, 4 countries)

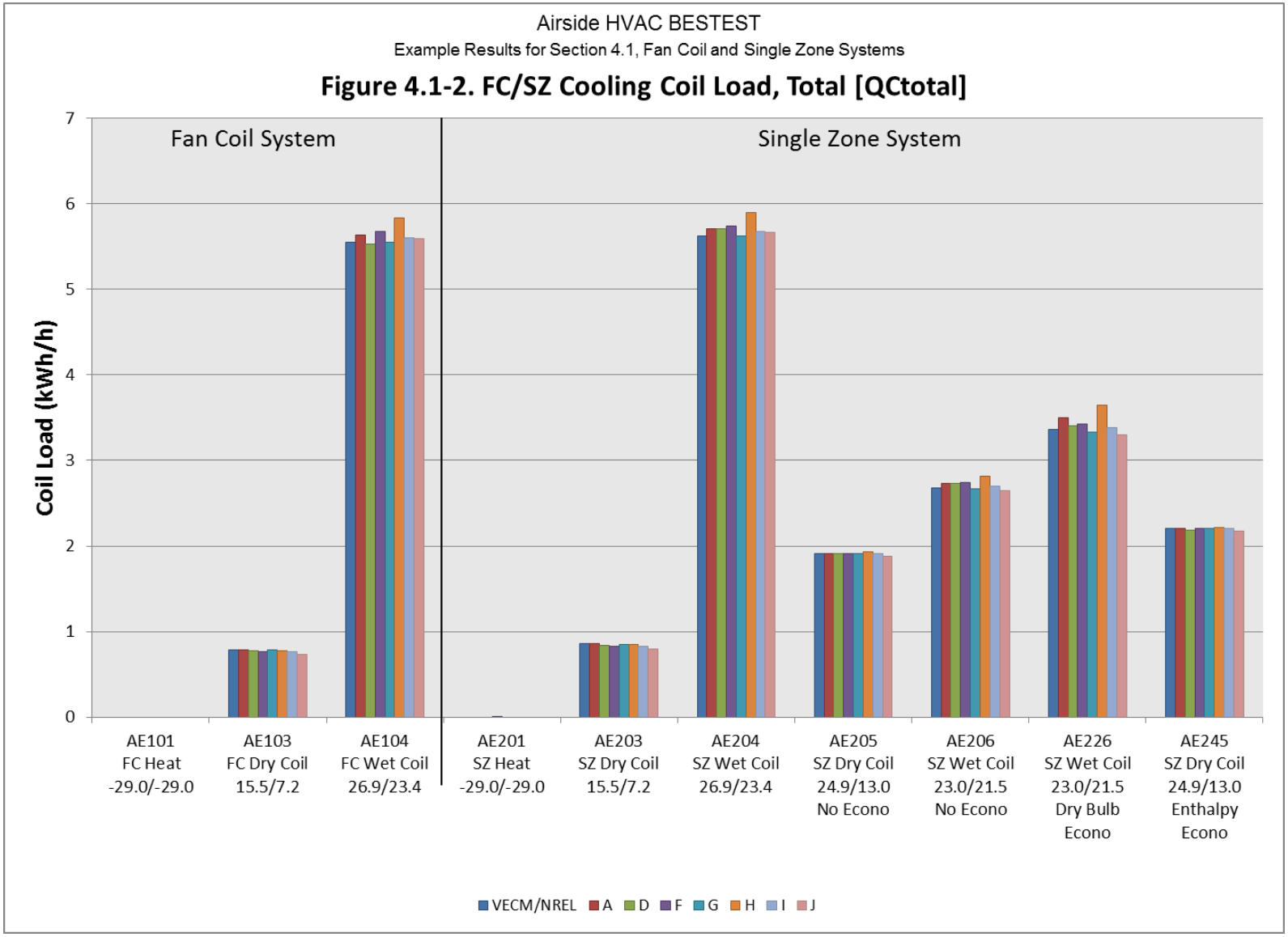
Model	Authoring Organization	Implemented By
VECM (reference benchmark)	PSU/TAMU/NREL, U.S.	NREL, U.S.
AAON – DEEAP	AAON Inc., U.S.	AAON Inc., U.S.
DeST	Tsinghua U., China	Tsinghua U. (Ch.), LBNL (U.S.)
DOE-2.2	J.J. Hirsch & Assoc., U.S.	NREL, U.S.
EnergyPlus	U.S. DOE, U.S.	GARD Analytics, U.S.
IES-VE	IES, U.K.	IES, U.K.
LCEM	MLITT, Japan	TTE, Japan
TRNSYS-17	TESS, U.S.	TESS, U.S.

Airside HVAC Model Test Results – Early (Jun 2012)



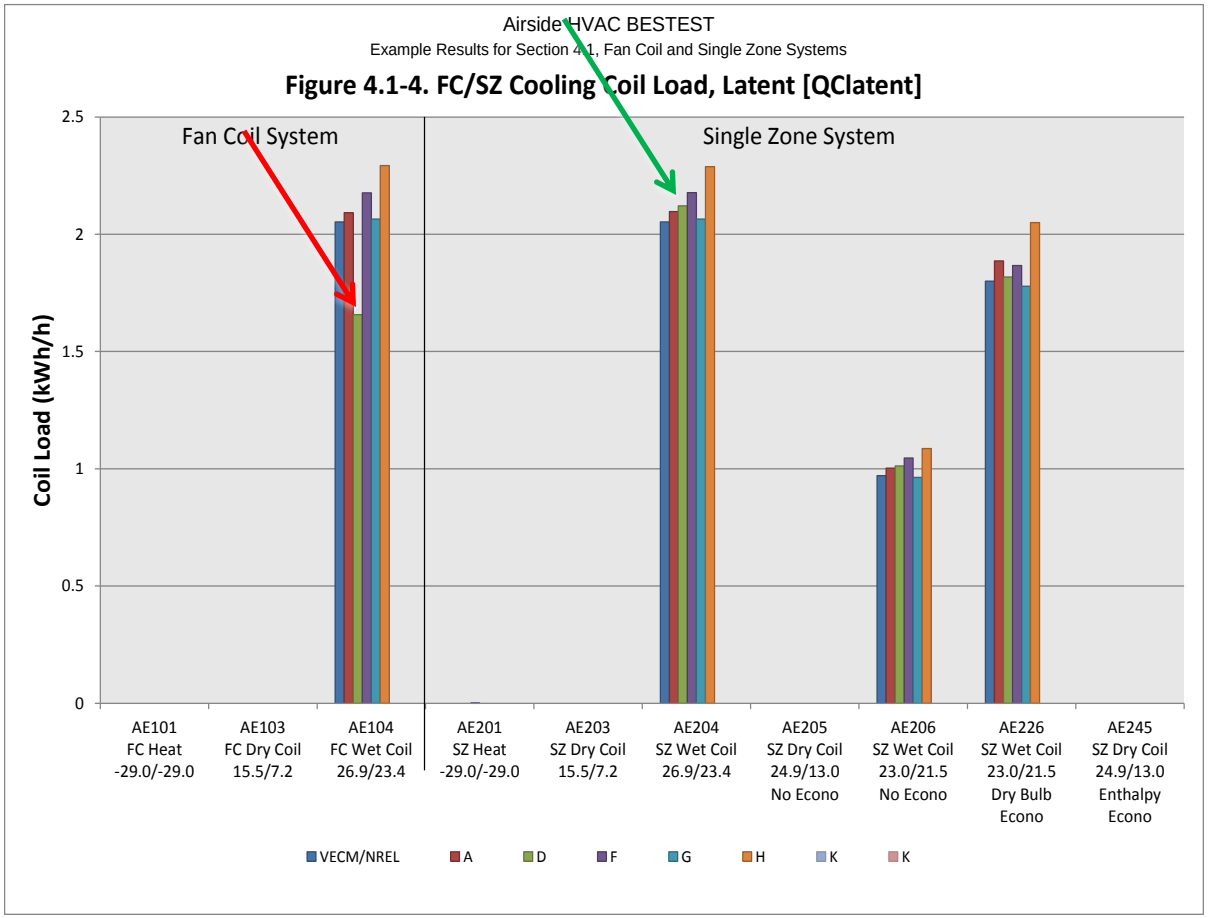
Before bug fixes, model and spec improvements

Airside HVAC Model Test Results – Current (Jan 2014)



After bug fixes, model and spec improvements

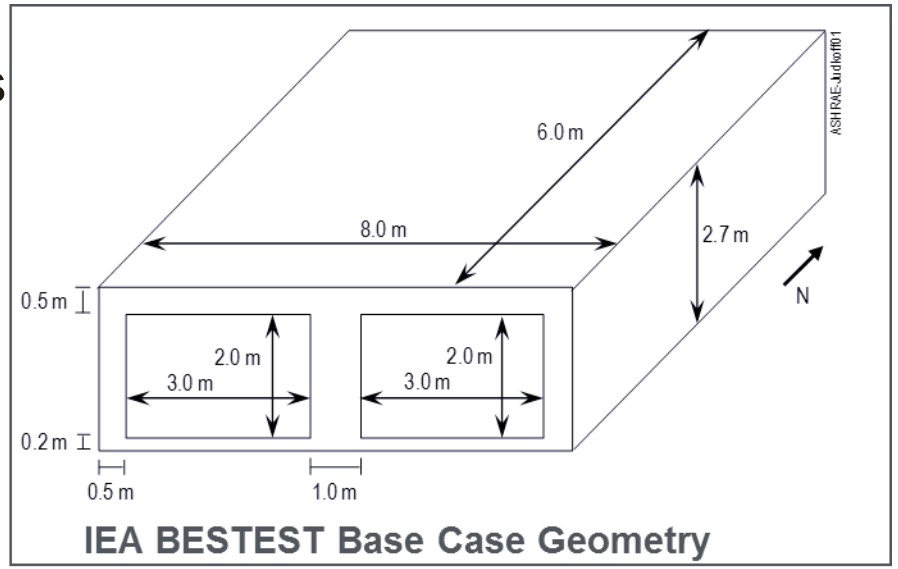
Airside HVAC Model Example Bug – Program D Bug (2)



Zone latent gains not picked up in Program D's FC system model; SZ system model was ok

Projects in Progress – IEA BESTEST Update

- **First published 1995, basis of ANSI/ASHRAE Std 140**
- **Test building thermal fabric modeling (envelope +)**
- **Comparative tests, software to software**
- **39 Cases: Basic and In-Depth**
  - Sensitivity Features: Thermal mass, windows, shading, orientation, internal gains, sunspace, night ventilation, thermostat settings
- **Update for advances in modeling tools state of the art:**
  - Weather data (TMY 3)
  - Surface heat transfer coefficients
  - Weather driven infiltration
  - Windows
  - Other
- **Simulation trials begin 2014**
  - SSPC 140 and others worldwide
  - Spec update in progress



IEA BESTEST Base Case Geometry

Next Steps and Future Plans

FY14 & Beyond (budgeted)

- Finish airside HVAC Tests Vol 1.
- Finish draft of updated Fabric BESTEST and start field trials
- Tech support for publication of Ground Coupling tests by ANSI/ASHRAE at Seattle meeting, July 2014 (galley reviews, etc.)
- Tech support for Std 140-2014 continuous maintenance revision
- BESTEST Multi-zone non-airflow mandatory language

Future Thoughts (not budgeted)

- Volume 2 of Airside HVAC (SSPC-140 interested in this)
- FLEXLAB or other Emp test facility (controlled, repeatable, side x side)
  - Energy hog physics, 1D vs 3D conduction, empirical BESTEST, etc.
- Multi-Zone Airflow (Sendai U, MITI, Japan)
- BESTEST-EX and Residential HVAC
- More realistic ground coupling tests (e.g., walk-out basements)
- WETTEST: Moisture physics
- Hydronic Equipment tests
- Plant tests
- See Standard 140 Annex B-23 for more


Much
To Do
END
Much
Accomplished

REFERENCE SLIDES

Project Budget

Project Budget: See Table
Variances: No variances to report.
Cost to Date: $580k
Additional Funding: Cost Share noted in table

Budget History					
Oct 2012 – FY2013 (past)		FY2014 (current)		FY2015 – Mar 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$405k	$150k	$400k	$450k	$747k	$500k

Project Plan and Schedule