Standard 140 Test Suite Prioritization Roadmap, June 24, 2019

Contents — Page

Introduction

There is a long list of test suites to potentially be added to Standard 140. Some of these test suites are already well-developed and others are simply ideas of areas that could benefit from testing. All of these test suites cannot be developed at the same time. It is necessary to prioritize the topics and produce a roadmap for developing the test suites for adding to the standard going forward. The process of developing a roadmap began at the ASHRAE meeting in January 2018 in Chicago and is culminating in this report.

Initial Topic Prioritization

ASHRAE Meeting January 2018 – Chicago

At the SSPC 140 meeting at the ASHRAE Conference in Chicago in January 2018, the list of potential test suites was presented to the committee members. After a brief discussion of the different topics, votes were taken from the people in attendance at the meeting as to which test suites should be a priority. The potential test suites were separated into two groups: Empirical Validation Tests and Analytical Verification and Comparative Tests. The voting results for the candidates:

Empirical Validation Tests

Test Suite	**Votes**
HVAC BESTEST 1&2 with NREL empirical data	16
LBNL/Flexlab test cases	14
ORNL/FRP test cases	14
ETNA Bestest	10
NREL "i-Unit" Lab	10
IEA 34/43 Hydronic Equipment - TUD	5
IEA 58 Fraunhofer, Holzkirchen Twin Houses	3
IEA 34/43 Shading/Daylighting/Loads - EMPA	3
IEA 34/43 Double-Skin Façade – Aalborg U.	1
IEA SHC 22 Daylighting/HVAC Interaction Tests	0
IEA SHC 22 Economizer Control Tests – Iowa EC	0

Analytical Verification and Comparative Tests

Test Suite	**Votes**
Airside HVAC BESTEST Volume 2	13
Weather Drivers	13
Weather-Driven Infiltration	12
IEA 34/43 Multi-zone Test Suite	11

Additional Ground Coupling Cases	11
2-D or 3-D Conduction	8
ASHRAE RP-1052 Building Thermal Fabric Analytical Verification Tests	8
RADTEST Radiant Heating and Cooling Test Cases	7
BESTEST-EX Physics Tests	6
IEA 34/43 Hydronic Equipment	5
MZ-Type Test with Overlapping Shading	4
IEA 34/43 Airflow Tests	2
IEA 34/43 Double-Skin Facade	2
RESNET Mechanical Equipment Test Cases	1
IEA BCS 42 Residential Cogeneration Devices	0

A very large caveat for the potential empirical test suites is that the uncertainty analysis to be completed by Argonne National Lab shows sufficiently minimized uncertainty such that SSPC-140 judges the suite(s) to be definitive, robust, and worthwhile in the context of Standard 140 (doable by simulationists with a reasonable amount of effort).

ASHRAE Meeting June 2018 – Houston

At the SSPC 140 meeting at the ASHRAE Conference in Houston in June 2018, further prioritization was tabled, because no further information concerning the test suites was available beyond that which was available in Chicago. Instead, it was determined that for the next SSPC 140 meeting, one-page summaries of the different test suites would be developed to provide a level playing field for the prioritization process. The one-page descriptions would include what the test suites will do, what parts of the software are being tested, and how far along the test suite is (e.g., completely new, modification of existing tests, etc.).

ASHRAE Meeting January 2019 – Atlanta

At the SSPC 140 meeting at the ASHRAE Conference in Atlanta in January 2019, the one-page descriptions for the proposed test suites were presented along with 5 minutes of questions and answers for each topic. (See Appendix A for the one-page descriptions.)

After all of the potential test suites were presented, a prioritization vote was held using an on-line system to accommodate committee members that could not attend the meeting in person. Each person interested in voting was able to vote for the 6 topics that they felt were the highest priority for inclusion in Standard 140. The results of the voting were assembled in two different ways: just SSPC 140 Members (voting and non-voting) and all meeting attendees voting.

SSPC Member Voters (10):

Test Suite	**Votes**
Update HVAC BESTEST Performance Maps with Empirical Data	7
Airside HVAC BESTEST Volume 2	6
Weather Drivers	6
Analytical Building Fabric Tests - 1052-RP	5
Standard 205 Performance Map Tests	5
Weather-Driven Infiltration and Natural Ventilation	5

Domestic Hot Water	4
Empirical Test Set from LBNL Flexlab and ORNL FRP	4
Empirical Test Set from NREL Indoor/Outdoor Modular Apartment	4
Ground Coupling (expand Section 5.2.4)	4
Multi-Zone Non-Airflow (MZ) Test Suite – IEA34-43/NREL	4
ETNA BESTEST Empirical Validation – EdF(Fr)/JNA/NREL	3
Thermal Bridging (2-D/3-D Conduction)	3

All Voters (18):

Test Suite	**Votes**
Update HVAC BESTEST Performance Maps with Empirical Data	13
Empirical Test Set from LBNL Flexlab and ORNL FRP	10
Ground Coupling (expand Section 5.2.4)	10
Weather Drivers	9
Weather-Driven Infiltration and Natural Ventilation	9
Domestic Hot Water	8
Empirical Test Set from NREL Indoor/Outdoor Modular Apartment	8
Multi-Zone Non-Airflow (MZ) Test Suite – IEA34-43/NREL	8
Standard 205 Performance Map Tests	8
Airside HVAC BESTEST Volume 2	7
Analytical Building Fabric Tests - 1052-RP	7
Thermal Bridging (2-D/3-D Conduction)	7
ETNA BESTEST Empirical Validation – EdF(Fr)/JNA/NREL	4

In both voting lists, the Update HVAC BESTEST Performance Maps with Empirical Data test suite was the top vote getter. Otherwise, the remaining topics received a similar total number of votes and no further conclusions can be gathered.

Further Requested Information

Some attendees participating in the voting process wanted further information about the proposed topics, including:

- What does it add to the standard
- Does it fix a current issue with the standard
- Does it help move the industry forward
- When could it be done/Level of difficulty in developing the test cases
- Number of programs that can currently apply the test
- Impact Factor of the test suite

This information has been developed for the proposed test suites and can be seen in Appendix B.

Other thoughts raised by the participants included voting for more topics and being able to rank their choices.

June 2019 Topic Prioritization

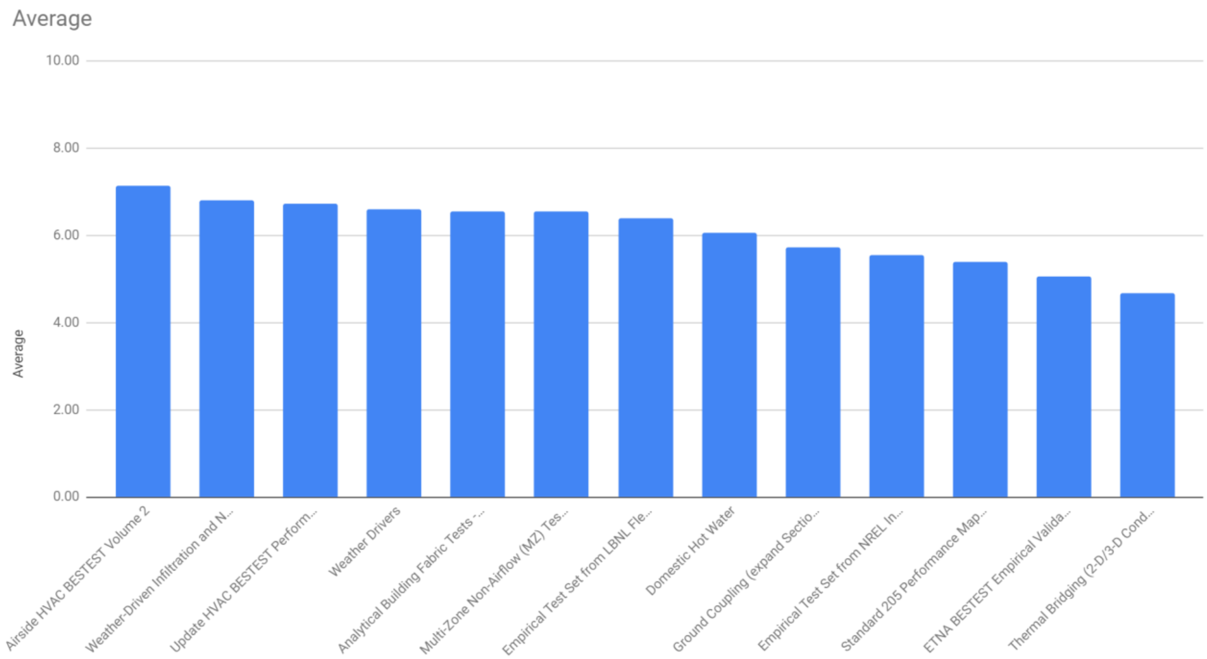
Email Poll, June 2019

A new poll was conducted among SSPC 140 members (VMs, NVMs and those rolling on after July 1) in June 2019 prior to the Kansas City meeting for the purpose of clarifying the Atlanta poll results. This poll required survey participants to rank all test cases from 10 to 1 (10 = highest priority, most points), with the intent to provide clearer ratings of topics. This poll also provides additional information about each topic requested at the Atlanta meeting in Appendix B; Appendix B is supplementary to the earlier topic descriptions of Appendix A. The results of the voting among SSPC 140 Members follows.

SSPC Member Voters (15 total votes):

Test Suite	Average Score
Airside HVAC BESTEST Volume 2	7.13
Weather-Driven Infiltration and Natural Ventilation	6.80
Update HVAC BESTEST Performance Maps with Empirical Data	6.73
Weather Drivers	6.60
Analytical Building Fabric Tests - 1052-RP	6.53
Multi-Zone Non-Airflow (MZ) Test Cases (IEA 34/43)	6.53
Empirical Test Set from LBNL Flexlab and ORNL FRP	6.40
Domestic Hot Water	6.07
Ground Coupling (expand Section 5.2.4)	5.73
Empirical Test Set from NREL Indoor/Outdoor Modular Apartment	5.53
Standard 205 Performance Map Tests	5.40
ETNA BESTEST Empirical Validation	5.07
Thermal Bridging (2-D/3-D Conduction)	4.67

The following figure illustrates these results graphically and indicates topic ratings are relatively close, with one topic ranked slightly higher than all of the others, a group of 6 topics that are closely ranked in second and then the remaining 6 topics ranked lower, but without any obvious cutoff point for considering elimination.



However, we have now done three polls and it turns out that four topics have been scoring consistently high throughout all of the polls. A summary of these topics in the various polls is tabulated below.

Test Suite Rankings Summary	Jun 2019, poll all topics, 140 Members, Rank (Score)	Jan 2019, poll all topics, 140 Members, Rank	Jan 2018, polled without V&U, All attendees, Rank
Airside HVAC BESTEST Volume 2	1 (7.13)	2 tied	1 tied
Update HVAC BESTEST Perf. Maps w/ Empirical Data	3 (6.73)	1	not listed
Weather-Driven Infiltration and Natural Ventilation	2 (6.80)	4 tied	3
Weather Drivers	4 (6.60)	2 tied	1 tied

Conclusion

The SSPC 140 test suite development prioritization process has helped to narrow down the potential test suites to the ones that SSPC 140 feels are the most important. This roadmap will be used to help direct the committee resources in the development of future test suites. It can also be used by other parties to prioritize the development of test suites for consideration by SSPC 140 for inclusion in the standard. Of course, any outside party developing test suites will apply their own prioritization based on their own criteria.

This document is intended to be a “living” document and will be updated periodically by SSPC 140 when new topics are proposed and priorities shift.

Appendix A: One Page Descriptions of Test Suites

Airside HVAC BESTEST Volume 2

Purpose: Expand Standard 140's "Airside HVAC BESTEST Volume 1" test suite (Section 5.5). The current Section 5.5 tests are in-depth diagnostic analytical verification tests for modeling airside HVAC equipment, with quasi-analytical solution benchmarks, based on ASHRAE 865-RP. These tests apply steady-state weather data and other idealizations, and provide the foundation for establishing realistic comparative tests. The new Volume 2 tests would apply hourly-varying annual weather data and would add physics tests not included in Volume 1. Adding the Airside HVAC Volume 2 test cases follows the precedent of the Standard 140, Section 5.3 working-fluid-side tests, which currently includes HVAC BESTEST Vol. 1 (Std. 140, Secs. 5.3.1 and 5.3.2) and Volume 2 (Std. 140, Secs. 5.3.3 and 5.3.4).

Possible Tests:

- **Non-Idealized Bypass Factor (BF):** Volume 1 tests apply BF = 0; new tests would apply realistic value (e.g., BF = 0.05) and corresponding apparatus dew point, geometry, and other equivalent inputs.
- **Apply Annual (Non-Steady-State) Weather Data to Existing Test Cases:** This allows scaling of differences among programs with annual and peak energy use, important for qualification tests.
- **Dry-Bulb & Enthalpy Economizer Controls For Robust Net Energy Savings in Hot/Dry and /Humid Climates.**
- **Duct Heat Gain/Loss.**
- **Fan Energy Consumption.**
- **Other:** See Section 3.5.2 of *Airside HVAC BESTEST, Vol. 1.* https://www.nrel.gov/docs/fy16osti/66000.pdf

Status: Idea. Volume 2 tests build off of completed Airside HVAC Volume 1 (Standard 140, Sec. 5.5)

Analytical Building Thermal Fabric Tests

Purpose: Add analytical thermal fabric tests based on ASHRAE 1052-RP "Development of an Analytical Verification Test Suite for Whole Building Energy Simulation Programs – Building Fabric" (Spitler, J.D., Rees, S.J., and Dongyi, X., ASHRAE 1052-RP Final Report, April 2001). Each test models a specific heat transfer mechanism, such as conduction. The analytical solutions were implemented in an interactive program with user inputs to generate a variety of cases for each test type (e.g. varying wall material properties for conduction tests). All tests use single zone, 3m x 3m x 3m.

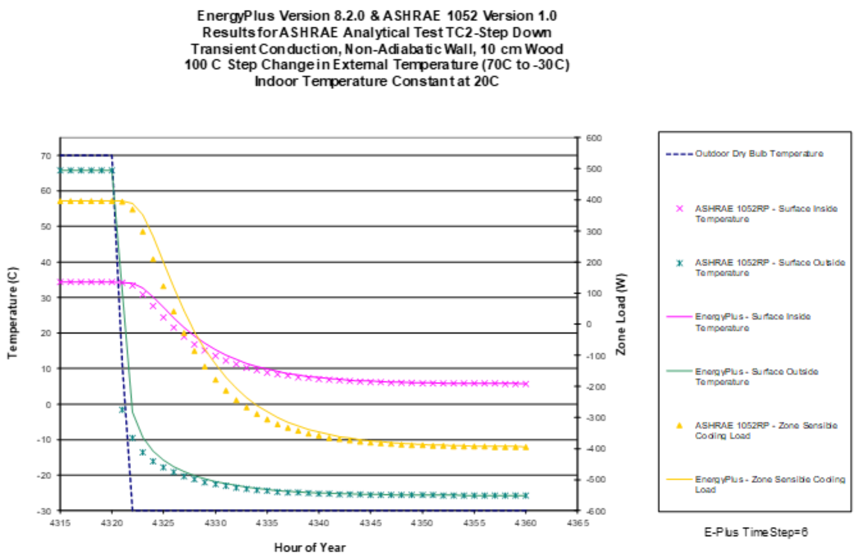
Types of Tests Available:

- **Convection and Conduction:** Steady state, transient
- **Solar Gains and Shading:** Exterior and interior through glazing (shading, reveal, internal distribution)
- **Infiltration:** Fixed and stack effect (overlap with Weather Driven Infiltration)
- **Long Wave Radiation:** Interior and exterior
- **Miscellaneous:** Internal heat gains (convective and radiative), ground coupling (slab-on-grade floor, overlap with Sec. 7)

Status:

- Technical work completed in 2001. ASHRAE site shows only a pdf, not sure if the software is still available.

- EnergyPlus simulation trials were conducted at the time and updated through 2014, see testing report.
- Analytical toolkit output files from that work are available.



Domestic Hot Water

Purpose: Water heating systems represent a significant component of building energy use (~10%). Tests for water heating systems are not currently covered by ASHRAE 140. This task will develop tests to compare the modeling of hot water storage, heating, and distribution. These will largely test the models in an isolated context (outside of the whole-building energy simulation). However, some test cases may highlight a basic energy balance in a zone containing a water heating system. Energy efficiency standards cover hot water systems and require tools conduct 140 tests, but there are no tests for hot water system calculations. This is a greater need in the context of residential buildings, but its relevance to commercial buildings is increasing due to the application of central heat pump water heaters.

Types of Tests:

- Various tank sizes (including tankless)
- Electric, Gas, and Heat Pump Water Heater
- Empirical tests based laboratory-grade
- Range of environmental conditions (simulating standby losses)
- Range of tests under a wide variety of draw scenarios.

Status:

- RESNET has some tests for modeling of water heating systems, but they are limited in scope. We could coordinate with SSPC 118 to help develop new tests.

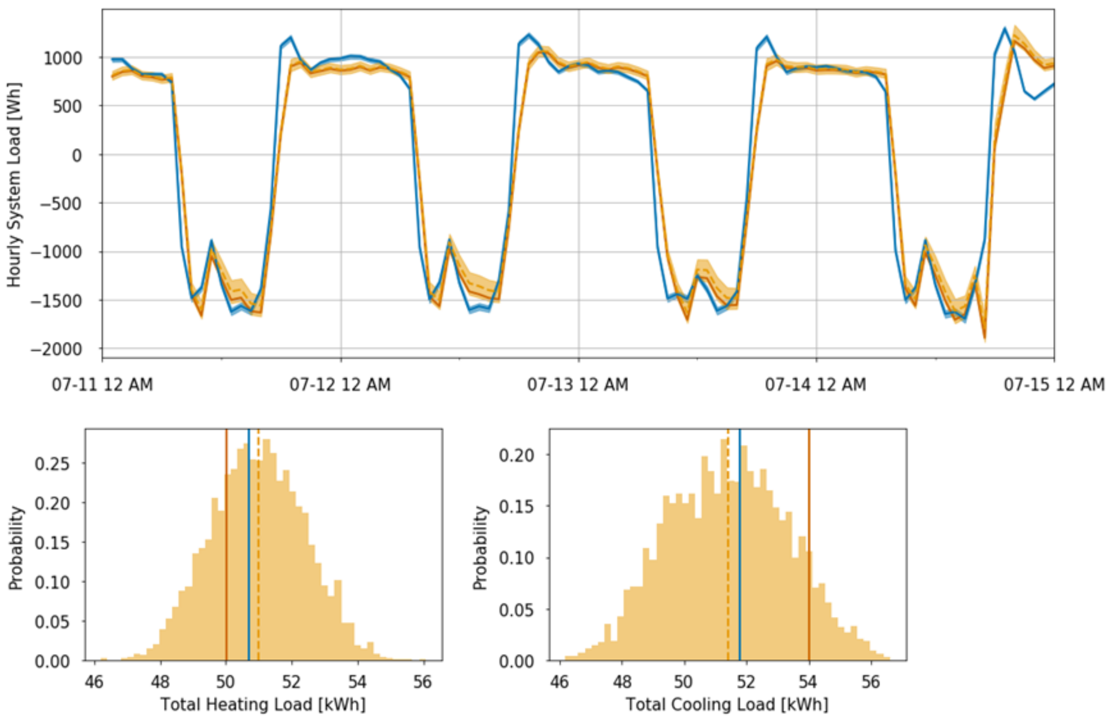
Empirical Test Set from LBNL Flexlab and ORNL FRP

Purpose: Create an empirical test set using data from LBNL Flexlab and ORNL FRP facilities. Previous attempts at empirical validation have used outdoor test facilities of varying complexity and had too much model input uncertainty to create definitive tests. The LBNL and ORNL facilities are facilities that provide well instrumented and well controlled versions of a small single zone commercial office space and a small multizone commercial building.

Tests:

- LBNL Flexlab: Single zone heating and cooling tests based on BESTEST 600, 640, 800VIG, 840VIG, and 940, a combination of high mass, low mass and with/without exterior windows.
- ORNL FRP: Multizone heating and cooling tests
- Possible Output Modeled vs Measured Tests:
  - Cumulative and hourly heating and cooling loads or energy use
  - Supply air flow rates and temperatures, room air temperatures

Status: Three years of experiments and comparisons have been completed. One more year of experiments planned to reduce uncertainties and correct for errors in some experiments. New metrics for comparing measurements to models including uncertainty have been developed.



Experimental results and models (including uncertainty) for a BESTEST 940 like case with high thermal mass and solar loading. Top plot is hourly data with heating being positive and bottom plots are cumulative heating and cooling loads.

Measured data are given by —, model without uncertainty is given by —, and model with uncertainty is given by ---.

Empirical Test Set from NREL Indoor/Outdoor Modular Apartment

Purpose: Create an empirical test set using an indoor/outdoor test building to better control model input uncertainty. Previous attempts at empirical validation have used outdoor test facilities of varying complexity and had too much model input uncertainty to create definitive tests. The NREL indoor/outdoor 380 ft2 modular apartment test building reduces model input uncertainty by allowing key input parameters to be empirically determined (indoors) via calorimetry and other test methods. Once the indoor input characterization tests are completed the building can be moved outdoors to create data sets against which simulation programs can be tested. The Golden, CO weather provides very strong climate signals providing favorable signal to noise ratios in the outdoor experiments.

Indoor Input Determination Tests:

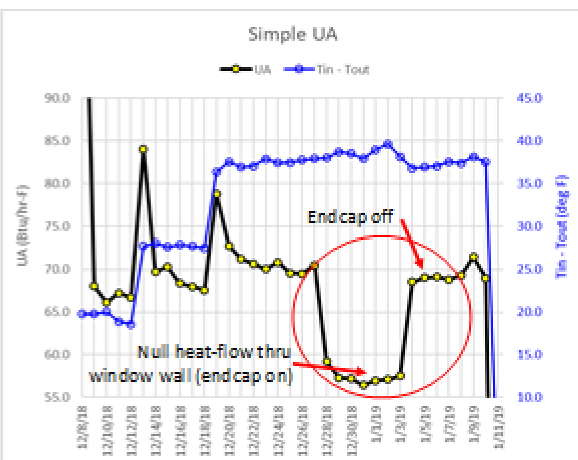
- UAo tests
- Tracer gas infiltration tests
- Blower door tests
- Duct blaster tests
- Heat capacitance tests
- In-situ equipment COP tests to determine COP curves

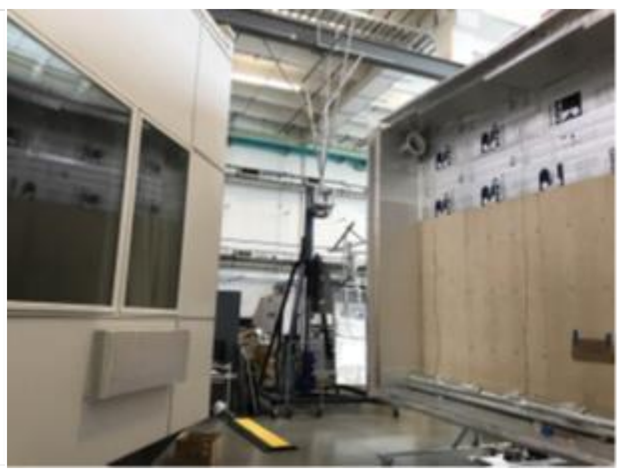
Output Modeled vs Measured Tests:

- Heating energy consumption at varying time intervals from sub hourly to > monthly
- Cooling energy consumption at varying time intervals from sub hourly to > monthly
- Measured temperatures vs model predicted temperatures

Status: Indoor testing complete and results being analyzed. Unit moved outdoors and being prepared for starting outdoor testing.

UA for All 6 sides and for Window wall **Endcap Detached from Test Building (Indoor Tests)**





ETNA BESTEST Empirical Validation

Purpose: Develop empirical validation test cases based on diagnostic framework of thermal fabric BESTEST cases of Std 140 Sections 5.2.1, 5.2.2, 5.2.3. These tests were run at the thermally guarded twin test cells of the Electricité de France (EdF) “ETNA” facility from 1999 to 2003. Test cells have removable south guard zone for artificial climate and natural climate tests. Heating system mimics well-mixed air assumption of simulations. A public-domain test specification (Jan 2004) is available on request from J. Neymark & Associates. Also see 2005 IBPSA conference paper http://www.ibpsa.org/proceedings/BS2005/BS05_0839_846.pdf.

Tests, Artificial climate (south wall enclosed):

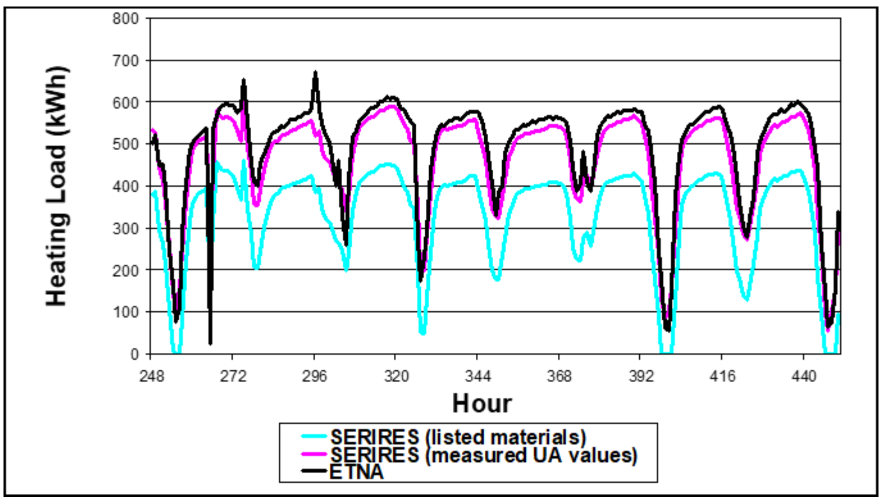
- *Test cell characterizations (empirical determination of inputs):* steady-state overall building heat loss coefficient and thermal conductance of individual walls, floor ceiling, and windows; internal thermal capacitance; interior convective surface coefficients; incident-angle dependent window optical transmittance.
- *Parametric variations:* outside air ventilation/infiltration, internal gains, heater type.

Tests, Natural climate (south wall exposed):

- dynamic thermal diffusion and solar gains; *parametric variations:* 0-solar gains, thermostat setback, thermal mass, heater type, interior surface convective coeff, and interactions of these.

Status:

- Data acquired as of 2004 (see "Purpose" above). Limited sims completed (see figure). *Figure shows importance of empirically determined inputs:* magenta line is sim with empirically determined U-values; cyan is with manufacturer properties.
- Project not completed due to research prioritization shift at EdF.
- Additional data *not* needed. Remaining analysis of *existing* data prior to sim trials needed, including: evaluate test cell thermal capacitance, interior surface convective coeffs, etc; preliminary simulation of all test cases.



Ground Coupling

Purpose: Expand on the existing ground coupled heat transfer tests to include a wider variety of foundation types, boundary conditions, and insulation configurations. The impact of ground coupled heat transfer on overall building loads is poorly understood because its long-time-scale and multi-dimensional nature has not been adequately represented in even the most complex whole-building simulation tools. These tests will be largely comparative, since empirical tests are difficult to frame within reasonable uncertainty.

Types of Tests:

- Slab-*on*-grade
- Basements and crawlspaces

- Real weather files (non-sinusoidal temperature variations)
- Time varying convection and radiation coefficients
- Interior/exterior, horizontal/vertical insulation configurations with varying insulation thickness
- In-slab radiant heating
- Tests integrating into whole-building energy simulation tools (with dynamic coupling between the zone and surrounding ground).

Status:

- Since the original IEA-BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-on-Grade Construction, there have been substantial developments, including proposed basement cases with insulation (Deru, 2003). Other potential verified numerical models have been developed (Kruis, 2015).

Multi-Zone Non-Airflow (MZ) Test Cases (IEA 34/43)

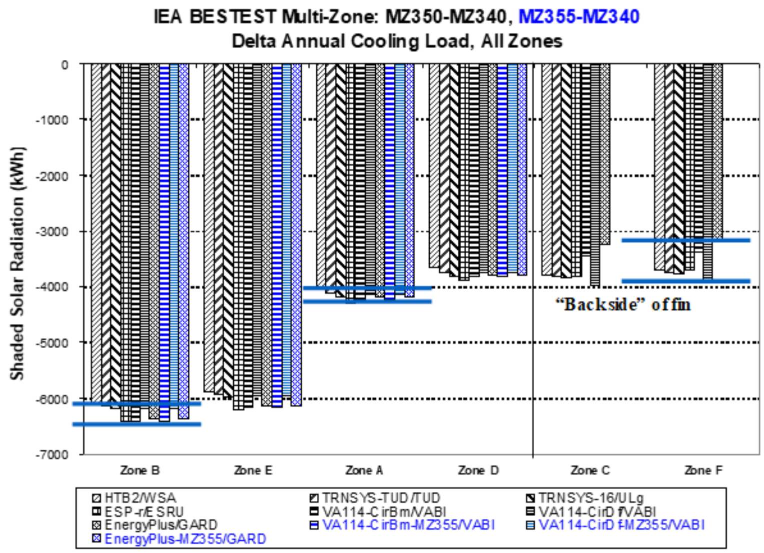
Purpose: Expand Standard 140's Section 5.2 thermal fabric test cases to include multi-zone tests, listed under "Tests" below; also see published NREL 2008 final report https://www.nrel.gov/docs/fy08osti/43827.pdf. These test cases have improved agreement for the shading cases versus the current Section 5 cases.

Tests:

- Three-Zone Steady-State Conduction Analytical Verification Test (MZ320)
- Multi-Zone Shading Tests: Unshaded Calorimeter Base Case (MZ340); Multi-Zone Fin Shading (MZ350); and Multi-Zone Automated Building Self-Shading (MZ355)
- Internal Window Calorimeter (MZ360)
- *[Possible new case?]: Shading devices that cause overlapping shading*

Status:

- Technical work completed with IEA 34/43 in 2008 (see example results in figure). Adaptation of Feb 2010 previously approved by SSPC 140 as addendum to 140-2007, but not completed because of changes to ASHRAE Standards language requirements in later 2010;
- HERS BESTEST, Ground-Coupled Slab, Airside HVAC, & Thermal Fabric addenda prioritized ahead.
- Updated or new results from Spring 2015 simulation trial (Thermal Fabric Pre Round #2); draft results not shown, mostly good agreement with 2008.
- Updated addendum needs: 1) further standards language revs; 2) check for consistency with 140-2017, e.g., numbering of sections, figures, tables, etc.; 3) include selected updated results from Spring 2015.



Standard 205 Performance Map Tests

Purpose: Standard 205 defines the format of manufacturer's performance data to be transmitted to BEM programs. The data will be supplied as performance maps of the complete performance envelope for the equipment. There could be multiple maps per piece of equipment representing different operation states or levels. BEM programs will need to properly read the Standard 205 files and interpret the performance data and performance states. Most programs will need to add n-dimensional interpolation routines or curve-fitting routines to make use of the performance data. At the edges of the performance map the BEM programs will need to solve for the performance point and decide if the equipment is able to operate at the conditions.

Types of Tests:

- Correct file reading
- N-dimensional interpolation or curve-fitting of performance data
- Determination of correct operational state
- Determination of On/Off state at the edges of the performance map

Status: Standard 205 had its first public review in the Spring of 2019. A parallel project to create a Standard 205 toolkit may simplify the required coding for BEM programs, but testing that the toolkit routines are properly applied would still be necessary.

Thermal Bridging

Purpose: Develop tests to compare calculation of multi-dimensional heat transfer through exterior building components. These tests can be tested in isolation (i.e., simulated hot-box performance with defined boundary conditions), and in the context of whole-building energy simulation (as part of the thermal fabric test suite). The tests will establish detailed verified numerical reference models similar to the ground coupling test cases. Individual tools may use whatever method is most appropriate for their level of detail including, dynamic numerical methods, pre-processed numerical results, or tabular lookup of point and linear thermal transmittance multipliers.

Types of Tests:

- Clear field assemblies (e.g., framing)
- Point thermal bridges (isolated protrusions)
- Linear thermal bridges (surface interfaces)

Status:

- Few tools have the capability to explicitly describe multi-dimensional heat transfer through surfaces. Currently thermal bridging is applied largely as a pre-process step resulting in "equivalent" one-dimensional layers. We can utilize the BC Hydro Building Envelope Thermal Bridging Guide v1.2 (2018) to determine a subset of cases to test.

Update HVAC BESTEST Performance Maps with Empirical Data

Purpose: Add empirically derived performance maps for high efficiency RTUs to HVAC BESTEST Volumes 1 and/or 2. The current HVAC BESTEST Volumes 1 and 2 (Standard 140-2017 section 5.3) address a very simple constant speed unitary split system and are based on a combination of measured and modeled data provided by manufacturers (Trane & Carrier). The current tests do not include the new generation of high efficiency variable equipment. The new tests would be based on performance map data collected by NREL and published in the DOE/NREL TPEX in FY18. These performance maps include a 5-ton SEER 17 RTU[1] and a 6-ton IEER 23 RTU[2], both with different degrees of fan and compressor variability. The measured performance maps include realistic part load conditions not available with the previous performance maps.

Possible Tests:

Most tests would be the same as those already in HVAC BESTEST Volumes 1 and 2. Some new tests might be added to explore the modeling of variable speed fans and compressors.

Status: Idea, Performance Map data has been collected. Tests would build off of the already completed HVAC BESTEST Volumes 1 and 2.

- Trane Precedent: Multi-stage scroll compressor, single speed condenser fan, direct drive variable supply air fan with hi efficiency motor, low leak dampers, hot gas re-heat humidity control, economizer.
- Trane Precedent eFlex: Variable speed everything, direct drive compressor

Weather-Driven Infiltration and Natural Ventilation

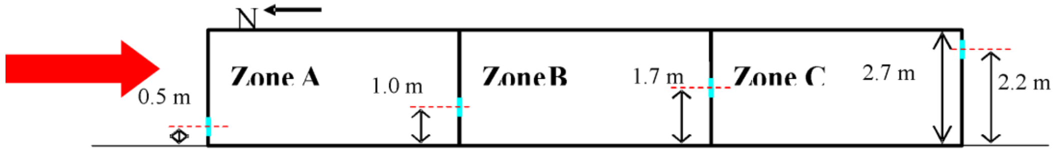
Purpose: Expand Standard 140's Section 5.2 thermal fabric test cases to include weather-driven infiltration tests. The current Section 5 tests specify ACH independent of weather conditions (constant for most cases, varying for 650 and 950). Cases are needed for testing that models can apply aperture, leakage, or crack area, etc., to accurately calculate an infiltration air flow rate as f(wind speed, ΔT, orientation).

Possible Tests:

- Steady-state and hourly-varying cases exercising "simplified" algorithms, including: Sherman-Grimsrud 1990 (see BESTEST-EX), Coblentz and Achenbach 1963, Walker and Wilson 1998, ACH = ACH50/20 (Sherman 1997, 1998), Judkoff 1991, etc.; compare to detailed models such as COMIS, CONTAM, TRNFLow, etc.
- See IEA 34/43 Japan (unpublished) airflow steady-state analytical verification tests.
- Test cases vary: wind speed, zone temperatures, outdoor temperature; separately and some combinations
    - Include mechanical fan with separate case
    - Single-zone tests with different aperture heights on windward and leeward sides,
    - Multi-zone tests with different aperture heights on windward and leeward sides, and inter-zone apertures.
- Include hourly-variation applying realistic weather to scope energy use impacts of tools' results differences

Status:

- Test cases can build off of IEA 34/43 Japan cases; see figure.
- Japan report compares 8 sim models with 2 analytical solutions.
- Originally intended as sensitivity tests for Thermal Fabric Update, but other base-case updates and sensitivity cases became higher priority; level of effort to develop these cases requires separate test suite.



Weather Drivers

Purpose: Test the BEM software's ability to read and interpret the weather file formats correctly. In most of the test suites we assume that all of the programs are correctly applying the data from the weather file in the simulation. This test suite would provide a check on whether the programs are correctly determining these program drivers, including data that occurs at different intervals in the data file (sum over the hour, instantaneous reading, etc).

Types of Tests:

- Temperatures, Humidities – interpolating instantaneous values
- Sub-hourly Solar Radiation – interpolating sum values
- Tilted-Surface Solar Radiation – determining radiation on walls and windows
- Southern Hemisphere – switching north and south
- Elevation – applying correct altitude corrections
- Time Zone – different (possibly fractional) time zone effects

Status: Just an idea at this point, but the tests could use Case 600 or Case 900 as the base case of the excursion tests.

Appendix B: Further Information on Test Suites (per request at Jan 2019 meeting)

Airside HVAC BESTEST Volume 2

- How does it improve the Standard
  - Adds more Airside HVAC tests, which build on the existing Volume 1 (steady-state) test cases applying more realistic weather drivers and operating conditions
  - Some of the idealistic operating conditions are difficult for some programs to apply and the new test cases can address those issues
- Test suite development level of effort and timing (Small/Medium/Large)
  - Medium
  - Some test cases will build from existing test cases with changes in operating conditions. Other test cases will need to be created from scratch.
- Number of programs that can currently apply the test
  - All of the programs that currently run Volume 1 should be able to run the new test cases and more realistic operating conditions should allow more programs to apply the tests.
- Does it help move the industry forward
  - Use of realistic annual hourly weather data allows scaling (assessment of importance to a typical simulation) of differences among programs in the Volume 1 analytical verification test cases.
- Impact Factor of the test suite (Narrow, Moderate, Broad)
  - Broad
  - The new test cases will expand the HVAC airside tests in the standard to include more realistic operating conditions that are more applicable to actual HVAC systems.

    - HVAC Air distribution systems are very common.

Analytical Building Fabric Tests - 1052-RP

- How does it improve the Standard
    - Adds analytical verification test cases for the building fabric.
    - The current building fabric test cases are all comparative tests, which do not have a mathematical truth standard.
- Test suite development level of effort and timing
    - Medium
    - Technical work for developing the test cases completed in ASHRAE research project in 2001.
- Number of programs that can currently apply the test
    - All programs perform the building fabric calculations. It is just a question of whether they have access to the necessary inputs and outputs.
- Does it help move the industry forward
    - Analytical tests would provide a clearer validation of the building physics algorithms than the comparison tests.
- Impact Factor of the test suite
    - Broad
    - Nearly all simulations require a building envelope.

Domestic Hot Water (DHW)

- How does it improve the Standard
    - The standard currently does not include any domestic hot water test cases.
- Test suite development level of effort and timing
    - Medium
    - The test cases would need to be developed from scratch, but could be based on existing DOE and/or RESNET test procedures.
- Number of programs that can currently apply the test
    - Most programs include DHW calculations, but whether they include the system detail necessary for the test cases is unclear.
- Does it help move the industry forward
    - DHW is covered by most energy standards that also reference Standard 140.
- Impact Factor of the test suite
    - Broad
    - DHW systems are very common (and account for ~10% of building energy according to Scout).

Empirical Test Set from LBNL Flexlab and ORNL FRP

- How does it improve the Standard
    - Adds empirical validation test for single-zone and multi-zone heating and cooling tests based on experimental data.
    - The standard currently has no empirical validation tests.
- Test suite development level of effort and timing
    - Large
    - Three years of experiments are complete and one more year of work is in progress to correct issues and concerns. Uncertainty analysis of the results is also in progress. Development of test specifications is a part of the project. The level of detail in the

building specifications is high and the influence of more simple inputs would need to be evaluated. In addition appropriate simulation input parameters will need to be developed based on the actual system parameters.

- Number of programs that can currently apply the test
  - All programs that currently apply the Standard 140 building fabric comparative test cases should be able to apply the empirical validation test cases if appropriate input parameters can be developed.
- Does it help move the industry forward
  - The addition of empirical test cases would address an area of criticism about Standard 140 in the industry.
- Impact Factor of the test suite
  - Broad
  - Empirical validation, if successful, Improves the credibility of the industry.
  - Very common aspects of modeling are tested.

Empirical Test Set from NREL Indoor/Outdoor Modular Apartment

- How does it improve the Standard
  - Add empirical thermal fabric test cases with reduced input uncertainty.
  - The Standard currently has no empirical tests.
  - The indoor tests allowed an in-situ performance map to be developed for the HVAC system thus allowing thermal load modeling to be disaggregated from HVAC modeling.
  - The indoor tests allowed the UA of the window wall and the window to be disaggregated from the UA for the entire building.
- Test suite development level of effort and timing
  - Large
  - Indoor measurements with controlled ambient conditions are completed. The apartment module has been moved outdoors and is being prepared for outdoor testing. Uncertainty analysis and specifications need to be completed and test cases implemented.
- Number of programs that can currently apply the test
  - With the well-defined input parameters from the indoor tests, more programs should be able to run the test cases, but this cannot be confirmed until the test case specifications are developed.
- Does it help move the industry forward
  - The addition of empirical test cases would address an area of criticism about Standard 140 in the industry. A highly controlled empirical thermal envelope experiment tests the most fundamental function of a BEM and is a good basic starting point for other more complex empirical validation tests. It follows the Standard 140/BESTEST methodology of starting simple and moving toward complexity in careful steps.
- Impact Factor of the test suite
  - Broad
  - Empirical validation, if successful, Improves the credibility of the industry.
  - Nearly all simulations require an adequate model of the building envelope.

ETNA BESTEST Empirical Validation – EdF(Fr)/JNA/NREL

- How does it improve the Standard
  - Adds empirical validation for thermal fabric models developed with thermally guarded twin test cells, BESTEST logic, and many empirically determined inputs.

    - The standard currently has no empirical test cases.
- Test suite development level of effort and timing
    - Medium to Large
    - Preliminary public-domain test spec exists with full data set.
    - Evaluation of experimentally determined input parameters related to walls, floor, and ceiling conductance along with preliminary simulations was completed.
    - Further analysis of the data and full simulations were not completed because of a shift in the original sponsor's institutional research priorities.
    - Further analysis of the existing measured data needs to be completed to determine the correct input parameters for characterizing thermal capacitance and surface coefficients in the test specification; this does not require additional data collection.
- Number of programs that can currently apply the test
    - Experiments were based on existing comparative tests; all programs that can currently run those test cases should be able to apply the new empirical validation test cases.
- Does it help move the industry forward
    - The addition of empirical test cases would address an area of criticism about Standard 140 in the industry.
    - Larger number of empirically determined inputs can provide uncertainty benchmark.
- Impact Factor of the test suite
    - Broad
    - Empirical validation, if successful, Improves the credibility of the industry.
    - Nearly all simulations require a building envelope.

Ground Coupling (expand Section 5.2.4)

- How does it improve the Standard
    - Expands on the existing ground coupled heat transfer analytical-verification tests to include a wider variety of foundation types, boundary conditions, and insulation configurations; including slab-*on*-grade, basements and crawlspaces, in-slab radiant heating, etc.
    - The current ground coupling test cases are idealized/simplified and not realistic.
- Test suite development level of effort and timing
    - Medium
    - Test cases would need to be developed from the existing test cases and NREL report. Typical foundation and basement configurations are well defined, but test cases for the configurations would need to the developed.
- Number of programs that can currently apply the test
    - There are a handful of detailed ground coupling models connected to building energy modelling software programs.
- Does it help move the industry forward
    - Ground coupled heat transfer is still an underestimated building energy phenomenon due to lack of analysis capabilities.
- Impact Factor of the test suite
    - Moderate
    - Ground coupling is more significant for low-rise buildings, though this will impact virtually all buildings.
    - Increases confidence in the ground coupling algorithms in the software.

Multi-Zone Non-Airflow (MZ) Test Suite – IEA34-43/NREL

- How does it improve the Standard

    - Adds multi-zone building calculations to the existing single-zone thermal fabric tests, including multi-zone shading, thermal diffusion, and internal windows.
- Test suite development level of effort and timing
    - Small
    - Draft addendum completed in 2010 would need to be updated to match current standard and some results updated.
- Number of programs that can currently apply the test
    - Programs currently applying the building fabric tests should be able to complete the multi-zone test cases.
- Does it help move the industry forward
    - Currently multi-zone effects of the MZ test suite are not tested by the standard.
- Impact Factor of the test suite
    - Broad
    - Most building analyses are multi-zone buildings and these test cases would add more multi-zone effects to the standard.

Standard 205 Performance Map Tests

- How does it improve the Standard
    - Adds tests specifically for reading and interpreting Standard 205 compliant performance maps
- Test suite development level of effort and timing
    - Large
    - Standard 205 had its first public review in the Spring of 2019 -- comment resolution is in progress -- and a software toolkit is under development. The test cases should evolve from the development of the Standard 205 software toolkit.
- Number of programs that can currently apply the test
    - Many programs will need to reprogram their codes to deal with the new performance maps.
- Does it help move the industry forward
    - If Standard 205 is adopted by the manufacturers and software developers, it will change how HVAC equipment is modeled in the software.
    - These tests would lend confidence that programs correctly apply the performance maps.
- Impact Factor of the test suite
    - Broad
    - HVAC equipment systems are very common.

Thermal Bridging (2-D/3-D Conduction)

- How does it improve the Standard
    - Tests of reliability of 1-D approximations of 2-D and 3-D conduction.
    - All results for above-grade thermal fabric conduction heat transfer processes currently in the standard apply 1-D conduction. Programs generating these results apply 1-D approximations for 2-D and 3-D effects.
- Test suite development level of effort and timing
    - Medium
    - Test cases could be derived from BC Hydro Building Envelope Thermal Bridging Guide.
    - Since most software does not model 2-D/3-D effects, the verified numerical solutions would need to be developed for comparison sake.
- Number of programs that can currently apply the test

    - Programs currently do not directly model 2-D/3-D conduction for above-grade thermal fabric elements, so the tests would be evaluating the 1-D approximation methods.
- Does it help move the industry forward
    - Often 2-D/3-D conduction effects are ignored or 1-D approximations applied. These test cases would test the effectiveness of the approximations.
- Impact Factor of the test suite
    - Moderate
    - 2-D/3-D conduction effects are important in real buildings but not handled by the software.

Update HVAC BESTEST Performance Maps with Empirical Data

- How does it improve the Standard
    - Replaces the existing full-load performance map based on limited and outdated manufacturer data with a more complete empirically determined modern performance map
    - More detailed part-load performance data
    - Revised test cases to eliminate required limited extrapolation.
- Test suite development level of effort and timing
    - Medium
    - Straightforward effort for SEER-17 map, concept development needed to use IEER-23 map.
    - The development of the empirically determined performance maps is complete.
    - Existing test cases may be used with the new data, possibly adding more test cases.
- Number of programs that can currently apply the test
    - All that can run current CE tests.
- Does it help move the industry forward
    - Updating test suites originally published in 2002 and 2004 to keep pace with changes to the state of the art in mechanical equipment make the standard more credible.
- Impact Factor of the test suite
    - Broad
    - Packaged DX equipment is very common.

Weather-Driven Infiltration and Natural Ventilation

- How does it improve the Standard
  - Adds tests for determination of infiltration and natural ventilation airflow rates and related building loads based on the weather.
  - Currently infiltration rates in the standard are constant or scheduled and not based on the weather.
- Test suite development level of effort and timing
  - Medium
  - Test cases could be developed starting from the IEA 34/43 Japan cases. Parameters for multiple simplified infiltration models would need to be provided.
- Number of programs that can currently apply the test
  - Most programs include simplified methods for infiltration or bulk air flow models that could apply the test cases given appropriate input parameters.
- Does it help move the industry forward
  - Currently infiltration rates in the standard are constant or time-varying and not based on the weather. Applying weather-driven infiltration tests in Standard 140 would address a commonly modeled area that is not currently tested.
- Impact Factor of the test suite
  - Broad
  - Weather driven infiltration occurs in all buildings.

Weather Drivers

- How does it improve the Standard
  - Adds tests to check whether the programs are correctly determining program drivers, including data that occurs at different intervals in the data file (sum over the hour, instantaneous reading, etc.), such as temperatures and humidities that are interpolated from instantaneous values, solar radiation that is interpolated from hourly totals, tilted surface solar radiation, and weather files from different hemispheres, elevations, and time-zones.
  - Except for global horizontal solar radiation, the standard currently assumes the programs correctly interpret the data in the weather files. These cases would test all other weather data interpretation assumptions
- Test suite development level of effort and timing
  - Small
  - The test cases do not exist but could be based on excursion from existing case 600 set-ups. The concepts are basic and would add test cases for basic driving forces in simulations.
- Number of programs that can currently apply the test
  - All programs currently use and interpret weather files. Though not all programs allow for the output of those values.
- Does it help move the industry forward
  - If the programs are not correctly interpreting the weather files then all of their results are suspect.
- Impact Factor of the test suite
  - Broad
  - Weather data is required for all simulations.