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TWENTY YEARS ON!: UPDATING THE IEA BESTEST BUILDING THERMAL FABRIC TEST CASES FOR ASHRAE STANDARD 140

R. Judkoff[1] and J. Neymark[2]

[1]National Renewable Energy Laboratory, Golden, Colorado, U.S.
[2]J. Neymark & Associates, Golden, Colorado, U.S.

ABSTRACT

ANSI/ASHRAE Standard 140, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* applies the IEA BESTEST building thermal fabric test cases and example simulation results originally published in 1995. These software accuracy test cases and their example simulation results, which comprise the first test suite adapted for the initial 2001 version of Standard 140, are approaching their 20th anniversary. In response to the evolution of the state of the art in building thermal fabric modeling since the test cases and example simulation results were developed, work is commencing to update the normative test specification and the informative example results.

INTRODUCTION

Background: The Building Energy Simulation Test and Diagnostic Method (BESTEST) and ANSI/ASHRAE Standard 140

Modern whole-building energy simulation software may contain on the order of a half million lines of code. It is therefore helpful to develop testing and diagnostic methods that identify errors and indicate where in the code those errors reside to facilitate corrections.

The National Renewable Energy Laboratory (NREL), in collaboration with the International Energy Agency (IEA), has developed a number of building energy simulation test (BESTEST) suites for evaluating and diagnosing errors in software used for energy analysis of commercial and residential buildings. ASHRAE Standard 140, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (ANSI/ASHRAE 2011), has adopted five BESTEST suites for testing a variety of building thermal fabric and mechanical HVAC system modeling features. The theoretical basis for the BESTEST procedures is described in the literature (ASHRAE 2009, Judkoff 1988, Judkoff et al. 2008, Judkoff and Neymark 2006, 2009). This literature also describes how software-to-software comparative tests, such as IEA BESTEST, may be applied in conjunction with other analytical verification and empirical validation tests.

IEA BESTEST (Judkoff and Neymark 1995a) is the foundation for Standard 140's building thermal fabric test cases, beginning with the initial version published in 2001. This founding test suite has been carried forward with no substantive revisions through to the current version, Standard 140-2011.

IEA BESTEST was developed in the early 1990s. Work on the IEA BESTEST example results was completed in 1993, and some final input files go back to 1992. The example results are therefore now 20 years old. All versions of the programs used for generating the example results have been obsolete for some time, and some of the programs are no longer supported. Software developers on the ASHRAE Standard 140 project committee therefore support a maintenance upgrade to the Standard 140 Class I building thermal fabric test (IEA BESTEST) example results. Such an upgrade also provides an opportunity to update the test specification to address advances in the state of the art of building energy modeling, and this work is commencing.

This paper provides:

- A review of the history of the application of the IEA BESTEST building thermal fabric test cases
- The currently published Standard 140/IEA BESTEST building thermal fabric test cases
- A summary of relevant advances in the building thermal fabric modeling state of the art, and an initial listing of potential improvements to consider for the building thermal fabric test suite
- The proposed process for revising the test specification, conducting simulation trials, and adapting the updated test suite for Standard 140.

Industry Use of Standard 140 and IEA BESTEST

Many entities have adopted or cited Standard 140 and/or the component BESTEST suites. The impact of the work is apparent from the following:

- ASHRAE lists Standard 140-2011 ASHRAE as its 7th most popular document of 130 current Standards and Guidelines (ASHRAE 2013).
- Standard 140 is referenced by:
  - ASHRAE building energy efficiency Standards 90.1 and 189.1 (ANSI/ASHRAE/IESNA 2010, ANSI/ASHRAE 2009)
  - The U.S. tax code for certifying software used to evaluate building energy efficiency tax credits for commercial and residential buildings (IRS 2008a, 2008b); 12 building energy simulation programs are listed as qualified software for

  commercial buildings, and 5 programs are listed for residential buildings. (U.S. DOE 2013, IRS 2008b)
  - International Energy Conservation and International Green Construction Codes (IECC 2012)
  - State and federal agencies (California Energy Commission, Florida Building Commission, National Weatherization Program, etc.)
  - The newly developing COMNet User's Manual, which may also provide the basis for ASHRAE's proposed "Building Energy Quotient" building rating system (Eley 2011)
  - *2009 ASHRAE Handbook of Fundamentals,* Chapter 19, validation section (ASHRAE 2009).
- Several European Union countries, as part of the building energy performance assessments under the European Community's Energy Performance Directive (European Union 2002), use software tools that have been checked with IEA BESTEST.
- The Committee for European Normes used IEA BESTEST to check its reference cooling load calculation general criteria.
- Australia and New Zealand reference IEA BESTEST in their codes and standards.
- Researchers have translated BESTEST procedures into Dutch, German, and Japanese.
- A study comparing 20 whole-building energy simulation tools (Crawley et al. 2005) indicated that 19 of the 20 tools reviewed had been tested with at least one IEA BESTEST procedure.
- Major international commercial equipment providers such as Carrier Corp. (HAP) and Trane Company (TRACE) are using BESTEST/Standard 140 for testing their software.
- Many BESTEST suites have been directly integrated within ESP-r (an advanced simulation tool developed by the University of Strathclyde, and well known in Europe and Canada) for automated testing of revisions to the software.
- EnergyPlus, the U.S. Department of Energy's most advanced building energy simulation program, maintains its Standard 140 results on a web site.
- Standard 140 is listed as a preparation resource for ASHRAE's Building Energy Modeling Professional (BEMP) certification exam.
- The recently published International Building Performance Simulation Association Building Simulation proceedings includes 392 papers, 24 of which cite BESTEST and/or Standard 140 (IBPSA 2011).

Further discussion and supporting references are included elsewhere (Judkoff and Neymark 2006).

Current Building Thermal Fabric Test Cases

Current IEA BESTEST building thermal fabric test cases originally published by NREL in 1995 (Judkoff and Neymark 1995a, ANSI/ASHRAE 2011) test the ability to model the thermal physics related to many typical building features. A series of buildings are specified that proceed from the thermally simple to the realistic approximately one parameter at a time. The cases are defined so that thermal properties, geometric proportions, and thermal responses are meaningful in terms of actual envelope load-dominated buildings.

Figure 1 shows the basic building geometry, which remains similar for all cases with minimal changes.

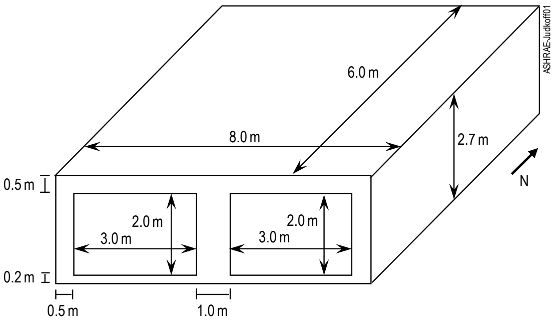

Figure 1. Base building: south windows, unshaded (Judkoff and Neymark 1995a, ANSI/ASHRAE 2011)

There are 39 test cases organized into a basic series and an in-depth series. Table 1 provides a partial list of the test cases (395 through 960). The basic series (Cases 600 through 650 and 900 through 960) is relatively realistic and was defined to test such features as thermal mass, direct gain windows, window shading, window orientation, internal gains sunspaces, night ventilation, and dead-band and setback thermostat control. Sensitivity to thermal mass is assessed under a number of parametric variations where overall heat transmission coefficient is equivalent in the heavy and lightweight cases. Cases were not defined that required simulation of mechanical systems. The equipment was assumed 100% efficient and adequately sized to meet peak loads. The in-depth series cases 195 through 320 (not shown in Table 1) are more primitive and are designed to provide excitation of a particular heat transfer mechanism or path while suppressing signals from other mechanisms or paths. These diagnostics minimize interacting effects. The in-depth series cases 395 through 440, 800, and 810 were developed because not all programs can model cases 195 through 320. For example, cases 195 through 215 require suppression of infrared radiation, and not all programs allow explicit control of this effect.

Input Equivalency

The test cases are specified such that equivalent input files could be defined for a variety of detailed and simplified building energy simulation tools. Input equivalence is not always a straightforward concept, especially where the modeling approach varies significantly between codes. Even if all specification ambiguities and input errors are eliminated, legitimate differences in interpretation can lead to significant differences in simulation results. To minimize interpretive problems, input information was provided at several levels of physical detail.

Example results are provided for the tested programs with Informative Annex B8 of Standard 140. These include the results for each test case and parametric sensitivity results (shown as differences between selected cases). An example of the 600-series annual heating load results is shown in Figure 2. These results indicate a fairly wide range of disagreement among programs. We are interested to see how this range of disagreement may change for the updated test suite and example results.

Table 1. BESTEST Cases 395-960 (Judkoff and Neymark 1995a, ANSI/ASHRAE 2011)

See Note 1	SETPOINTS				OPAQUE SURFACE		OPAQUE SURFACE				
CASE #	(c) H ,C ,V	MASS	(w) INTGEN	ACH INFILTR	INT IR EMISSIV	EXT IR EMISSIV	INT SW ABSORPT	EXT SW ABSORPT	(m2) GLASS	ORIENT	(m) SHADE
395	20,27	L	0	0	.9	.9	NA	.1	See Notes 2, 3	S	no
400	20,27	L	0	0	.9	.9	NA	.1	0	S	no
410	20,27	L	0	.5	.9	.9	NA	.1	0	S	no
420	20,27	L	200	.5	.9	.9	NA	.1	0	S	no
430	20,27	L	200	.5	.9	.9	NA	.6	0	S	no
440	20,27	L	200	.5	.9	.9	.1	.6	12	S	no
600	20,27	L	200	.5	.9	.9	.6	.6	12	S	no
610	20,27	L	200	.5	.9	.9	.6	.6	12	S	1.0mH
620	20,27	L	200	.5	.9	.9	.6	.6	6,6	E,W	no
630	20,27	L	200	.5	.9	.9	.6	.6	6,6	E,W	1.0mHV
640	SETBACK	L	200	.5	.9	.9	.6	.6	12	S	no
650	27,V	L	200	.5	.9	.9	.6	.6	12	S	no
800	20,27	H	200	.5	.9	.9	NA	.6	0	S	no
810	20,27	H	200	.5	.9	.9	.1	.6	12	S	no
900	20,27	H	200	.5	.9	.9	.6	.6	12	S	no
910	20,27	H	200	.5	.9	.9	.6	.6	12	S	1.0mH
920	20,27	H	200	.5	.9	.9	.6	.6	6,6	E,W	no
930	20,27	H	200	.5	.9	.9	.6	.6	6,6	E,W	1.0mHV
940	SETBACK	H	200	.5	.9	.9	.6	.6	12	S	no
950	27,V	H	200	.5	.9	.9	.6	.6	12	S	no
960	2ZONE SS	SEE SPECIFICATION IN TEXT (ASHRAE 2011, Section 5.2.2.2.7)									

Note1:TITLES: H=Heating,C=Cooling,V=Venting/L=Lightweight,H=Heavyweight
INTGEN 200 means a constant heat input of 200W (60% radiant, 40% convective)
ACH INFILTR=Air Changes per Hour Infiltration/INT=Interior,EXT=Exterior,EMISSIV=Emissivity
SW=ShortWave, ABSORPT=Absorptivity/ORIENT=Orientation,S=South,EW=East&West
SHADE=Window shading device, 1.0mH=1meter deep Horizontal shade
HV=combination Horizontal & Vertical shade

Note2: Cases with 0 glass area (except case 395) have a "High Conductance Wall" in place of the window and with same area as the window. See ASHRAE (2011), Annex B1 for details.
Note3: Case 395 has neither a window, nor an "opaque window". It consists of 100% normally insulated wall

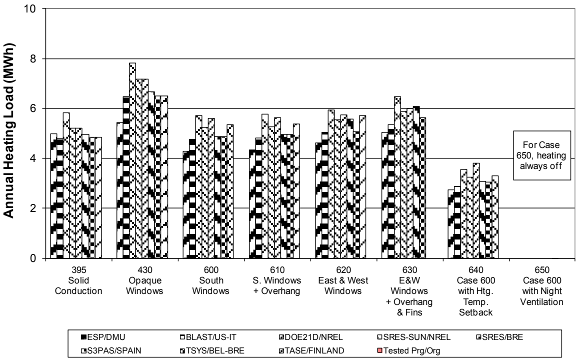

Figure 2. Low mass annual heating loads (Judkoff and Neymark 1995a, ANSI/ASHRAE 2011)

TEST SPEC DEVELOPMENT PROCESS

Philosophy of Test Case Revisions

In opening up the test suite for changes, we want to integrate improvements in the state of the art of modeling during the past 20 years. Simultaneously, we must maintain the original kernel of fundamental diagnostic capability, as this functionality has facilitated the isolation of many software errors over the years. This implies integrating revisions and constraining the work to maintain as much of the original framework as possible for the base case and parametric sensitivity tests. Other advantages of adhering to the original framework are:

- The current parsimonious approach reduces the probability of specification and input errors.
- It simplifies development of input files for software developers who have already run the previous version of the test cases.
- It facilitates sensitivity tests of various changes to the test specification during spec development.
- It simplifies adaptation of the spec for Standard 140.

The overall process of identifying potential test suite revisions follows:

- Identify advancements in the state of the art of modeling not covered by the current cases.
- Examine procedures developed by others to diagnose differences in software predictions initially found by applying BESTEST or other comparative tests, which go beyond the diagnostic capability of the current test cases.
- Identify other revision ideas.
- Present ideas to the simulation trial participants, and prioritize implementation based on a consensus process.

The following section provides an initial set of revisions to consider. More revision ideas may arise for consideration as we proceed with the simulation trial process.

Advancements Specified in BESTEST-EX

During the development of BESTEST-EX (Judkoff et al. 2011), a number of improvements were made versus the original HERS BESTEST (Judkoff and Neymark 1995b) cases. These improvements include:

Weather Data

Current weather data are in TMY format, which is obsolete and applies solar time rather than standard time, requiring data rebinning for accurate use. We will review newer formats, including TMY2, TMY3, and other formats and select an appropriate format based on industry consensus.

Surface Heat Transfer Coefficients

Surface coefficients define the heat and mass transfer from building surfaces to exterior and interior air. They substantially affect the calculation of steady-state conduction through windows and uninsulated opaque surfaces, insulated opaque surfaces exposed to direct sunlight, thermal storage dynamics for all surfaces, thermostat operation, etc. Current test cases allow automated calculation of surface coefficients and define default values for combined (convective and radiative) coefficients to accommodate software that does not contain more sophisticated dynamic modeling of surface transfer.

For **exterior surface coefficients,** current test case default values are based on applying a second-order polynomial in wind speed, where wind speed is taken directly from the weather data and polynomial coefficients vary depending on surface roughness. For BESTEST-EX default values, the same polynomial equation is applied, but the effective wind speed is adjusted based on the average height of the given surface above the ground, and by applying an appropriate terrain class. Table 2 indicates variation of default combined exterior coefficients for BESTEST-EX versus HERS BESTEST (which also applied the earlier algorithm). Additional work may be needed to refine the BESTEST-EX coefficients.

For **interior surface coefficients,** current test case default values are based on the *ASHRAE Handbook of Fundamentals* (2009). For BESTEST-EX default values, a more detailed algorithm is applied for the convective portion of the surface coefficient. Table 3 indicates resulting variation of combined surface coefficients for BESTEST-EX ("B-EX-1") versus HERS BESTEST ("HERS"), which also applied the earlier algorithm. Appendix C of BESTEST-EX indicates further refined values (see "B-EX-2" values in Table 3), which could not be implemented for BESTEST-EX because of time constraints. Additional work is needed to confirm updated default values for combined interior surface coefficients.

Reduced values of exterior and interior surface coefficients for BESTEST-EX indicate that example simulation results applying default surface coefficients specified in earlier test cases (e.g., for SERIRES [now SUNREL] and SUNCODE) have some input bias error that may be correctable. For example, for the BESTEST-EX base case inefficient building versus the original comparable test case of HERS BESTEST, the listed changes to surface coefficients cause a decrease in UA value of 26% for windows, 5% for exterior walls, 8% for doors, and 2% for composite ceiling/roof. This comprises a 14% decrease in the combined UA value of these surfaces.

Table 2 Default Exterior Surface Coefficients: BESTEST-EX versus HERS BESTEST

Surface	**BESTEST-EX** (W/(m^2 K))	**HERS BESTEST** (W/(m^2 K))
Windows	14.8	24.2
Exterior Walls	20.6	32.6
Roof/Gables	22.5	32.6
Raised Floor	12.5	12.5

Table 3 Default Interior Surface Coefficients: BESTEST-EX versus HERS BESTEST

Surface (W/(m^2 K))	**B-EX-1**	**B-EX-2**	**HERS**
Vertical Opaque	6.89		8.29
Vertical Clear Glass	6.33	6.62	8.29
Vertical Low-e Glass	6.08	6.31	7.57
Horizontal Opaque	6.60		7.42

Weather-Driven Infiltration

Current test cases specify a constant infiltration rate. BESTEST-EX allows testing of weather-driven infiltration models by specifying the airflow rate at 50 Pa depressurization (a typical blower door measurement). Equivalent inputs for air changes per hour at 50 Pa, equivalent leakage area at 50 Pa, and effective leakage area at 4 Pa are also provided. Equivalent seasonal constant infiltration rate is provided as well. Appendix D of BESTEST-EX provides supporting documentation for the various conversions, applying Sherman and Grimsrud (1980) and ASHRAE (2009), and describes appropriate terrain and shelter class specifications. Additional details we may consider when applying weather-driven infiltration to the test suite include:

- Determining appropriate levels of infiltration for the test cases, e.g., should we set up parameters to match current infiltration levels for basic and in-depth cases?
- Adding a sensitivity test with 0.5 x base leakage area (in addition to 0 infiltration [Case 400]).
- Should we add a blower door test series at various pressurization and depressurization pressure differences (required for the original unsimplified Sherman and Grimsrud model)?

- Should we define the leakage percentages specific to vertical and horizontal surfaces (required for the original unsimplified Sherman and Grimsrud model)?

Additional research may be needed regarding appropriate stack and wind coefficients, and terrain types and shelter classes.

Windows

Current test cases apply a clear double-pane window, and do not have a sensitivity test for varying window type. BESTEST-EX applies a single-pane window with thermal break for its base case, and provides a sensitivity test for varying to a low-e window. We may consider including a window-type sensitivity test in a more diagnostic context, and if yes, consider going to a single-pane window (without or with thermal break) in the base case.

The current test cases applied WINDOW 4.0 for developing detailed equivalent inputs. BESTEST-EX applies WINDOW 5. For BESTEST-EX versus HERS BESTEST, variation of angle dependent optical properties evaluated with WINDOW 5 versus WINDOW 4.1 are on the order of 0.1% for transmittance, and 1% for reflectance, absorptance, and solar heat gain coefficient. WINDOW 6 (2012) has recently become available, and can be applied.

Other Revisions to Consider

Wind Speed Sensitivity

Weather-driven infiltration and exterior surface coefficients are sensitive to wind speed, so we can consider a sensitivity test for varying the wind speed in the weather data.

Exterior Shading

Example results for the current cases indicate a relatively wide range of sensitivities to shading (see Figure 3). We developed enhanced shading diagnostic cases, which led to improvement of most of the programs that participated in the simulation trials (see Figure 4). (Neymark et al. 2011) These test cases are being adapted for Standard 140. As part of the example results development, we plan to require all tested programs to run the multi-zone shading cases, and correct any errors found there.

Replace High R-Value Floor with Suspended Floor

We continue to exclude ground-coupled heat transfer tests from the IEA BESTEST update because a separate BESTEST analytical verification test suite addressing ground coupling is available (Neymark et al. 2009). Current test cases apply a highly insulated floor (25 m^2K/W) to decouple the building from the ground. BESTEST-EX and HERS BESTEST accomplish decoupling by suspending the floor above the ground. An ideal suspended building takes ground modeling out of the problem; however, we need to determine that enough models can address this configuration. Another advantage is that minor differences in results that may be caused by limitations in the amount of insulation between the floor and the ground allowed by a model are avoided. A disadvantage is that differences caused by automated calculation of exterior surface coefficients may increase.

Exterior and Interior Short- and Long-Wave Absorptance/Emittance

For the current basic cases, exterior shortwave absorptance = 0.6. We can consider raising this value to 0.8 or 0.9 for sensitivity tests; we can also consider lowering the absorptance = “off” value from 0.1 to 0.01 or 0. We may also consider lowering the “off” value for interior shortwave absorptance and for interior and infrared emittances.

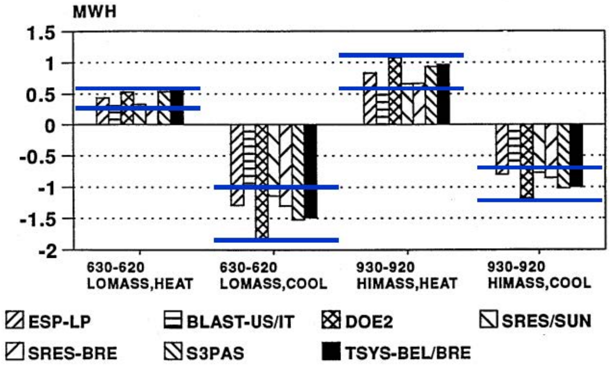

Figure 3 IEA BESTEST single-zone east- and west-shaded window delta sensitivity, annual heating and sensible cooling loads (Judkoff and Neymark 1995a)

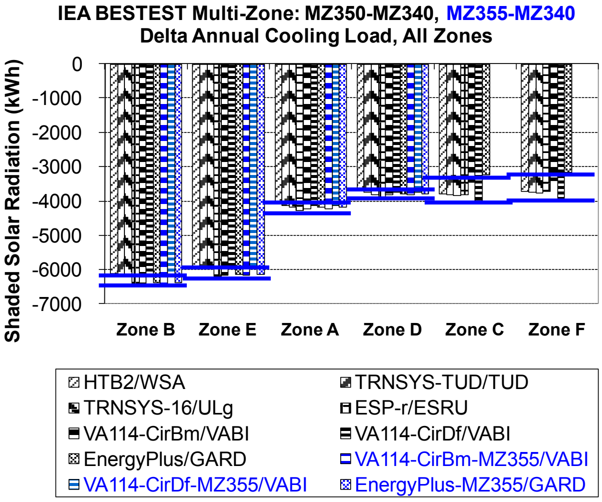

Figure 4 In-depth diagnostic multi-zone delta sensible cooling loads (Neymark et al. 2011)

Uninsulated Wall/Roof Sensitivity

Current diagnostic test cases do not vary wall or roof insulation. (HERS BESTEST and BESTEST-EX include variations of insulation levels.) The physics of convective heat transfer in an empty cavity is a challenging modeling problem, and adding a diagnostic test case for that may be worthwhile, especially for retrofit audit software. To accomplish an empty wall-cavity test case in the context of the ideal "shoebox" configuration of Figure 1, we also must consider if tools can model an ideally wide air gap without regularly spaced structural members. Also, is there any fundamental modeling interaction context (between other physical aspects of the building model) that justifies adding such a test case? For example, is there any thermal mass and/or solar gains interaction difference for an insulated versus an uninsulated wall?

Dynamic Internal Gains

Currently dynamics related to internal gains are addressed by solar radiation dynamics, which involve a series of calculations to convert ambient solar radiation provided in the weather data to internal gains in the building. This induces some noise because of legitimate solar radiation model differences. We may consider if there is value to applying a more direct dynamic internal gains variation in a 0-window configuration.

We may also consider the value of varying the ratio of convective to radiative gain from a given source.

General Parametric Sensitivities

Questions to address as we proceed through the simulation trials include:

- Can cleaner diagnostic sensitivity tests be provided?
- Can redundancies among the basic and in-depth sensitivity tests be eliminated?

As we proceed through the simulation trials, we plan to identify which sensitivity results have the largest substantial ranges of disagreement, and determine whether further diagnostics can be developed to address a given issue.

"Universal" Building Description Languages

There has been progress on programming languages designed to be universally accessible for developing descriptions of buildings and their mechanical systems. An advantage of this is facilitation of the transfer of input and output data among a variety of tools. However, achieving interoperability with a wide variety of modeling capabilities and input schemes is challenging. As part of the project, we plan to consider providing an equivalent version of the test spec in gbXML (2013). This is a task to consider toward the middle to end of the simulation trial process, after physical details of the test spec revisions are complete (or nearly so).

Recent Relevant Work by Others

The authors have cursorily reviewed the following reports and papers.

- Zhu et al. (2012) varied configurations of cases 195 and 600 to diagnose differences among tested software. They also created additional customized cases to test dynamic single- and multi-zone heat balances.
- Kruis et al. (2012) described customized comparative testing of window heating load calculations.
- Nouidui et al. (2012) described customized comparative testing and empirical validation of window models.

As the project proceeds, we will more carefully review these and other publications to help identify other diagnostic tests.

Simulation Trials and Standard 140 Adaptation

An iterative process of test specification development is applied. Such a process includes:

- Revising the test specification
- Obtaining and analyzing internal model and industry model results, and obtaining feedback on the test spec
- Further improving the test spec as needed
- Allowing modelers to correct modeling errors, and to document corrections.

The process is repeated until we have eliminated ambiguity in the test specification and readily correctable errors in the modeling. After completing the primary technical work, we will adapt the test specification, example results, and supporting material for inclusion with ASHRAE Standard 140.

Potential Value of Collaboration with IEA

A major part of this work is to conduct simulation trials for developing an updated set of example results that represent the current state of the art in building energy modeling. To represent the greatest array of detailed modeling approaches, it is important to include as many major internationally developed modeling tools as possible in the simulation trials—in addition to the major U.S. and Canadian tools represented in ASHRAE SSPC 140. IEA provides an established vehicle for international collaboration, maximizing software developer participation in simulation trials, and had an important role in the development of the BESTEST procedures. IEA also provides a means for leveraging domestic funding on mutually beneficial projects. For example, our most recent work with IEA allowed us to leverage our resources by about 2:1 (Judkoff 2007).

Historically, NREL and IEA maintained a validation effort related to building energy simulation software, beginning with Energy Conservation in Buildings and Community Systems (ECBCS) Programme Annex 1, which ran from 1977 to 1980, through a series of projects nominally ending in 2007 (Judkoff and Neymark 2009). The work to develop the original IEA BESTEST was completed under SHC Task 12/ECBCS Annex 21. Three test suites for mechanical equipment models that comprise the remaining Class I tests of Standard 140 were developed under subsequent IEA SHC Task 22. Two more specialized building thermal fabric test suites developed under IEA SHC Task 34/ECBCS Annex 43 are in various stages of adaptation for Standard

140 (Neymark et al. 2009, 2011). The diversity of feedback provided by the simulation trial participants during test suite development, along with documentation of hundreds of bug fixes and logical justifications for final disagreements, were essential to establishing the credibility of the test procedures.

RESULTS

We plan to conduct simulation trials of the revised BESTEST cases in collaboration with industry participants representing a number of detailed state-of-the-art whole-building energy simulation programs from around the world. A final version of the example results will be included as an updated informative annex to Standard 140. This will take a few years to complete.

CONCLUSIONS

Summary

Developed 20 years ago, IEA BESTEST is the founding procedure for ASHRAE Standard 140, and has been applied worldwide by the building energy modeling industry. In response to the evolution of the state of the art in building thermal fabric modeling since the IEA BESTEST test cases and example simulation results were developed, work is commencing to update the sections of Standard 140 adapted from IEA "Envelope" BESTEST. This includes the normative test specification and the informative example results. The revision will address relevant advancements in the state of the art of building energy modeling. Simultaneously, we must maintain the original kernel of fundamental diagnostic capability, as this functionality has facilitated isolation of many software errors over the years. This implies integrating revisions and constraining the work to maintain as much of the original parsimonious framework as possible for the base case and parametric sensitivity tests.

Current IEA BESTEST results indicate a fairly wide range of disagreement among programs. We are interested to see how this may change for the updated test suite and example results.

Future Work

Over the course of the project we will apply the same process for updating and vetting the test specification and example results as was applied for the original IEA BESTEST. This includes an iterative process of revising the test specification and conducting simulation trials until we have eliminated specification ambiguities and easily correctable modeling errors. After completing the primary technical work, we will adapt the test specification, example results, and supporting appendices for inclusion with ASHRAE Standard 140.

For the Longer Term

Building energy simulation software must constantly be augmented to keep pace with new technology development. Thus, there is always a need for model validation. A continuation of the validation work is recommended by SSPC 140 and previous IEA validation task experts. Such additional tests could include, but are not limited to, those for models of the following:

- HVAC systems and system configurations beyond those not currently included in, or being added to, Standard 140
- More ground-coupled heat transfer tests than the analytical verification tests currently being added to Standard 140
- On-site generation equipment, including conventionally fueled and renewable energy-based systems
- Model calibration methods for existing buildings (for predicting retrofit energy savings).

Other existing test suites and recommended additional research are discussed in informative Annex B23 of Standard 140 (ANSI/ASHRAE 2011).

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NOMENCLATURE

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BESTEST: Building Energy Simulation Test and Diagnostic Method

ECBCS: Energy Conservation in Buildings and Community Systems Programme, of IEA

HERS: Home Energy Rating System

IBPSA: International Building Performance Simulation Association

IEA: International Energy Agency

NREL: National Renewable Energy Laboratory

SHC: Solar Heating and Cooling Programme, of IEA

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