Argonne NATIONAL LABORATORY

ANL-25/11

140 User's Manual

for
ANSI/ASHRAE Standard 140-2023

Method of Test for Evaluating Building Performance Simulation Software

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February 21, 2025

PREFACE

GENERAL

ANSI/ASHRAE Standard 140 Method of Test for Evaluating Building Performance Simulation Software [1] specifies the method to test the core competency of building performance simulation (BPS) software, a broad class of software which includes building energy modeling (BEM) software. Standard 140 has been widely used by BEM software vendors to help diagnose and compare the results from the program with other modeling programs. The Standard is also referenced by codes, standards, government programs, and other incentive programs as a part of minimum requirements for qualifying BEM software. The explanatory information, summary tables and figures in this 140 User's Manual (referred to as "this Manual") are provided to help users in implementing various suites of tests specified in Standard 140-2023 (referred to in this manual as "Standard 140" or "the Standard").

AUDIENCE

This Manual is intended to be used by

a. Software vendors implementing the tests in the Standard to see how their software compares and to diagnose issues;
b. Code officials and policy makers that seek to reference the Standard;
c. Users of BPS software to understand the Standard and what it really tests.

SCOPE

The purpose of this user's manual is to help users understand the Standard. This Manual describes the 2023 version of the Standard which is similar to earlier versions but contains changes and additions including new tests and a major reorganization of the test suite sections. The user's manual does not address any approved changes or changes in review that are not included in the current published version of Standard 140-2023. The user's manual is recommended to be used in conjunction with the Standard.

ADDENDA

ANSI/ASHRAE Standard 140 is a dynamic document undergoing continuous maintenance, with addenda, errata, and interpretations. The ASHRAE committee responsible for maintaining the Standard is expected to approve addenda as part of the continuous maintenance process. Users of this manual are recommended to check the ASHRAE website at: https://www.ashrae.org/technical-resources/standards-and-guidelines/standards-addenda for any approved addenda to the 2023 edition of the Standard.

OFFICIAL INTERPRETATION OF THE STANDARD

While this user's manual is designed to help understand the Standard, the Standing Standards Project Committee (SSPC) 140 provides official interpretations of the Standard upon written request. Interpretations are restricted to the words contained within the Standard itself and cannot encompass design reviews and/or proposals for changes. Address requests for interpretations to ASHRAE, Senior Manager of Standards, 180 Technology Parkway NW, Peachtree Corners, GA 30092. Interpretations are also posted on the ASHRAE website at http://www.ashrae.org.

NAVIGATING THE USER'S MANUAL

This Manual provides an overview of the Standard and introduces important concepts and procedures for navigating and using the Standard. The symbol "§" and *italics* are used to reference sections, tables, and figures in the Standard.

CONTENTS

CONTENTS (CONT.)

TABLES

ACKNOWLEDGMENTS

We extend our sincere gratitude to the members of the ASHRAE Standing Standard Project Committee (SSPC) 140, Method of Test for Evaluating Building Performance Simulation Software, for their visionary leadership, insightful contributions, and thorough review comments during the development of this User's Manual.

We are especially appreciative of the support and guidance provided by Amir Roth of the U.S. Department of Energy's Building Technologies Office.

This manual was developed with support from the Building Technologies Office of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, under Contract Number DE-AC02-06CH11357.

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1. INTRODUCTION

This User's Manual provides an overview of ANSI/ASHRAE Standard 140-2023 (referred to in this manual as "Standard 140" or "the Standard" [1]) and introduces important concepts and procedures for navigating and using the Standard. This section discusses the purpose and scope, test methods, test suites, acceptance criteria, how to reference the Standard, and what it means to comply with the Standard.

A. PURPOSE AND SCOPE

Standard 140 focuses on testing the core competency of building performance simulation (BPS) software. Not every aspect of the software will be tested. Acceptance criteria have been developed for a subset of test suites and can be adopted by jurisdictions and incentive programs to demonstrate the basic competency of BPS software. See *§1 and §2 of the Standard* and Section 5 Acceptance Criteria of this Manual for more details.

B. TEST CASES

A test case in the Standard describes a building energy simulation model including building geometry, thermal zones, envelope, HVAC equipment/systems, controls, and weather data. Each test case is designed to test a specific function or feature of BPS software.

Q 1-a

How many test cases are there in total?

A 1-a

There are 176 test cases in total which examine a variety of different algorithms in BPS software. The test cases are not software specific.

Q 1-b

What's unique about the weather data used for different test cases in ASHRAE Standard 140?

A 1-b

Weather data serve as boundary conditions/drivers for BPS. To test and evaluate specific features/functions of BPS, constant hourly weather data (outdoor dry-bulb temperature, relative humidity, and wind speed) as well as harmonically varying outdoor dry-bulb temperature and relative humidity were used for some test cases in the Standard. Detailed weather data characteristics for each test case are summarized in *§Normative Annex A1 Weather Data*.

C. TEST METHODS

Test methods currently in Standard 140 include analytical and comparative testing methods for evaluating BPS software:

- Analytical testing compares simulation results to mathematical solutions for applicable test cases with a given set of parameters and simplified assumptions.
- Comparative testing compares results from different BPS programs with each other to determine the degree of disagreement among the programs. The test cases in comparative testing cannot be solved analytically and normally employ more realistic boundary conditions.

Empirical testing compares simulation results to experimental data with the consideration of uncertainties from measurements and simulation programs. There are no empirical test cases in ASHRAE Standard 140-2023. Future editions of the Standard may include empirical testing. Definitions and detailed discussion of test methods may be found in the *§Foreword, §3.1, §4, and §Annex B23*.

Q 1-c

Is my simulation software suitable for the test methods specified in ASHRAE Standard 140?

A 1-c

The Standard does not specify the requirements of simulation software for testing. In general, to use with Standard 140, the BPS software should be able to predict building heating/cooling loads as well as energy consumption for an entire year in a time-series format and be capable of conducting simulations using an hourly or subhourly timestep. Currently, the methods of test in the Standard focus on first-principle-based BPS software. Software based on data-driven modeling methods, degree-day or bin methods are not suitable for the test methods specified in ASHRAE Standard 140.

Q 1-d

What are the differences between the "Analytical Verification" and "Comparative" test cases?

A 1-d

Analytical Verification Test Cases employ simplified boundary conditions and have analytical, quasi-analytical, or verified numerical model solutions (as defined in *§3*) to compare against results from BPS. When analytical, quasi-analytical, or verified numerical model solutions are not available, a software-to-software comparative testing approach is adopted. In software-to-software Comparative Test Cases, results from different BPS programs are compared with each other to determine the degree of disagreement among the programs. They employ more realistic boundary conditions than Analytical Verification Test Cases and do not have analytical solutions.

D. TEST SUITES

Test suites are a grouping of test cases with a common testing scope. The test cases in Standard 140 are grouped into different test suites which are further grouped into Class I tests and Class II tests.

The test suites for Class I *(§6-11*) were designed as detailed diagnostic tests for testing basic physics and functionality of BPS software. Class I has 132 test cases and includes six test suites, including:

- Weather Drivers Tests
- Building Thermal Envelope and Fabric Load Tests
- Ground-Coupled Slab-on-Grade Analytical Verification Tests
- Space-Cooling Equipment Performance Tests
- Space-Heating Equipment Performance Tests
- Air-Side HVAC Equipment Performance Tests

The test suite for Class II *(§12*) focuses on software intended for modeling single-family residential buildings, has 41 test cases, and is designed to represent various degrees of modeling complexity in basic building design elements and passive solar design features.

The test suites in Class I and Class II are described below:

Weather Drivers Tests (Class I)

The Weather Drivers Tests *(§6*) specify six test cases for different weather files which were designed to identify differences between program algorithms related to psychrometric functions, sky models, trigonometry for tilted surfaces, and differences in how instantaneous weather file data are mapped into the corresponding hour. These tests are typically referenced using WD followed by a three-digit number such as WD600.

Building Thermal Envelope and Fabric Load Tests (Class I)

This test suite examines the simulation algorithms for building envelope heat transfer. The test suite includes testing cases for external shading, windows, thermostat controls, construction materials, sunspaces, and night ventilation. There are 27 "Basic Tests" and 25 "In-Depth Tests." The "In-Depth Tests" are primarily used to further diagnose problems detected when comparing the results of the "Basic Tests*." §Table 5-1 and §Tables B1-2 and B1-3 in §Annex B1* provide a summary of test cases and key features associated with each test. These tests are typically referenced by a three-digit number such as 600 or 985, sometimes with TF as a prefix.

Ground-Coupled Slab-on-Grade Analytical Verification Tests (Class I)

These tests primarily test the simulation program algorithm for heat transfer through the floor of a building that is in direct contact with the ground. There are 17 test cases for "Ground-Coupled Slab-on-Grade Analytical Verification Tests." *§Tables B1-4 and B1-5* summarize the features of the test cases. These tests are typically referenced by using GC followed by a two-digit number and then 'a' or 'b' such as GC40b or GC80b.

Space-Cooling Equipment Performance Tests (Class I)

The aim of this test suite is to examine the related algorithms for cooling the building through a unitary split air-conditioning system at varying weather conditions, cooling set points, and sensible/latent internal heat gains. There are "Analytical Verification Tests," and "Comparative Tests" in the space-cooling equipment performance tests. There are 34 test cases in total for this set of tests. *§Tables B1-6 and B1-7* summarize the features of the space cooling equipment performance analytical verification tests. *§Table B1-8* summarizes the features of the space cooling equipment comparative tests. These tests are referenced in the form CE followed by a three-digit number such as CE100 or CE320.

Space-Heating Equipment Performance Tests (Class I)

The aim of this test suite is to examine the algorithms related to equipment that provides heating to the building at varying weather conditions, fan operating modes, furnace efficiency, and furnace capacity. There are 11 test cases in total for space heating equipment performance tests including one base case, seven test cases for analytical verification tests, and three test cases for comparative tests. *§Table B1-9* summarizes the key features of each test in this test suite. The tests are referenced using the nomenclature HE followed by a three-digit number such as HE100 or HE230.

Air-Side HVAC Equipment Analytical Verification Tests (Class I)

This test suite is focused on testing how the HVAC air-distribution and related zonal systems—including four-pipe fan-coil systems, single-zone air systems, constant-volume systems, and variable air volume systems—are modeled related to controls and operation of conditioned air being provided to the building. There are 24 test cases in total. *§Tables B1-16 and B1-17* summarize the key features of each test in this test suite. The form for referencing these tests is the letters AE followed by a three-digit number such as AE100 or AE426.

Class II Tests

The test suite for Class II was designed to represent various degrees of modeling complexity in basic building design elements and passive solar design features and was primarily developed for testing BPS software used for single family residential buildings. There are 21 test cases in total. *§Table B1-18* summarizes the key features of each test in this test suite.

Q 1-e

What do the abbreviations ("WD," "CE," "HE," "AE," "L," and "P") in front of test case numbers refer to?

A 1-e

WD: Weather Drivers in Weather Drivers Tests in Class I
CE: Space-Cooling Equipment in Class I
HE: Space-Heating Equipment in Class I
AE: Air-Side HVAC Equipment in Class I
L: Base-case configuration in Class II
P: Passive solar series cases in Class II
Test cases without the letter codes are part of the thermal fabric tests in Class I.

Q 1-f

Several of the tests require prescribed inputs (e.g. surface coefficients for building thermal envelope tests) in order to meet the acceptance criteria. Should these prescribed inputs be used in simulations for compliance evaluation?

A 1-f

No. Compliance evaluation simulations should use applicable input specifications that are prescribed in the compliance method.

E. REFERENCES TO STANDARD 140

Standard 140 has been referenced by building codes, standards, and incentive programs such as ASHRAE Standard 90.1, qualified software for calculating commercial building tax deductions under IRS 179D, RESNET Home Energy Rating System, International Energy Conservation Code, and California Energy Commissioning Title 24. Detailed examples of how to reference Standard 140 can be found in Section 6 of this Manual.

F. DOES THIS SOFTWARE COMPLY

The requirements of the normative sections of Standard 140 ensure that users follow the specified method of test and that test results are provided as specified. Until the publication of Standard 140-2020 addendum b (now *§Annex A3 of Standard 140-2023*) there was no normative results requirement to compare against. *§Normative Annex A3* specifies acceptance criteria for selected outputs for Class I tests. To comply, the software must demonstrate that a sufficient number of software results are within the ranges specified for each set of test cases. (see *§4.4.1*).

Organizations or standards that cite Standard 140 and require results submittal should explicitly define the scope of testing, which portions of the acceptance criteria apply, and how tested programs can be used for their purposes (see *§4.5*). Where specific sections are not called out for acceptance criteria, all test groups of *§Normative Annex A3* shall apply.

For software aimed at simulating residential buildings that have been tested using the *§12* Class II test procedure, Tier 1 test ranges are shown in "Procedures for Verification of RESNET Accredited HERS Software Tools" RESNET Publication 002-2020. Some background information on how those ranges were created is in *§Annex B21*.

For test cases or specific outputs without acceptance criteria, results may be compared with either the example results provided in *§Informative Annexes B8, B16, and B20*, or with other results generated using this method of test. For such results, determination of agreement is left to the organization referencing the method of test or to other users who may be running the tests for their own quality assurance purposes (see *§4.4.1*).

2. HOW DO I APPLY STANDARD 140?

Standard 140 is intended to be used by

- software vendors implementing the tests in the Standard to see how their software compares and to diagnose issues,
- code officials and policy makers that seek to qualify software for use in code and policy, and,
- users of BPS software to understand the software and to build confidence in tested software.

A. FOR BPS SOFTWARE DEVELOPERS

For BPS software developers testing the performance of their software, Standard 140 provides input/output specifications for each test case, normative acceptance criteria, and informative example results. The overall process typically involves:

- Select a test suite
- Develop the inputs for the base case and run the base case test in the software
- Review outputs for the base case and compare against example results
- If results fall outside the range of the example results, review and understand the causes, revise inputs as appropriate
- Develop inputs for remaining test cases in the test suite and run them
- Review results and compare against acceptance criteria and example results
- If any results fail acceptance criteria or fall outside the range of the example results, review and understand the causes, revise inputs as appropriate
- Write a modeler's report

Because this process involves many sets of inputs, is often iterative, and will likely be repeated for future versions of the same software, it is highly recommended to automate the process as much as possible. Within each test suite, there is usually a base case and subsequent test cases which often modify just a single feature or set of features to emphasize a modeling physics sensitivity. By reviewing the differences in the output results between these two test cases, it is possible to determine if the results for that single feature change are logical.

For example, Case 600 is the base case for the Building Thermal Envelope and Fabric Load Tests (ref *§7.2.1*). This is a single thermal zone model with south-facing windows and is relatively easy to compose. It is a classic case to start with and has been used for testing, comparison, and validation in scholarly publications. Case 610 in *§7.2.2.1.1* adds an overhang to the Case 600 model to understand the effect of an external shading device on building energy profiles such as heating load, peak heating demand, cooling load, and peak cooling demand. The difference in energy profiles between Case 610 and Case 600 demonstrate the impacts of the external shading device. Comparing differences, or deltas, between two test cases forms the basis for nearly all of the acceptance criteria, is frequently presented in the example results, and is useful for diagnosing issues with the inputs or the tested software.

It is recommended that developers create models for the base case of each test suite first and check it carefully versus the test specifications, example results, and acceptance criteria. Most of the remaining test cases within the same test suite can be established by modifying the input files from the base case or secondary base case by adding new features or modifying existing features.

If possible, automation using scripts or other tools to generate the test cases and extract results is highly recommended, both for quality assurance and to save time. *§Table 7-1* summarizes the key feature of each test case in this suite, and *§Table 7-14* lists which base case(s) each test is built on. Pseudo code illustrating the process for creating a couple of test cases from the base case 600 is presented in Section 4 of this Manual.

B. FOR CODE OFFICIALS AND POLICY MAKERS

Those who seek to reference the Standard may include:

- Authority Having Jurisdiction (AHJs), who enforce requirements of codes and standards referencing Standard 140 and request BPS as part of the codes/standards or program procedure,
- Writers and maintainers of other codes and standards that reference Standard 140,
- Policy and regulatory experts related to BPS.

Standard 140 sets rigorous requirements to test the core competency of BPS software including the building envelope and various types of HVAC systems. The Standard specifies detailed input/output requirements for each test case and acceptance criteria (range of valid results) for the software to pass. The intent of this testing is to increase the confidence of code officials and policy makers with building energy predictions generated by BPS software that passed the acceptance criteria of Standard 140. While it is not important for code officials and policy makers to review the details of every test, it is important to understand the scope of the various test suites and how the acceptance criteria in *§Annex A3* are applied. Detailed examples of how to reference Standard 140 can be found in Section 6 of this Manual.

C. FOR BPS SOFTWARE USERS

The Standard can be an evaluation tool and a learning resource for BPS software users. For practical users who develop models for code compliance and design, Standard 140 test results can build confidence for the BPS software of interest. BPS users can compare the test results for the program of interest to the results from other software represented in the example results (various *§Annexes B1 thru B24*) and acceptance criteria *(§Annex A3*). Depending on the user's application, such as ASHRAE Standard 90.1 compliance modeling, there may be a requirement that the BPS software has been tested with Standard 140. Testing results may be published by the BPS software developer or may be available on a public web site such as IBPSA-USA's "ASHRAE Standard 140 Acceptance Criteria Public Software List" (https://ashraestd140validatorweb.azurewebsites.net/public_software_list).

Composing models for test cases in test suites, performing simulations, and understanding the trend of variation for simulation results can help users master modeling core components of buildings and build a strong foundation for those who are learning to use BPS software

Based on the modeling specifications provided by the Standard, users can learn to understand the key input parameters and simulate core functionalities of BPS software including, but not limited to, thermostat setback, thermal mass, night ventilation, air economizer control, unitary split air-conditioning systems, furnace heating systems, four-pipe fan-coil systems, single-zone air systems, constant-volume systems, and variable air volume systems.

3. NAVIGATING THE STANDARD AND APPENDICES

ASHRAE Standard 140-2023 includes twelve sections, three normative annexes, and 25 informative annexes as well as the supplemental files for the Standard including model input files, weather data, report templates, and examples.

The *§Foreword* provides a historical perspective on the development of the Standard.

§Sections 1 and 2 are administrative and do not contain any requirements:

- *§Section 1*, "Purpose"—states the purpose of the Standard.
- *§Section 2*, "Scope"—describes where the Standard does and does not apply.
- *§Section 3*, "Definitions"—provides definitions of terms that are used throughout the Standard and supports the requirements from *§Sections 4-12*.

§Sections 4-12 are the technical sections of the Standard and contain requirements of test cases for evaluating BPS software.

- *§Section 4*, "Methods of Testing"—provides a summary of test suites for Class I and Class II.
- *§Section 5*, "General Test Procedures"—describes the general modeling approach and output requirements of test suites for Class I and Class II. Examples of general modeling approach are time and geometry conventions, equivalent modeling methods, and use of alternative inputs for convective or combined surface coefficient, interior solar distribution fractions and air density at specific altitudes.
- *§Sections 6-11* provide input specifications and output requirements of the six test suites in the Class I tests. The six test suites are:
    i. Weather Drivers Tests (*§6*)
    ii. Building Thermal Envelope and Fabric Load Tests (*§7*)
    iii. Ground-Coupled Slab-on-Grade Analytical Verification Tests (*§8*)
    iv. Space Cooling Equipment Performance Tests (*§9*)
    v. Space Heating Equipment Performance Tests (*§10*)
    vi. Air-Side HVAC Equipment Performance Tests (*§11*)
- *§Section 12*, "Building Thermal Envelope and Fabric Load Tests (Class II)" —provides input specifications and output requirements of the Class II test cases.

Normative *§Annexes A1 thru A3* are part of the requirements of the Standard.

- *§Annex -1* "Weather Data" – describes the weather data to be used for the various test suites.
- *§Annex A2* "Standard Output Reports" – describes the required output reports for the various test cases, including standard spreadsheets of results and modeling notes.
- *§Annex A3* "Software Acceptance Criteria" – describes acceptance criteria (acceptable ranges of results) for a subset of the test cases.

Informative *§Annexes B1 through B24* provide additional explanation and are not part of the requirements of the Standard.

Different from most other ASHRAE Standards, Standard 140 has many informative explanations in addition to normative language to help users better understand the Standard. After you have a big picture of the test suites documented in the Standard, you may use the Standard as a comprehensive reference. Look up specific information such as test case specifications, output requirements, and weather data information whenever you need more details during the process of test preparation and results processing and reporting.

There are also supplemental files associated with the Standard. Each test suite has two subfolders: Normative Materials (weather data files and output files) and Informative Materials (model input files and sample results). These files may be downloaded from ASHRAE's website at https://data.ashrae.org/standard140/accompany.html.

Q 3-a

Standard 140 has over 400 pages. Where should I start if I want to be familiar with the Standard?

A 3-a

Standard 140-2023 includes both normative statements and informative explanations. The *§Foreword, §4 and §5* provide an overview of the test suites and testing methods and procedures of the Standard. After having a general idea of the test suites, you can read *§6-12* about detailed input specifications and output requirements for each testing suite. These sections are relatively independent test suites. You don't need to complete reading one section before moving to the next.

For example, you can explore detailed specifications first in *§Section 7* "Building Thermal Envelope and Fabric Load Tests" in Class I and come back to test cases in *§6* "Weather Drivers Tests" depending on your preferences. Start with case 600—a classic base case for Building Thermal Envelope and Fabric Load Tests in the Standard. If there are terminologies you need to look up while exploring different test cases you can always refer to *§3* "Definition, Abbreviations, and Acronyms".

Within each section, you may read the input specifications of a test case and then read the corresponding output requirements. You may also consider moving on to the Class II test cases in *§12* after understanding the input and output requirements for Class I test cases.

4. RUNNING THE TESTS

A. INPUT REQUIREMENTS

§6 -12 of the Standard provide detailed input specifications for the Class I and Class II test cases. Input specifications cover building geometry, construction materials, internal heat gains, infiltration, ventilation, radiative and convective surface coefficients, mechanical heating and cooling equipment, controls, and weather data.

Base case models for a given test suite should be created first. Double check the base-case input files versus the specifications and compare the results versus the informative Standard 140 example results. Once you are confident that the base case is correct, then modify existing features or add new features to the base case model to build the remaining test case models.

B. AUTOMATING TEST CASE INPUT FILES

While the standard is silent about using automation when constructing the modeling input files for each test case, developing automation might be a good investment for someone trying to generate models for Standard 140 since most of the modeling files consist of relatively small changes from other files. Automation tools also help if modeling input file field names and other facets of the file format change with modeling software updates since the changes would be restricted to just a few files rather than dozens. The process of building test case models can be automated through script languages such as Python, JavaScript, Ruby, or Perl. Automation is especially helpful in two scenarios:

- To avoid manual changes in the many files that correspond to each test case when problems are found related to the base case description.
- When updating results of the analysis for a new version of software.

In either case, automation allows faster updates to files and avoids repetitive manual editing with the benefit of also making the set of input files corresponding to each test case more consistent with one another and less prone to random manual editing errors.

The following illustrates the automation of Cases 610, 900 and 910 based on Case 600 from "Building Thermal Envelope and Fabric Load Tests." Case 600 is a single thermal zone model with south-facing clear double-pane windows and is the base case of "Building Thermal Envelope and Fabric Load Tests." The simulation model file for Case 600 would need to be created by hand or through a user interface as a first step by following the details in *§7.2.1*.

For case 610 (see *§7.2.2.1.1*), a south horizontal overhang is added across the entire length of the south wall from the edge of the roof. For the EnergyPlus files included with the standard (see 140-2023-AccompanyingFiles\Accompanying FIles\Std140_TF_Files\Informative Materials\InputFiles_TF\EnergyPlus\EnergyPlus-ASHRAE140-EnvelopeRound5.zip") when you compare the 600 and 610 files the main difference is the addition of:

```
Shading:Zone:Detailed,
  SOUTH WALL OVERHANG,     !- Name
  ZONE SURFACE SOUTH,      !- Base Surface Name
  SCH 2,                   !- Transmittance Schedule Name
  4,                       !- Number of Vertices
  0.000,-1.0000,2.700000,  !- X,Y,Z ==> Vertex 1 {m}
  0.000,0.00000,2.700000,  !- X,Y,Z ==> Vertex 2 {m}
  8.000,0.00000,2.700000,  !- X,Y,Z ==> Vertex 3 {m}
  8.000,-1.00000,2.700000;  !- X,Y,Z ==> Vertex 4 {m}
```

For CSE, another simulation program, the files included with the standard (see 140-2023-AccompanyingFiles\Accompanying FIles\Std140_TF_Files\Informative Materials\InputFiles_TF\CSE\Std140-5-2-CSE-04152019-InputFiles.zip) show the main difference is the addition of:

```
wnVfSkyDf= 0.39363710370433924
SHADE
  ohDepth = 3.28084
  ohDistUp = 1.64042
  ohExL = 1.64042
  ohExR = 14.76378

wnVfSkyDf= 0.39363710370433924
SHADE
  ohDepth = 3.28084
  ohDistUp = 1.64042
  ohExL = 14.76378
  ohExR = 1.64042
```

While the syntax is quite different, in both programs, a shading surface has been added. A general algorithm for this addition can be seen below:

```
copy_file “case600.file” to “case610.file”
open_file “case610.file”
set shade_coordinates
set shade_surface_properties
add_overhang shade_coordinates, shade_surface_properties
close_file “case610.file”
```

Changes between test cases within each test suite are incremental and can often be reused. For example, the difference in input files between case 900 and 910 are the same as those between case 600 and 610. A similar general algorithm for the modifications from Case 900 to Case 910 is shown below:

```
copy_file “case900.file” to “case910.file”
open_file “case910.file”
set shade_coordinates
set shade_surface_properties
add_overhang shade_coordinates, shade_surface_properties
close_file “case910.file”
```

§Figure 7-2 and §Table 7-14 summarize the relationship between test cases and test features for the Building Thermal Envelope and Fabric Load Tests.

Case 900 (see *§7.2.2.2.1*) is the high mass building test case from "Building Thermal Envelope and Fabric Load Tests" and can be obtained by modifying material thermal properties for exterior wall, floor, and roof from the original values shown in *§Table 7-2* to the values shown in *§Table 7-27*.

Both the exterior walls and raised floor have replaced the lighter weight element of plasterboard and timber flooring with concrete block material. The roof remains the same.

For TRNSYS (see 140-2023-AccompanyingFiles\Accompanying FIles\Std140_TF_Files\Informative Materials\InputFiles_TF\TRNSYS\190425_TS_TRNSYS18_InputFiles.zip), multiple files are used to describe each case but the b18 file shows for Case 600:

```
FLOOR  =FLOOR_LW     : SURF=  1 : AREA=        48 : EXTERNAL : ORI=H_0_180 : FSKY=0 :
GEOSURF=1
ROOF   =ROOF_LW      : SURF=  2 : AREA=        48 : EXTERNAL : ORI=H_0_0 : FSKY=1
WALL   =EXT3_LW      : SURF=  3 : AREA=      21.6 : EXTERNAL : ORI=N_180_90 : FSKY=0.5
WALL   =EXT4_LW      : SURF=  4 : AREA=      16.2 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
WALL   =EXT5_LW      : SURF=  5 : AREA=       9.6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WINDOW=DblPaneClr_S6 : SURF=  6 : AREA=         6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WINDOW=DblPaneClr_S7 : SURF=  7 : AREA=         6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WALL   =EXT8_LW      : SURF=  8 : AREA=      16.2 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
```

And for case 900:

```
FLOOR  =FLOOR_HW     : SURF=  1 : AREA=        48 : EXTERNAL : ORI=H_0_180 : FSKY=0 :
GEOSURF=1
ROOF   =ROOF_HW      : SURF=  2 : AREA=        48 : EXTERNAL : ORI=H_0_0 : FSKY=1
WALL   =EXT3_HW      : SURF=  3 : AREA=      21.6 : EXTERNAL : ORI=N_180_90 : FSKY=0.5
WALL   =EXT4_HW      : SURF=  4 : AREA=      16.2 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
WALL   =EXT5_HW      : SURF=  5 : AREA=       9.6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WINDOW=DblPaneClr_S6 : SURF=  6 : AREA=         6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WINDOW=DblPaneClr_S7 : SURF=  7 : AREA=         6 : EXTERNAL : ORI=S_0_90 : FSKY=0.5
WALL   =EXT8_HW      : SURF=  8 : AREA=      16.2 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
```

Note the use of _HW instead of _LW for each surface. In the case of TRNSYS, both the lightweight surfaces for Case 600 and the heavyweight surfaces for Case 900 are all described in each file but only the reference to the materials differs.

```
CONSTRUCTION EXT3_LW
 LAYERS   = PLASTERBOARD FIBERGLASS WOODSIDING
 THICKNESS= 0.012        0.066      0.009
 ABS-FRONT= 0.6 : ABS-BACK= 0.6
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT   = VERTICAL : HBACK= INPUT 1*Hconv_S3

CONSTRUCTION EXT3_HW
 LAYERS   = CONCBLOCK FOAMINSUL WOODSIDING
 THICKNESS= 0.1       0.0615    0.009
 ABS-FRONT= 0.6 : ABS-BACK= 0.6
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT   = VERTICAL : HBACK= INPUT 1*Hconv_S3
```

In ESP-r (see 140-2023-AccompanyingFiles\Accompanying FIles\Std140_TF_Files\Informative Materials\InputFiles_TF\ESP-r\ESP-r_archive.zip) Case 600 and Case 900 are also described in a series of files but the main difference is in the .con file, for Case 600:

```
# conduc-  |  density | specific | thick- |dpnd|  ref. |  temp. |moisture| surf|lyr
# tivity   |          | heat     |ness(m) |type|  temp | factor | factor |     |
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  1   1
     0.0400,      12.0,     840.0,  0.0660,   0,   0.00, 0.00000, 0.00000  #      2
     0.1600,     950.0,     840.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  2   1
     0.0400,      12.0,     840.0,  0.0660,   0,   0.00, 0.00000, 0.00000  #      2
     0.1600,     950.0,     840.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  3   1
     0.0400,      12.0,     840.0,  0.0660,   0,   0.00, 0.00000, 0.00000  #      2
     0.1600,     950.0,     840.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  4   1
     0.0400,      12.0,     840.0,  0.0660,   0,   0.00, 0.00000, 0.00000  #      2
     0.1600,     950.0,     840.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  5   1
     0.0400,      12.0,     840.0,  0.0660,   0,   0.00, 0.00000, 0.00000  #      2
     0.1600,     950.0,     840.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #      3
     1.0000,    2470.0,     750.0,  0.0030,   0,   0.00, 0.00000, 0.00000  #  6   1
```

And case 900:

```
# conduc-  |  density | specific | thick- |dpnd|  ref. |  temp. |moisture| surf|lyr
# tivity   |          | heat     |ness(m) |type|  temp | factor | factor |     |
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  1   1
     0.0400,      10.0,    1400.0,  0.0615,   0,   0.00, 0.00000, 0.00000  #      2
     0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  2   1
     0.0400,      10.0,    1400.0,  0.0615,   0,   0.00, 0.00000, 0.00000  #      2
     0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  3   1
     0.0400,      10.0,    1400.0,  0.0615,   0,   0.00, 0.00000, 0.00000  #      2
     0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  4   1
     0.0400,      10.0,    1400.0,  0.0615,   0,   0.00, 0.00000, 0.00000  #      2
     0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #      3
     0.1400,     530.0,     900.0,  0.0090,   0,   0.00, 0.00000, 0.00000  #  5   1
     0.0400,      10.0,    1400.0,  0.0615,   0,   0.00, 0.00000, 0.00000  #      2
     0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #      3
```

Again, while the syntax is quite different, fundamentally the change is from a series of lightweight materials to a series of heavy materials. A general algorithm for this substitution of materials, can be seen below:

```
copy_file “case600.file” to “case900.file”
open_file “case900.file”
define_material concrete_block(k=0.51, th=0.100, dens=1400, cp=1000)
define_material foam_insulation(k=0.04, th=0.0615, dens=10, cp=1400)
define_material concrete_slab(k=1.13, th=0.080, dens=1400, cp=1000)
for each construction:
  if includes material plasterboard then
    substitute concrete_block for plasterboard
  endif
  if includes material fiberglass_quilt then
    substitute foam_insulation for fiberglass_quilt
  endif
  if includes material timber_flooring then
    substitute concrete_slab for timber_flooring
  endif
endfor
close_file “case900.file”
```

The approach of creating each case based on other cases using scripting can be applied to all the various test cases in each test suite described in Standard 140. Not all of the test cases will be as easy to implement as the ones chosen for these examples, but investing the time to automate the generation of the files will reduce future repetitive manual editing and help ensure that the files are all consistent with one another.

C. OUTPUT REQUIREMENTS

The output results required from each simulation test vary by the class and type of test suite and sometimes the individual test. Detailed output requirements are documented in *§6-12 of the Standard*. Types of output include time series data as well as aggregated results such annual sums and peaks. *§Normative Annex A2* Standard Output Reports describes the format for reporting output results. The accompanying files include report templates and examples showing how to report results for each test suite. The templates for testing results, located in the subfolder “Normative Materials” for each test suite must be used for reporting testing results. The example files for reporting results may be found in the subfolder “Informative Materials” for each test suite. Detailed instructions for each template are provided in *§Annex A2*. Also see *§Informative Annex B10*: Instructions for Working with Results Spreadsheets Provided with the Standard.

Automating the flow of information from the simulations into the results spreadsheets is highly recommended, both for accuracy and saving time when re-running simulations. Mapping the output results into the various spreadsheet cells may require an intermediate post-processing step to find peaks, or aggregate annual sums, or select data for a specific date. Future versions of the Standard will move toward simplifying the simulation output requirements by requiring a full set of time series output for each test case but not necessarily asking for aggregation or peaks. *§6.3.1* Weather Driver Test Outputs already uses this approach, specifying a list of outputs to be “provided at each time step for the annual simulation”. Scripts have been developed to read the time series data and produce aggregated results and graphs to compare against example results (see *§Informative Annex B11* “Production of Example Results for Weather Drivers Tests of Section 6, Building Thermal Envelope and Fabric Load Tests of Section 7, and Ground-Coupled Slab-on-grade Tests of Section 8”).

IBPSA-USA (https://www.ibpsa.us/) has developed a web portal where software developers can submit test results, view automated comparisons against example results and acceptance criteria, and then publish these results for public inspection. See https://ashraestd140validatorweb.azurewebsites.net/public_software_list.

D. MODELING NOTES

In addition to the simulation outputs, the Standard requires users to provide input files and modeling notes for each test suite. The modeling notes are described in *§Annex A2, Attachment A2.8* "Standard 140 Output Form—Modeling Notes" and includes sections to document the following:

1) Software information – version, vendor, etc.
2) Alternative modeling methods –optional software settings used for each test
3) Equivalent modeling methods –equivalent methods used when the software cannot model a particular test specification
4) Use of nonspecified inputs –software settings used for inputs that are not declared in the test specification, e.g. convection coefficients for some test cases
5) Omitted test cases and results –reasons for omissions, if any
6) Changes to source code for the purpose of running the tests – if such changes are not available in a public release version
7) Discussion of anomalous results – optional section to explain reasons why results may differ significantly from the example results.

Example modeling notes may be found in \Accompanying Files\Std140_AE_Files\Informative Materials\S140outNotes_Examples.txt"). These are complete examples which are worth reading to understand the intent of each section.

In particular, modeling notes are a useful way to understand how to start creating a model for a test in specific software and what settings might be necessary in the software to implement that test. Comparing modeling notes and input files for different software is a good way to learn differences in how different software models the exact same scenario/configuration.

5. ACCEPTANCE CRITERIA

To comply with Standard 140-2023 as published, the simulation test results must satisfy the applicable acceptance criteria in *§Normative Annex A3*. References to Standard 140 by other standards or codes may limit or explicitly omit the acceptance criteria requirement. If the reference is silent about acceptance criteria, then all acceptance criteria apply.

The acceptance criteria have been determined based on the degree of disagreement from a set of reference software or analytical solutions. An overall passing criterion is also set based on the number of passed tests. In the current acceptance criteria, a subset of test suites was selected to be applied for developing acceptance criteria. These test suites include:

- Building Thermal Envelope and Fabric Load Tests
- Space-Cooling Equipment Performance Tests
- Space-Heating Equipment Performance Tests
- Air-Side HVAC Equipment Analytical Verification Tests.

§Informative Annex B12 describes the development of the acceptance criteria. The core basis consists of (1) statistical analysis of a set of reference software results to set the core bounds of what is acceptable and what is not acceptable; (2) additional bounds/limits to deal with "reasonably close", round off errors, comparison of small numbers, and interpretations of "what is zero." If the tests of a software are within the bounds, it passes the test in question. Specifically, the acceptance criteria were determined based on the methods as follows.

a) For comparative tests, a set of reference software was selected to determine the upper and lower thresholds of acceptance criteria of comparative test cases of Class I. Criteria were set based on the degree of disagreement in the magnitude of results of individual tests or magnitude of differences between two test cases that occurred for the set of reference software. Refer to *§Tables A3-1 through A3-13* for upper and lower thresholds.

b) For analytical verification tests, criteria were set up based on the degree of disagreement that occurred for other simulation results versus the analytical and quasi-analytical solutions (see *§3* for definitions of these types of solutions).

c) An overall passing criterion was set up based on the number of verified model results. Refer to *§Table A3-14* for the minimum count to meet or exceed required for each test suite.

Note that the acceptance criteria use only selected outputs from each test suite. Meeting the acceptance criteria does not guarantee the complete examination of any energy simulation software. No specific diagnostic tests are currently available if acceptance criteria are not met. The acceptance criteria were specifically developed to flag software that significantly differs with other reference software or the analytical/quasi-analytical solution. This approach allows for software to have variations in algorithms and solvers and still pass the criteria and does not identify any particular software as being more accurate than other passing software.

6. HOW TO REFERENCE

This section provides examples of how to reference Standard 140. Please note that standards or codes will often reference an older version of Standard 140 rather than the current version due to different standard/code updating cycles. It is hoped that the references to Standard 140 will be updated somewhat regularly in order to reflect the fact that Standard 140 is not a static document but is undergoing continuous maintenance.

For code officials and program administrators that require users to perform building performance simulations as part of their process, Standard 140 may be referenced as either a requirement or recommendation. Simulation programs that have followed the testing procedures in Standard 140 have gone through a rigorous core-competency quality assurance program and should provide a higher level of confidence to both the modeler as well as the referencing organization.

Many codes, standards, regulatory bodies, and incentive programs already reference Standard 140. New organizations seeking to reference it may want to emulate one of these existing references. The following is a non-exhaustive list of regulations and standards that reference Standard 140:

- ASHRAE Standard 90.1-2019
- ASHRAE Standard 189.1
- California Energy Commission Title 24
- DOE Qualified Software List under IRS 179D energy deduction regulations for commercial buildings
- National Energy Code of Canada for Buildings (NRC 2017-new version)
- RESNET Home Energy Rating System software approval process
- International Energy Conservation Code
- International Green Construction Code

In addition, the following codes, standards, and regulatory bodies have been reported to reference Standard 140:

- European Community's Energy Performance of Buildings Directive (EU 2018))
- Florida Building Commission
- National Weatherization Program
- Washington State Energy Code – Commercial 2018 Edition Chapter 51-11C WAC effective November 1, 2020
- Australia National Construction Code, Vol 1, Section-J
- COMNET – Commercial Buildings Energy Modeling Guidelines and Procedures
- BC Hydro's New Construction Programs Energy modeling guideline
- ASHRAE Building EQ

A. GENERAL GUIDE ON WHAT TO INCLUDE IN REFERENCES

§4.5 of the Standard discusses how to reference Standard 140. There are different ways to reference Standard 140. The most common way of referencing the Standard is to require software to be tested based on the Standard or specific sections of the Standard. The requirement of testing based on Standard 140 can also be listed as one of the primary qualification steps for software certification programs. You may consider specifying who is responsible for performing the testing and providing the results as well as adopting pass/fail criteria for test suites. The section below provides some detailed examples of how to reference Standard 140. These examples may serve as a basis for the type of reference to add. In general, a reference to Standard 140 from a code, standard or another program, may want to consider the following questions to determine the best form of reference:

- Which version of 140 is being referenced?
- Which sections of 140 are to be completed? Should the test be performed for all or a subset of test suites of the Standard?
- Should the software vendor be responsible for performing the testing by being responsible for providing the results?
- How should the results be provided?
- Whether acceptance criteria will be waived? (For Standard 140-2023, acceptance criteria apply unless specifically excepted in the reference.)
- Whether all acceptance criteria test groups are applicable?
- Whether untested algorithms/alternative algorithms are allowed to be used in simulations?
- Whether untested numerical settings are allowed to be used in simulations?
- Whether using non-user accessible inputs to perform the tests is allowed to be used in simulations?
- Whether using software without modification of source code for 140 testing is allowed to be used in simulations?
- Details about the software version? Whether using untested versions of a software is allowed to be used in simulations?
- If testing of a simulation engine is not a substitute for testing the entire software package?
- Is a list of compliant/certified software going to be provided?

B. REFERENCE EXAMPLES FROM ASHRAE STANDARD 90.1

One of the most basic references to Standard 140 occurred in the 2004 version of ASHRAE Standard 90.1 and read:

> "The simulation program shall be tested according to ASHRAE Standard 140 and the results shall be furnished by the software provider."

This explicitly requires testing of the software but also makes clear that the software provider is the responsible party to complete the tests and provide the results.

This reference in Standard 90.1 became more detailed with time and the version from 90.1-2019 reads:

> "The simulation program shall be tested according to ASHRAE Standard 140, except for Sections 7 and 8 [now Section 12 in Standard 140-2023] of Standard 140. The test results and modeler reports shall be posted on a publicly available website and shall include the test results of the simulation program along with the results of the other simulation programs included in ASHRAE Standard 140, Annexes B8 and B16. The modeler report in Standard 140, Annex A2, Attachment A2.7, shall be completed for results exceeding the maximum or falling below the minimum of the reference values or for missing results. ***Informative Note:*** There are no pass/fail criteria established by this requirement."

This specifies:

- details on how the results are provided, what the results should consist of, and which tests are performed;
- the use of the modeler report for values that are out of the reference program range or missing;
- explicitly states that no pass/fall criteria are included (which has been a source of confusion).

Standard 90.1-2022 references Standard 140-2020 outline and reads:

> "G2.2.4 Simulation program testing requirements
>
> G2.2.4.1 The simulation program shall be tested according to ASHRAE Standard 140, except for Sections 7 and 8 [now Section 12 in Standard 140-2023] of Standard 140. The required tests shall include building thermal envelope and fabric load tests (Sections 5.2.1, 5.2.2, and 5.2.3 [now Section 7 in Standard 140-2023]), ground -coupled slab-on-grade analytical verification tests (Section 5.2.4 [now Section 8 in Standard 140-2023])), space-cooling equipment performance tests (Section 5.3 [now Section 9 in Standard 140-2023]), space-heating equipment performance tests (Section 5.4 [now Section 10 in Standard 140-2023]), and air-side HVAC equipment analytical verification tests (Section 5.5 [now Section 11 in Standard 140-2023]), along with the associated reporting (Section 6 [now part of Sections 7-11 in Standard 140-2023]).
>
> G2.2.4.2 The test results and modeler reports shall be posted on a publicly available website and shall include the test results of the simulation program and input files used for generating the results along with the results of the other simulation programs included in ASHRAE Standard 140, Annexes B8 and B16. The modeler report in Standard 140, Annex A2, Attachment A2.7 shall be completed for results exceeding the maximum or falling below the minimum of the reference values or and for omitted results.
>
> G2.2.4.3 The testing shall be performed for the version of the simulation program used to calculate the proposed building performance and baseline building performance.

Informative Notes:

1. There are no pass/fail criteria established by this requirement.

2. Based on Section 3 definition, simulation program includes the simulation engine and the corresponding user interface. The testing of a simulation program only meets the requirements of G2.2.4 for that simulation program and cannot be used as proxy for documenting compliance of another simulation program that uses the same simulation engine."

This reference adds more specificity on the exact tests and output required including:

- input files are posted to a website along with the tested program results and Standard 140 example results;
- the version of the software tested must match the version used;
- testing of a simulation engine is not a substitute for testing the entire software package.

C. REFERENCE EXAMPLES FROM USDOE IRS 179D

Related to 90.1, the USDOE IRS 179D requirements reference Standard 140 in the following paragraphs:

"The U.S. Department of Energy (DOE) verifies and maintains the list of software that qualifies for the calculation of the energy and power cost savings for commercial building tax deductions under tax code Section 179D. The software requirements are listed under Internal Revenue Service (IRS) Code §179D (c)(1) and (d) Regulations, Notice 2006-52 Section 6, dated June 2, 2006 as amplified by Notice 2008-40, Section 4. The IRS Code §179D was recently updated per the PATH Act of 2015. This document provides a complete list of requirements and submission details.

Qualification steps for each version of the software to be listed:

1. Test the software according to ANSI/ASHRAE Standard 140-2014: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (except for sections 5.2.4, 7, and 8 [now Sections 8 and 12 in Standard 140-2023]).

2. Submit test results for all test cases, input files, output files, weather data, modeler reports, and the executable version of the software with which the tests were conducted to DOE and the National Renewable Energy Laboratory (NREL).

3. Submit a document with the software submission requirements listed on page 2. The manager responsible for the software development organization must sign the document affirming the claims.

4. NREL will review the submitted materials and coordinate any needed revisions.

5. NREL will verify the satisfactory qualification of the software and will post a notice on the DOE Web site (http://energy.gov/eere/buildings/qualified-software-calculating-commercialbuilding-tax-deductions) indicating the qualification."

The 179D qualified software list includes 13 software packages, each with one or more versions, and is similar to a certification program for software.

D. REFERENCE EXAMPLES FROM INTERNATIONAL ENERGY CONSERVATION CODE (IECC), CALIFORNIA TITLE 24, AND THE NATIONAL ENERGY CODE OF CANADA FOR BUILDINGS

This reference appears in the 2023 International Energy Conservation Code (IECC) and explicitly includes reference to the Pass/Fail Acceptance Criteria. This IECC reference reads:

> **"C407.5.1.2 Testing required by software vendors.** Prior to approval, software tools shall be tested by the software vendor in accordance with ASHRAE Standard 140, except Sections 7 and 8 [now Section 12 in Standard 140-2023]). During testing, hidden inputs that are not normally accessible to the user shall be permitted to avoid introducing source code changes strictly used for testing. Software vendors shall publish, on a publicly available website, the following ASHRAE Standard 140 test results, input files, and modeler reports for each tested version of a software tool:
>
> 1. Test results demonstrating the software tool was tested in accordance with ASHRAE Standard 140 and that meet or exceed the values for "The Minimum Number of Range Cases within the Test Group to Pass" for all test groups in ASHRAE Standard 140. Table A3-14.
>
> 2. Test Results of the performance analysis tool and input files used for generating the ASHRAE Standard 140 test cases along with the results of the other performance analysis tools included in ASHRAE Standard 140. Annexes B8 and B16.
>
> 3. The modeler report in ASHRAE Standard 140, Annex A2, Attachment A2.7. Report Blocks A and G shall be completed for results exceeding the maximum or falling below the minimum of the reference values shown in ASHRAE Standard 140 Table A3-1 through Table A3-13, and Report Blocks A and E shall be completed for any omitted results.
>
> **C407.5.2 Algorithms not tested.** Algorithms not tested in accordance with C407.5.1.2, including algorithms that are alternatives to those that were tested, and numerical settings not tested, such as timestamps and tolerances, shall be permitted to be used when modeling the proposed design and standard reference design."

California Title 24 Nonresidential Alternative Calculation Method Reference Manual for 2019 Building Energy Efficiency Standards. Title 24, Part 5 and associated regulations in Part 1.

> "This method of testing is provided for analyzing and diagnosing building energy simulation software using software-to-software and software-to-quasi-analytical-solution comparisons.

The method allows different building energy simulation programs, representing different degrees of modeling complexity, to be tested by comparing the predictions from other building energy programs to the simulation results provided by the compliance software in question. Compliance software must pass ASHRAE 140-2014 tests, but these tests are not part of the reference method."

The National Energy Code of Canada for Buildings includes a brief reference that allows alternatives and reads:

"4) If a computer program is used to carry out the compliance calculations, the calculation methods employed in the energy model shall conform to

a) ANSI/ASHRAE 140, 'Evaluation of Building Energy Analysis Computer Programs,' or

b) an equivalent test method."

E. REFERENCE EXAMPLES FROM RESNET AND COMNET

RESNET Publication No 002-2020 (RESNET 2020) Procedures for Verification of RESNET Accredited HERS Software Tools, RESNET Publication No. 002-2020, November 2020, Residential Energy Services Network, Inc., Oceanside, CA, provides an example of references to Standard 140 that includes pass/fail criteria. The criteria are limited to Class II software and currently three programs are included in the RESNET Registry of Rating Software Programs. Under the Software Verification Test Suite section shows:

"The ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 test procedure has been adopted by RESNET and is a requirement for all software programs to be accredited (See Section 4.1)."

and then Section 4.1 states:

"Standard 140, Class II Tests were developed from the HERS BESTEST for testing the accuracy of simulation software for predicting building loads. The ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 test procedure has been adopted by RESNET and is a requirement for all software programs to be accredited. Acceptance criteria for this suite of tests shall be as follows:

Annual Heating Loads
Colorado Springs, CO

Case	range max	range min
L100AC	79.48	48.35
L110AC	103.99	71.88
L120AC	64.30	35.98
L130AC	53.98	39.75
L140AC	56.48	43.24
L150AC	71.33	39.76
L155AC	74.18	42.66
L160AC	81.00	48.78
L170AC	92.40	58.11
L200AC	185.87	106.41
L202AC	190.05	111.32
L302XC	90.52	19.20
L304XC	75.32	23.51
L322XC	118.20	18.71
L324XC	80.04	32.71

Annual Heating Load Deltas
Colorado Springs, CO

Case	range max	range min
L110AC-L100AC	29.68	17.43
L120AC-L100AC	-7.67	-18.57
L130AC-L100AC	-5.88	-27.50
L140AC-L100AC	0.37	-24.42
L150AC-L100AC	-3.02	-12.53
L155AC-L150AC	6.88	-1.54
L160AC-L100AC	5.10	-3.72
L170AC-L100AC	17.64	7.12
L200AC-L100AC	107.66	56.39
L202AC-L200AC	11.25	-0.51
L302XC-L100AC	14.50	-31.43
L302XC-L304XC	17.75	-4.46
L322XC-L100AC	39.29	-33.54
L322XC-L324XC	38.27	-14.17

Annual Cooling Loads
Las Vegas, NV

Case	range max	range min
L100AL	64.88	41.47
L110AL	68.50	46.80
L120AL	60.14	40.08
L130AL	45.26	30.98
L140AL	30.54	19.52
L150AL	82.33	49.46
L155AL	63.06	35.58
L160AL	72.99	51.26
L170AL	53.31	34.05
L200AL	83.43	56.18
L202AL	75.96	49.50

Annual Cooling Load Deltas
Las Vegas, NV

Case	range max	range min
L110AL-L100AL	7.84	-0.98
L120AL-L100AL	0.68	-8.67
L130AL-L100AL	-9.69	-24.40
L140AL-L100AL	-20.29	-38.68
L150AL-L100AL	20.55	8.72
L155AL-L150AL	-9.64	-22.29
L160AL-L100AL	12.78	3.88
L170AL-L100AL	-4.83	-15.74
L200AL-L100AL	21.39	6.63
L200AL-L202AL	14.86	2.03

While these pass/fail criteria are only for Class II software (typically residential), a project in the 2000's called COMNET, while not as widely used as RESNET, provided similar requirements for Standard 140 Class I software (typically non-residential software). COMNET includes a description of ASHRAE Standard 140 and this paragraph:

> "COMNET software is required to perform the ASHRAE Standard 140-2007 suite of software tests and the results of these tests shall conform to the COMNET acceptance requirements. All tests shall be completed in accord with the requirements of ASHRAE Standard 140-2007. The resulting estimates of energy consumption shall fall between the minimum and maximum values established by COMNET, unless a valid explanation is provided. The portfolio folder for Appendix E contains spreadsheets wherein the software vendor enters the results of the Standard 140 simulations for comparison against the criteria. When results from candidate software fall outside the COMNET acceptance range or when candidate software is unable to perform one of the tests, the vendor shall provide an explanation of the reason as per ASHRAE Standard 140-2007 requirements. The portfolio folder for Appendix E also contains a methodology paper that describes how the acceptance criteria were developed."

The spreadsheets referenced are based on the Standard 140 results spreadsheets for thermal fabric, cooling equipment, and heating equipment tests and include minimum and maximum acceptance values for most of the user provided annual results including differences between test cases.

F. REFERENCE EXAMPLES FROM EUROPEAN UNION'S ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE (EPBD)

Unlike other codes and standards, the European Union's Energy Performance of Buildings Directive (EPBD) references Standard 140 as a validation approach to its own software rather than a criterion for software made by others that are used for compliance. The EPBD references several ISO documents including ISO 52016-1:2017 titled "Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures" which specifies the calculation procedure that is used when complying with the directive. This calculation procedure is essentially a simplified simulation method and so Standard 140 is cited in much the same way as building energy model software vendors would use the Standard. This is not a good source to emulate unless the referencing code or program has created its own simulation program in-house.

G. HOW TO UPDATE REFERENCES TO ALIGN WITH STANDARD 140-2023 SECTION RENUMBERING

Code officials and program administrators can refer to Table 1 which lists commonly referenced sections to update references and align with Standard 140-2023 section renumbering.

Table 1. Update references to align with Standard 140-2023 section renumbering

Commonly referenced section numbers in Standard 140-2020	Updated corresponding section(s) numbers in Standard 140-2023
Sections 5.2.1, 5.2.2, and 5.2.3	Section 7
Section 5.2.4	Section 8
Section 5.3	Section 9
Section 5.4	Section 10
Section 5.5	Section 11
Section 6	part of Sections 7-11
Sections 7 and 8	Section 12

7. HISTORY OF ASHRAE STANDARD 140

ASHRAE Standard 140 was first published in 2001, built upon the International Energy Agency (IEA) Building Energy Simulation Test (BESTEST) and Diagnostic Method [2]. It standardizes quality assurance procedures and evaluation methods focusing on building thermal envelope and fabric loads of BPS software. Standard 140 is under continuous maintenance to broaden the scope of test suites and update existing ones. Updates have been published in 2004, 2007, 2011, 2014, 2017, 2020, and 2023. Table 2 summarizes the history of new additions to the Standard.

Early BPS comparative work goes back to at least the 1970s with ASHRAE [3, 4] and the International Energy Agency (IEA) [5]. Development of formal building energy simulation test methods began in the 1980s at the National Renewable Energy Laboratory (NREL) in cooperation with three IEA research tasks [6]. This work culminated in the publication of several BESTEST reports [2, 6-8]. In 1989, ASHRAE Technical Committee 4.7 Energy Calculations (TC 4.7) initiated the formation of SPC 140. TC 4.7 sponsored two related research projects to develop analytical verification test suites for possible inclusion in Standard 140: 865-RP "Development of Accuracy Tests for Mechanical System Simulation"[9] and 1052-RP "Development of An Analytical Verification Test Suite for Whole Building Energy Simulation Programs – Building Fabric"[10]. In parallel with that, the first edition of Standard 140-2001 was developed based on the test procedures in BESTEST thermal fabric [2]. More details about the methodology and development of Standard 140 and related work may be found in [6, 11] and in Standard 140-2023, *§Informative Annex B23*.

Table 2. Standard 140 development history.

Section	Test Method	Initial Publication	Year	Primary Reference
§7 Building Thermal Envelope and Fabric Load Tests	Comparative	140-2001	2001	BESTEST[2]
§9 Space-Cooling Equipment Performance Tests	Analytical	140-2001 addendum a	2004	HVAC BESTEST [7]
§9 Space-Cooling Equipment Performance Tests	Comparative	140-2004 addendum b	2007	HVAC BESTEST [8]
§10 Space-Heating Equipment Performance Tests	Comparative	140-2004 addendum a	2007	Furnace BESTEST [12]
§12 Class II Test Procedures	Comparative	140-2007 addendum b	2011	HERS BESTEST [12]
§8 Ground-Coupled Slab-on-Grade	Analytical	140-2011 addendum a	2014	Ground-Coupled Slab BESTEST [14]
§11 Air-Side HVAC Equipment Analytical Verification Tests	Quasi-Analytical	140-2014 addendum a	2017	865-RP[8] Airside HVAC BESTEST Vol. 1 [15]
Revised *§7* Building Thermal Envelope and Fabric Load Tests	Comparative	140-2017 addendum a	2020	Update of ASHRAE Standard 140 Section 5.2 [16]
§6 Weather Drivers	Comparative	140-2020 addendum a	2023	[17]
§Annex A3 Acceptance Criteria		140-2020 addendum b	2023	[18]

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