BSR/ASHRAE Addendum b to
ANSI/ASHRAE Standard 140-2020

First Public Review Draft

Proposed Addendum b to
Standard 140-2020, Method of Test
for Evaluating Building
Performance Simulation Software

First Public Review Draft (August 2022)
(Draft shows Proposed Changes to Current Standard)

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ASHRAE, 180 Technology Parkway, Peachtree Corners GA 30092
Proposed BSR/ASHRAE Addendum b to ANSI/ASHRAE Standard 140-2020, Method of Test for Evaluating Building Performance Simulation Software

[Note to Reviewers: This addendum indicates addition of Acceptance Criteria to Standard 140. The following informative Foreword is new material for the addendum; underline text not applied. For the next Standard 140 continuous maintenance revision, portions of this Foreword may be integrated with the current Standard 140 Foreword at the discretion of the SSPC 140 Chair.]

(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

Foreword to Addendum b

Purpose of the Addendum

The purpose of this addendum is to add Software Acceptance Criteria to Standard 140, allowing organizations citing Standard 140 to require the results from software used for their purposes to be within the ranges included in this addendum. This provides those organizations with a measure of the acceptability of a building performance simulation software program based on the tests included in Standard 140. The acceptance criteria were developed by a working group including members of both ASHRAE Standing Standard Project Committee 140 (SSPC 140) and ASHRAE Standard Project Committee 90.1 (SSPC 90.1) – Energy Cost Budget (ECB) Subcommittee. Related project funding for development was provided by the U.S. Department of Energy through Argonne National Laboratory.

Background

Prior to this addendum, Standard 140 included test cases with example results to evaluate building performance software, but did not include any information on when a software’s results would be considered acceptable for the test cases. This meant that organizations that cited Standard 140 would only require that software ran the tests and not that their results had to be within a specific range of results. Historically, this caused confusion for jurisdictions adopting standards like 90.1 (that reference 140) when trying to determine if certain software passed or failed 140, when simply running the tests was all that was required.

To address that issue, this addendum introduces Acceptance Criteria to Standard 140 for determining if a software is suitable for a citing organization’s application. The Acceptance Criteria divide a subset of the Standard 140 test cases into test groups and into further results subsets for individual test cases and sensitivity tests (differences between selected individual test cases). The Acceptance Criteria also provide statistically derived acceptance ranges, against
which a tested software’s results are compared. The number of the test ranges that the software’s results must be within to be considered acceptable for a specific test group is also defined.

Informative sections on the development of the Acceptance Criteria procedure and advice to the citing organizations have also been added. These sections are intended to clarify the process of citing Standard 140 and provide guidance regarding appropriate considerations when approving software for an organization’s purposes.

All major building energy modeling software developers were invited to participate in the process to determine the acceptance ranges and many software developers participated. The acceptance ranges were set so that most commonly used software programs are within the ranges and additional software are expected to be within the ranges as software developers address outlying results. Overall, this approach will encourage building performance simulation software to be more accurate and consistent.

The Acceptance Criteria are presented in new Normative Annex A3 and Informative Annex B12.

Summary of changes in this addendum:

A listing of the substantive changes to Sections 5.6, and related sections, annexes, and accompanying electronic media follows (listed Sections are normative unless otherwise indicated):

- Update Section 3.1, “Definitions,” includes new defined terms.
- Update Section 4.1, “General,” includes reference to Acceptance Criteria.
- New Informative Section 4.5 “Citing Standard 140,” includes advice to organizations citing Standard 140.
- Update Section 5.1.4, “Consistent Modeling Methods,” includes requirements for consistent numerical settings.
- New Informative Annex B12, “Development of Acceptance Criteria,” includes a description of the procedure used to develop the Acceptance Criteria.
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Annex C Addenda Description Information
[Note to Reviewers: Annex C is informative material, briefly summarizing the addendum and its approval dates, to be included by ASHRAE Staff in the next continuous maintenance revision of Standard 140 (after publication of the addendum).]

Online Supporting Files: http://www.ashrae.org/140-2020
3.1 Terms Defined for This Standard

**annual heating load:** the heating load for the entire one-year simulation period. *(Informative Note: For example, for hourly simulation programs, this is the sum of the hourly heating loads for the one-year simulation period.)*

**annual sensible cooling load:** the sensible cooling load for the entire one-year simulation period. *(Informative Note: For example, for hourly simulation programs, this is the sum of the hourly sensible cooling loads for the one-year simulation period.)*

**building thermal envelope and fabric:** elements of a building that enclose spaces and that control or regulate heat and mass transfer between the interior spaces and the building exterior, the internal thermal capacitance, and heat and mass transfer between internal zones.

**calculation engine:** the component of the software that performs the building performance simulation calculations.

**convergence tolerance:** for an iterative solution process, the maximum acceptable magnitude of a selected error estimate; when the error criterion is satisfied, the process is deemed to have converged on a sufficiently accurate approximate solution.

**cooling-coil latent load:** the rate of heat extraction required to condense the moisture in cooling-coil entering air that becomes condensate. *(Informative Note: For an example, see 2012 ASHRAE Handbook—HVAC Systems and Equipment \(^{B-1}\), Chapter 23, Equation 38.)*

**cooling-coil sensible load:** the sum of the rate of heat extraction required to

a. cool the leaving moist air mass from the cooling-coil entering air temperature to the cooling-coil leaving air temperature,

b. cool any to-be-condensed vapor from the cooling-coil entering air temperature to the condensation temperature, and

c. cool any condensate from the condensation temperature to the leaving condensate temperature.

*(Informative Note: For examples, see 2012 ASHRAE Handbook—HVAC Systems and Equipment \(^{B-1}\), Chapter 23, Equations 39 and 39a.)*

**cooling-coil total load:** the sum of cooling-coil sensible load and cooling-coil latent load. *(Informative Note: For examples, see 2012 ASHRAE Handbook—HVAC Systems and Equipment \(^{B-1}\), Chapter 23, Equations 36 and 37.)*
cooling energy consumption: the site electric energy consumption of the mechanical cooling equipment, including the compressor, air distribution fan (regardless of whether the compressor is ON or OFF), condenser fan, and related auxiliaries.

heating-coil load: the rate of heat addition required to heat the moist air mass entering the heating coil from the heating-coil entering air temperature to the heating-coil leaving air temperature.

humidity ratio: the ratio of the mass of water vapor to the mass of dry air in a moist air sample.

infiltration: the leakage of air through any building element. (Informative Note: For example, air leakage through walls, windows, and/or doors.)

input interface: the component of the software used for communicating the inputs to the calculation engine.

latent heat: the change in enthalpy associated with a change in humidity ratio, caused by the addition or removal of moisture. (See humidity ratio.)

numerical settings: software settings related to minimum resolution (e.g., maximum timestep, maximum convergence tolerance, etc.).

output interface: the component of the software for processing, storing, and displaying the outputs of the calculation engine.

preheat-coil load: the rate of heat addition required to heat the moist air mass entering the preheat coil from the preheat-coil entering air temperature to the preheat-coil leaving air temperature.

quasi-analytical solution: the mathematical solution of a model for a given set of parameters and simplifying assumptions; such a solution is allowed to include minor interpretation differences that cause minor results variations. (Informative Note: Such a solution may be computed by generally accepted numerical methods or other means, provided that such calculations occur outside the environment of a whole-building energy simulation program and can be scrutinized.)

reheat-coil load: for a given zone reheat coil, the rate of heat addition required to heat the given zone supply air moist-air mass from the system supply air temperature to the zone supply air temperature for the given zone.

sensible heat: the change in enthalpy associated with a change in dry-bulb temperature caused by the addition or removal of heat

software: a package consisting of the user interface, input interface, calculation engine, and output interface, including any nesting of these elements within multiple input/output interfaces where applicable.

user interface: the component of the software for users to specify inputs to the input interface and for the output interface or calculation engine to display outputs to the user.
4.1 General. The test procedures shall be applied as specified in Normative Sections 5 through 8. Content of the normative sections and organization of the test procedures are described in Sections 4.1.1 and 4.1.2 and in greater detail in Informative Section 4.3. Normative Annex A3 Acceptable Software Criteria includes tables of numerical ranges for test cases applied for establishing acceptable software and describes results submission.

Codes and standards that reference Standard 140 shall be permitted to call out specific sections within Standard 140 to specify require individual test cases or groups of test cases. Where specific sections are not called out for acceptance criteria, all test groups of Annex A3 shall apply. Informative Note: Informative Section 4.5 provides additional items for organizations citing Standard 140 to consider.

4.5 (Informative) Citing Standard 140. 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. Considerations include, but are not necessarily limited to:

1. Sections of Standard 140 to be completed

Standard 140 is organized into sections that test different modeling aspects (e.g., building thermal fabric, equipment performance). Not all the sections may apply to the organization’s purpose in requiring building simulation and testing using Standard 140. Organizations should review sections and only cite those that are important for their purposes. For example, an organization that is interested in the performance of low-rise residential buildings may wish to only include the tests of Section 7 in its testing requirements.

2. Acceptance criteria test groups applicability

The acceptance criteria are grouped by the tested modeling aspect (e.g., building thermal fabric, equipment performance). Not all the modeling aspects may apply to the organization’s purpose in requiring building simulation and testing using Standard 140. Organizations should review the test groups and only cite those needed to test modeling aspects that are important for their purposes. For example, an organization that is interested in the thermal performance of buildings and not heating and cooling equipment performance may wish to only include the thermal fabric test groups (e.g., low mass building and high mass building) in its acceptance criteria requirements.

3. Untested algorithm usage in simulations performed for the organization’s purposes
An organization citing Standard 140 should explicitly state whether untested algorithms are allowed to be used in simulations performed for their purposes. Since Standard 140 does not test all aspects of building performance simulation, this decision may not be straightforward.

The intent of Standard 140 is to be a “P.E. exam” for software. This implies that if a software passes the Standard 140 test cases, which test a subset of algorithms applied in BPS software, the passing software is deemed as satisfactory to be applied for all BPS modeling applications, including applications not explicitly covered by the Standard 140 test cases. Based on this intent, an organization citing Standard 140 should avoid restricting untested algorithms unless there is clear cause to do otherwise or clear cause to specify the particular algorithms that must be tested where the current version of Standard 140 provides relevant tests.

4. Untested alternative algorithm usage in simulations performed for the organization’s purposes

An organization citing Standard 140 should explicitly state whether untested alternative algorithms are allowed to be used in simulations performed for their purposes. Since Standard 140 does not test all possible algorithms for specific aspects of building performance simulation, this decision may not be straightforward. This is because software may have several algorithms available for specific calculations. When running the Standard 140 test cases, the most appropriate or best practice algorithms may be selected. It is not practical to run all of the algorithm options for a given modeling aspect because some may not be appropriate given the context of the test case and/or the number of combinations and permutations of algorithm options is too large to run in a reasonable time frame.

The following discussion gives examples of why it is appropriate to allow alternative algorithms with more or less detailed inputs than the algorithm chosen by the modeler running the test cases for a given program.

a. There are situations where simple algorithms are prescribed for a Standard 140 test case because they make differences in results among software easier to diagnose. However, in practice, a more detailed algorithm would be more accurate for the purposes of an organization citing Standard 140. For example, many of the test cases specify a constant infiltration rate meaning most programs would set an infiltration rate and not use a weather-driven infiltration calculation. The weather-driven infiltration calculation may be more appropriate or even required for the calculations for the organization’s purposes. If untested alternative algorithms are not allowed, then software would have to use the constant infiltration rate and not the weather-driven infiltration algorithms.

b. A test case specification may describe more details for an aspect of the model than is needed or is practical for an organization’s purposes. For example, most of the windows in Standard 140 are specified with full detailed window inputs (e.g., including specular angle-dependent optical properties), but an organization citing Standard 140 may only specify the NFRC rating properties of a window (U-value and SHGC) and not require the full specular properties. In this case, it would be more appropriate for the software to be tested using the same NFRC rating inputs for the window that are available to the users of the software for the organization’s purposes and for an organization to not allow the software to be tested using the more detailed window model inputs.
untested

provided in the test case description when those same inputs are not available to the user in practice.

If unsure about whether untested alternative algorithms should be permitted for simulations performed for the organization’s purposes, allow more detailed algorithms than those prescribed by the test cases to be used; when the test cases allow for equivalent or alternative modeling inputs or algorithms, restrict the software to the modeling inputs and algorithms used in the test cases.

5. Untested numerical settings (for example, time steps and tolerances) usage in simulations performed for the organization’s purposes

Similar to the algorithms in software, there are a number of numerical settings that can influence the outputs from the software. These include settings like the timestep used in the calculations and tolerances used for determining convergence. An organization citing Standard 140 should explicitly state whether untested numerical settings are allowed for their purposes. For example, if for a given tested program, the test cases were run with a 15-minute timestep, the organization may want to restrict software from running with a longer timestep, like 1 hour. However, it is possible that the test cases are run with a longer timestep, like 1 hour, and the organization would not want to restrict software from running with a shorter timestep. Different test suites may have different numerical settings based on the nature of the tests included in the test suite. For example, programs running the air-side equipment test suite may need to use smaller timesteps than for the thermal fabric test suites in order to promote convergence. The thermal fabric test suites likely use numerical settings closest to those common in whole building simulations. If unsure about how the untested numerical settings apply for an organization’s purposes, allow numerical settings at or at a higher resolution (e.g., shorter timesteps) than those tested in Thermal Fabric tests (sections 5.2.1 and 5.2.2) to be used.

6. Non-user-accessible input internal modifications for the purposes of testing in accordance with the test descriptions of this standard but not made available to the user in the publicly available software

In some cases, an algorithm or input that is available in the calculation engine is restricted from the user by the user interface, and this non-user-accessible input is more appropriate for the test case. For example, the calculation engine can perform calculations with a constant infiltration rate as described in the test case, but the user interface restricts the user from selecting this option. Organizations citing Standard 140 should explicitly state whether using non-user accessible inputs to perform the tests is allowed for their purposes. If unsure about whether non-user-accessible inputs may be used in testing, allow them to be used.

7. Source code changes for the purpose of running tests that are not made available in the publicly available software

In some cases, a software is not capable of running a test case without a change to the source code, and the developers don’t believe releasing the software with the change is appropriate. For example, a test case requires a coil bypass factor of 0, which is not a realistically feasible bypass factor. A software’s algorithms do not allow for a bypass factor of 0 to be used. The developer modifies the code to allow the bypass factor of 0 to run the test case and check if the software performs within the acceptable criteria. The developer does not want to release the modified source code because it allows the user to specify an
unrealistic condition. Organizations citing Standard 140 should explicitly state whether using software without the modified source code is allowed for their purposes. If unsure about whether changes to non-publicly released source code may be used, do not allow non-publicly released source code to be used.

8. Unittested versions of the software

New release versions of a software may include changes to the calculation engine and/or to ancillary processes (i.e., input interface, output interface, and/or user interface) that do not affect the calculated results. Organizations citing Standard 140 should explicitly state whether using untested versions of a software is allowed for their purposes. If unsure about whether untested versions of the software may be used, do not allow untested versions of the software that include changes to the calculation engine to be used.

[Note to Reviewers: Sections 5.1.1 through 5.1.3 are not shown; that material is unchanged.]

[Note to Reviewers: Section 5.1.4 is revised as shown with edit tracking.]

5.1.4 Consistent Modeling Methods. Where options exist within a simulation program for modeling a specific thermal behavior, consistent modeling methods shall be used for all cases. Consistent numerical settings shall be used for all tests in a given test suite. The option and numerical settings that is used shall be documented in the Standard Output Report (as specified in Normative Annex A2).

Informative Notes:

1. For example, if a program gives a choice of methods for modeling windows, the same window modeling method is to be applied for all cases.

2. Test suites are outlined in Informative Section 4.3.

[Note to Reviewers: Sections 5.1.5 through Annex A2 are not shown; that material is unchanged.]

[Note to Reviewers: Following is new Annex A3; edit tracking is not applied.]

Normative Annex A3 “Software Acceptance Criteria”

This annex provides the acceptance criteria for the software. In order to comply, the software must demonstrate that a sufficient number of software results (see Section A.2) are within the ranges specified in Section A3.1 for each set of test cases.

Software includes the calculation engine and the corresponding user interface. The testing of software only meets the requirements of this annex for that software and cannot be used as a proxy for documenting compliance of another software that uses the same calculation engine but a different user interface.

A3.1 Class I Software Ranges

Tables A3-1 through A3-13 give the acceptance criteria ranges for the test groups. Ranges are given for both selected individual test-case results (e.g., Case 600) and differences between the results of two test cases, i.e., result sensitivities (e.g., Case 610 – Case 600). A software result is within a given range when
the software result is equal to or greater than the lower limit and less than or equal to the upper limit shown for the given range in the tables.

**Informative Note:** The setting of these ranges is based on the calculations shown in Informative Annex B12, Section B12.1 – Acceptance Criteria Bounds Calculations.

The following tables are related to the building thermal envelope and fabric load tests of Sections 5.2.1, 5.2.2, and 5.2.3.

Table A3-1 Low Mass Building – Annual Heating Load (MWh/yr)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 600</td>
<td>3.75</td>
<td>4.98</td>
</tr>
<tr>
<td>Case 610 – Case 600</td>
<td>-0.14</td>
<td>0.29</td>
</tr>
<tr>
<td>Case 620 – Case 600</td>
<td>-0.08</td>
<td>0.40</td>
</tr>
<tr>
<td>Case 630 – Case 620</td>
<td>0.02</td>
<td>0.74</td>
</tr>
<tr>
<td>Case 640 – Case 600</td>
<td>-2.17</td>
<td>-1.22</td>
</tr>
<tr>
<td>Case 660 – Case 600</td>
<td>-1.07</td>
<td>-0.16</td>
</tr>
<tr>
<td>Case 670 – Case 600</td>
<td>0.25</td>
<td>2.98</td>
</tr>
<tr>
<td>Case 680 – Case 600</td>
<td>-2.54</td>
<td>-1.90</td>
</tr>
<tr>
<td>Case 685 – Case 600</td>
<td>0.33</td>
<td>0.77</td>
</tr>
<tr>
<td>Case 695 – Case 685</td>
<td>-2.38</td>
<td>-1.94</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.2.1.1.1

Table A3-2 Low Mass Building – Annual Sensible Cooling Load (MWh/yr)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 600</td>
<td>5.00</td>
<td>6.83</td>
</tr>
<tr>
<td>Case 610 – Case 600</td>
<td>-2.26</td>
<td>-0.80</td>
</tr>
<tr>
<td>Case 620 – Case 600</td>
<td>-2.24</td>
<td>-1.64</td>
</tr>
<tr>
<td>Case 630 – Case 620</td>
<td>-1.68</td>
<td>-0.77</td>
</tr>
<tr>
<td>Case 640 – Case 600</td>
<td>-0.56</td>
<td>0.03</td>
</tr>
<tr>
<td>Case 650 – Case 600</td>
<td>-1.54</td>
<td>-0.95</td>
</tr>
<tr>
<td>Case 660 – Case 600</td>
<td>-3.09</td>
<td>-2.50</td>
</tr>
<tr>
<td>Case 670 – Case 600</td>
<td>0.05</td>
<td>0.84</td>
</tr>
<tr>
<td>Case 680 – Case 600</td>
<td>0.13</td>
<td>0.87</td>
</tr>
<tr>
<td>Case 685 – Case 600</td>
<td>2.70</td>
<td>3.31</td>
</tr>
<tr>
<td>Case 695 – Case 685</td>
<td>-0.21</td>
<td>0.44</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.2.1.1.2

Table A3-3 High Mass Building – Annual Heating Load (MWh/yr)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 900</td>
<td>1.04</td>
<td>2.28</td>
</tr>
<tr>
<td>Case 900 – Case 910</td>
<td>-0.52</td>
<td>-0.02</td>
</tr>
<tr>
<td>Case 920 – Case 900</td>
<td>1.51</td>
<td>1.92</td>
</tr>
<tr>
<td>Case 930 – Case 920</td>
<td>0.20</td>
<td>1.15</td>
</tr>
<tr>
<td>Case 940 – Case 900</td>
<td>-0.82</td>
<td>-0.37</td>
</tr>
</tbody>
</table>
Table A3-4 High Mass Building – Annual Sensible Cooling Load (MWh/yr)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 900</td>
<td>2.35</td>
<td>2.60</td>
</tr>
<tr>
<td>Case 900 – Case 910</td>
<td>0.35</td>
<td>1.74</td>
</tr>
<tr>
<td>Case 920 – Case 900</td>
<td>0.08</td>
<td>0.48</td>
</tr>
<tr>
<td>Case 930 – Case 920</td>
<td>-1.19</td>
<td>-0.44</td>
</tr>
<tr>
<td>Case 940 – Case 900</td>
<td>-0.19</td>
<td>0.06</td>
</tr>
<tr>
<td>Case 950 – Case 900</td>
<td>-2.00</td>
<td>-1.56</td>
</tr>
<tr>
<td>Case 960 – Case 900</td>
<td>-1.81</td>
<td>-1.27</td>
</tr>
<tr>
<td>Case 980 – Case 900</td>
<td>1.09</td>
<td>1.41</td>
</tr>
<tr>
<td>Case 985 – Case 900</td>
<td>3.52</td>
<td>4.18</td>
</tr>
<tr>
<td>Case 995 – Case 985</td>
<td>0.63</td>
<td>1.15</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.2.1.1.2

The following table is related to the space-cooling equipment performance tests of Section 5.3.

Table A3-5 Annual Total Cooling Energy Consumption (kWh/yr)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE300</td>
<td>33497</td>
<td>37023</td>
</tr>
<tr>
<td>CE310 – CE300</td>
<td>2671</td>
<td>6197</td>
</tr>
<tr>
<td>CE320 – CE300</td>
<td>2610</td>
<td>6136</td>
</tr>
<tr>
<td>CE330 – CE320</td>
<td>-766</td>
<td>2760</td>
</tr>
<tr>
<td>CE330 – CE300</td>
<td>3697</td>
<td>7223</td>
</tr>
<tr>
<td>CE340 – CE300</td>
<td>3172</td>
<td>6698</td>
</tr>
<tr>
<td>CE330 – CE340</td>
<td>-1393</td>
<td>2133</td>
</tr>
<tr>
<td>CE350 – CE300</td>
<td>-5354</td>
<td>-1828</td>
</tr>
<tr>
<td>CE360 – CE300</td>
<td>18084</td>
<td>21610</td>
</tr>
<tr>
<td>CE400 – CE300</td>
<td>-5783</td>
<td>-2179</td>
</tr>
<tr>
<td>CE410 – CE300</td>
<td>-5929</td>
<td>-371</td>
</tr>
<tr>
<td>CE420 – CE300</td>
<td>-3945</td>
<td>-419</td>
</tr>
<tr>
<td>CE430 – CE300</td>
<td>-4762</td>
<td>-1236</td>
</tr>
<tr>
<td>CE440 – CE300</td>
<td>-3694</td>
<td>-168</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.3.2.1.1.1(a)

The following tables are related to the space-heating equipment performance tests of Section 5.4.
Table A3-6 Furnace Input Energy (GJ)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE210</td>
<td>49.86</td>
<td>55.11</td>
</tr>
<tr>
<td>HE220 – HE210</td>
<td>-5.48</td>
<td>-0.23</td>
</tr>
<tr>
<td>HE230 – HE220</td>
<td>-9.10</td>
<td>-3.86</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.4.1.2

Table A3-7 Heating Equipment Cumulative Fan Energy (kWh)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE210</td>
<td>279.55</td>
<td>308.98</td>
</tr>
<tr>
<td>HE220 – HE210</td>
<td>-30.21</td>
<td>-0.78</td>
</tr>
<tr>
<td>HE230 – HE220</td>
<td>186.29</td>
<td>216.78</td>
</tr>
</tbody>
</table>

* For output specified in Section 6.4.2.1

The following tables are related to the air-side HVAC equipment performance tests of Section 5.5.

Table A3-8 Preheat-Coil Load (kWh/h)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE301</td>
<td>2.80</td>
<td>4.20</td>
</tr>
<tr>
<td>AE401</td>
<td>9.75</td>
<td>10.77</td>
</tr>
<tr>
<td>AE301 – AE401</td>
<td>-7.67</td>
<td>-6.16</td>
</tr>
</tbody>
</table>

* For output specified in Sections 6.5.3.2(a) and 6.5.4.2

Table A3-9 Heating-Coil Load (kWh/h)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE201</td>
<td>7.94</td>
<td>8.78</td>
</tr>
</tbody>
</table>

* For output specified in Sections 6.5.1.2(a) and 6.5.2.2

Table A3-10 Cooling-Coil Total Load (kWh/h)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE205</td>
<td>1.82</td>
<td>2.01</td>
</tr>
<tr>
<td>AE245 – AE205</td>
<td>0.20</td>
<td>0.39</td>
</tr>
<tr>
<td>AE206</td>
<td>2.54</td>
<td>2.85</td>
</tr>
<tr>
<td>AE226-206</td>
<td>0.55</td>
<td>0.82</td>
</tr>
<tr>
<td>AE305</td>
<td>8.77</td>
<td>9.85</td>
</tr>
<tr>
<td>AE305 – AE405</td>
<td>4.55</td>
<td>5.75</td>
</tr>
<tr>
<td>AE345 – AE305</td>
<td>-0.15</td>
<td>0.79</td>
</tr>
<tr>
<td>AE345 – AE445</td>
<td>4.76</td>
<td>6.01</td>
</tr>
<tr>
<td>AE306</td>
<td>13.65</td>
<td>15.08</td>
</tr>
<tr>
<td>AE306 – AE406</td>
<td>5.42</td>
<td>6.86</td>
</tr>
<tr>
<td>AE326 – AE306</td>
<td>5.68</td>
<td>7.12</td>
</tr>
<tr>
<td>AE326 – AE426</td>
<td>11.21</td>
<td>12.65</td>
</tr>
<tr>
<td>Range Case</td>
<td>Lower Limit</td>
<td>Upper Limit</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>AE205</td>
<td>1.82</td>
<td>2.01</td>
</tr>
<tr>
<td>AE205 – AE205</td>
<td>0.20</td>
<td>0.39</td>
</tr>
<tr>
<td>AE206</td>
<td>1.62</td>
<td>1.79</td>
</tr>
<tr>
<td>AE226-206</td>
<td>-0.23</td>
<td>0.06</td>
</tr>
<tr>
<td>AE305</td>
<td>8.77</td>
<td>9.85</td>
</tr>
<tr>
<td>AE305 – AE405</td>
<td>4.55</td>
<td>5.75</td>
</tr>
<tr>
<td>AE305 – AE405</td>
<td>-0.15</td>
<td>0.79</td>
</tr>
<tr>
<td>AE35 – AE445</td>
<td>4.76</td>
<td>6.01</td>
</tr>
<tr>
<td>AE306</td>
<td>8.30</td>
<td>9.37</td>
</tr>
<tr>
<td>AE306 – AE406</td>
<td>4.64</td>
<td>5.73</td>
</tr>
<tr>
<td>AE326 – AE306</td>
<td>-0.91</td>
<td>-0.01</td>
</tr>
<tr>
<td>AE326 – AE426</td>
<td>4.27</td>
<td>5.31</td>
</tr>
<tr>
<td>AE405</td>
<td>3.90</td>
<td>4.31</td>
</tr>
<tr>
<td>AE405 – AE405</td>
<td>-0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>AE406</td>
<td>3.45</td>
<td>3.82</td>
</tr>
<tr>
<td>AE406 – AE406</td>
<td>-0.22</td>
<td>0.14</td>
</tr>
</tbody>
</table>

* For output specified in Sections 6.5.1.2(d), 6.5.2.2, 6.5.3.2(d), and 6.5.4.2

Table A3-12 Zone 1 Reheat-Coil Load (kWh/h)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE301</td>
<td>7.23</td>
<td>8.10</td>
</tr>
<tr>
<td>AE401</td>
<td>4.27</td>
<td>4.72</td>
</tr>
<tr>
<td>AE301 – AE401</td>
<td>2.70</td>
<td>3.60</td>
</tr>
<tr>
<td>AE305</td>
<td>1.92</td>
<td>2.46</td>
</tr>
<tr>
<td>AE345 – AE305</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>AE306</td>
<td>1.92</td>
<td>2.48</td>
</tr>
<tr>
<td>AE326 – AE306</td>
<td>-0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>AE405</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>AE406</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

* For output specified in Sections 6.5.3.2(f) and 6.5.4.2

Table A3-13 Zone 2 Reheat-Coil Load (kWh/h)*

<table>
<thead>
<tr>
<th>Range Case</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE301</td>
<td>7.23</td>
<td>8.10</td>
</tr>
<tr>
<td>AE401</td>
<td>4.27</td>
<td>4.72</td>
</tr>
<tr>
<td>AE301 – AE401</td>
<td>2.70</td>
<td>3.60</td>
</tr>
<tr>
<td>AE305</td>
<td>1.92</td>
<td>2.46</td>
</tr>
<tr>
<td>AE345 – AE305</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>AE306</td>
<td>1.92</td>
<td>2.48</td>
</tr>
<tr>
<td>AE326 – AE306</td>
<td>-0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>AE405</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>AE406</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table A3-14: Acceptance Range Pass Criteria

<table>
<thead>
<tr>
<th>Test Group</th>
<th>Tables of Ranges</th>
<th>Number of Range Cases in Test Group</th>
<th>The minimum number of Range Cases within the Test Group to pass.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Fabric Low Mass</td>
<td>A3-1, A3-2</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Thermal Fabric High Mass</td>
<td>A3-3, A3-4</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Cooling Equipment</td>
<td>A3-5</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Heating Equipment</td>
<td>A3-6, A3-7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Air-side Equipment</td>
<td>A3-8, A3-9, A3-10, A3-11, A3-12, A3-13</td>
<td>54</td>
<td>48</td>
</tr>
</tbody>
</table>

A3.2 Number of Results Within Acceptance Range to Pass a Test Group

Table A3-14 gives the number of range cases for which a software’s results must be within the acceptable ranges to pass a test group. Software shall pass a test group when the count of results computed for each range case, from the corresponding tables of ranges, meets or exceeds the minimum count required in Table A3-14.

**Informative Note:** See Informative Annex B12, Section B12.4 for a description of the procedures used to determine the numbers in the table.

A3.3 Submission of Results

Test results shall be provided in the normative output forms of Normative Annex A2. Submittals shall also include a complete set of reports, as described in Normative Annex A2, Attachment A2.7, with all report blocks completed.

*For output specified in Sections 6.5.3.2(g) and 6.5.4.2*
Informative Annex B12 “Development of Acceptance Criteria”

B12.1 Acceptance Criteria Bounds Calculations

The results from a reference set of software programs (see Section B12.1.2), also called “reference results” here, are used to calculate the upper and lower limits for the acceptance criteria.

B12.1.1 Equations for Setting Bound Limits

The upper and lower limits for each range case applied for acceptance criteria are set by selecting the lower minimum value and higher maximum value of:

1. Statistical Bounds (SB):
   - Minimum: \( \text{MinSB} = \text{Median}_{\text{case}} - \text{MAD}_{3\text{sigma}} \)
   - Maximum: \( \text{MaxSB} = \text{Median}_{\text{case}} + \text{MAD}_{3\text{sigma}} \)
   where
   - \( \text{Median}_{\text{case}} \equiv \text{median value of reference results for a given case} \)
   - \( \text{MAD}_{3\text{sigma}} \equiv \text{Median Absolute Deviation (MAD) with 99.73\% (3 sigma) confidence interval, for the reference results of a given case} \)
   and
   \[
   \text{MAD}(X) = \text{Median}[[X - \text{Median}(X)]]
   \]
   for a Normal distribution, we can relate \( \text{MAD} \) to the standard deviation as
   \[
   \text{MAD} = \sigma \Phi^{-1}\left(\frac{3}{4}\right) = \sigma \sqrt{2} \text{erf}^{-1}\left(\frac{1}{2}\right) \approx 0.6745 \sigma
   \]
   where
   - \( \sigma \equiv \text{standard deviation} \)
   - \( \Phi \equiv \text{quantile function} \)
   - \( \text{erf} \equiv \text{error function} \)

   The bounds of the confidence interval can be set in terms of \( \pm \text{ standard deviation from the average or } \pm \text{MAD from the median. In this case, a 99.73\% confidence interval results from 3 standard deviations (or 3 sigma), which leads to a MAD multiplier (MAD}_{3\text{sigma}) of 2.024.} \)

2. Non-Statistical Bounds (NSB):
   a. Where no quasi-analytical solution results exist for an acceptance criteria test group:
      - Minimum: \( \text{MinNSB} = \text{Median}_{\text{case}} - \text{Median}_{\text{BC}} \times 0.05 \)
      - Maximum: \( \text{MaxNSB} = \text{Median}_{\text{case}} + \text{Median}_{\text{BC}} \times 0.05 \)
      where
      - \( \text{Median}_{\text{BC}} \equiv \text{median value of reference results of base case (BC) for a given case} \)
   b. Where quasi-analytical solution results (QAS) exist for an acceptance criteria test group:
      - Minimum: \( \text{MinNSB} = \text{QAS}_{\text{case}} - \text{QAS}_{\text{BC}} \times 0.05 \)
      - Maximum: \( \text{MaxNSB} = \text{QAS}_{\text{case}} + \text{QAS}_{\text{BC}} \times 0.05 \)
BSR/ASHRAE Addendum a to ANSI/ASHRAE Standard 140-2020, Method of Test for Evaluating Building Performance Simulation Software
First Public Review Draft

where

\[ Q_{AS_{case}} \equiv \text{QAS value for a given case} \]
\[ Q_{AS_{BC}} \equiv \text{QAS value of the base case (BC) for a given case} \]

B12.1.2 Reference Software for Setting Bound Limits

The reference set of software for setting the bound limits is selected based on the following criteria:

- A single set of results per calculation engine is included (multiple user interfaces for the same calculation engine are not included).
- Results are submitted by the calculation engine copyright holder(s) or by a modeler designated by the calculation engine copyright holder(s), applying a user interface specified by the calculation engine copyright holder(s) if appropriate.
- The set of selected software should represent a diversity of modeling methods, such as control-based and load-based.
- The calculation engine should be actively, reasonably, and widely used and actively maintained.
- Software satisfies the following:
  - Able to run at a timestep of an hour or less
  - Able to include hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation.
  - Include thermal mass effects.
- If a software did not participate in the simulation trials for the initial development of a test suite, then prior to the submittal, its results are reviewed and undergo iterative rounds of review and revisions as determined during the submission review process. The reviewer comments and submitter responses are documented from each round, with a logical basis for corrections to programs or inputs included in the documentation. This review process only applies to the initial submittal of a software and not subsequent submittals of that software for version updates.

The results from a reference software:

- Include justification via Annex A2, Attachment A2.7, Item G (“Report Block for Anomalous Results”) if they fall outside of the established bounds.
- Pass the minimum number of tests indicated for each test group in Table A3-14 that a given reference software provided results for.

The results from a reference software may be updated for each new public release of the calculation engine.

For future continuous maintenance revisions of Standard 140, SSPC 140 may:

- Include any additional software in the acceptance criteria-bounds reference set that apply and meet the criteria for inclusion.
- Remove any software from the reference set that no longer meet the criteria for inclusion.
- Update the acceptance criteria with the most recent results from the reference set of software.
The current reference set of software used to determine the acceptance criteria are (in alphabetical order): CSE, DeST, DOE-2.2, EnergyPlus, ESP-r, IDA ICE, IES-VE, TAS, and TRNSYS. Not all software are applied for all test groups.

B12.2 Acceptance Criteria Results Comparison

Given the upper and lower acceptance bound limits for the test cases are determined from the reference set of software, the results from other software can be compared against those limits. A software result is designated as an “outlier” for a given acceptance-criteria range case if that result is less than the lower limit or greater than the upper limit.

Tolerances will be used for comparisons to bounds

1. A relative tolerance of 1% (i.e., numbers within ≤ 1% of each other are considered equivalent)
2. An absolute tolerance of 1E-4 (i.e., numbers within 1E-4 of each other are considered equivalent even if that is more than 1%)

B12.3 Acceptance Criteria Tests Included

Not all test suites and test cases included in Standard 140 are appropriate to be used in acceptance criteria. The following criteria are applied in determining which test results are used in the acceptance criteria:

- A test group has enough of the reference set of software that can adequately perform all of the tests within the test group to produce statistically meaningful acceptance ranges. (In the addendum to Standard 140-2020 that first introduced the acceptance criteria, there are at least five reference-set software that can adequately perform the tests within each test group.)
- The tests are grouped to provide separate acceptance criteria for different sections of the standard
- When available, acceptance-criteria tests include outputs such as annual total load, energy use, or other annual summations based on realistic, time-varying conditions
- Differences between the results of two tests (i.e., result sensitivities) are preferred
- A base case for each test suite or portion of the test suite should be included

Based on these criteria, the following five test groups were selected for the acceptance criteria (selected outputs within each test group are also described, and test group 5 has separate selected outputs specific to its test cases):

1. Thermal Fabric Low Mass Test Group Range Cases

   Annual heating load and annual sensible cooling load

   Case 600
   Case 610 – Case 600
   Case 620 – Case 600
   Case 630 – Case 620
   Case 640 – Case 600
   Case 650 – Case 600 (cooling only)
2. Thermal Fabric High Mass Test Group Range Cases

*Annual heating load and annual sensible cooling load*

Case 900
Case 900 – Case 910
Case 920 – Case 900
Case 930 – Case 920
Case 940 – Case 900
Case 950 – Case 900 (cooling only)
Case 960 – Case 900
Case 980 – Case 900
Case 985 – Case 900
Case 995 – Case 985

3. Cooling Equipment Test Group Range Cases

*Annual total cooling energy consumption*

CE300
CE310 – CE300
CE320 – CE300
CE330 – CE320
CE330 – CE300
CE340 – CE300
CE330 – CE340
CE350 – CE300
CE360 – CE300
CE400 – CE300
CE410 – CE300
CE420 – CE300
CE430 – CE300
CE440 – CE300

4. Heating Equipment Test Group Range Cases

*Furnace input energy and cumulative fan energy*

HE210
HE220 – HE210
HE230 – HE220
5. **Air-side Equipment Test Group Range Cases**

*Heating-coil load*

AE201

*Preheat-coil load*

AE301
AE401
AE301 – AE401

*Cooling-coil total load and cooling-coil sensible load*

AE205
AE245 – AE205
AE206
AE226 – AE206
AE305
AE305 – AE405
AE345 – AE305
AE345 – AE445
AE306
AE306 – AE406
AE326 – AE306
AE326 – AE426
AE405
AE445 – AE405
AE406
AE426 – AE406

*Reheat-coil loads – zone 1 and zone 2*

AE301
AE401
AE301 – AE401
AE305
AE345 – AE305
AE306
AE326 – AE306
AE405
AE406

**B12.4 Acceptance Criteria Overall Passing**

Since there may be legitimate physical modeling reasons (see Informative Annex B11, Section B11.1.4) why a software’s results would fall outside of the acceptance range for an individual test or difference
between two tests, it is not reasonable to expect a software to pass all acceptance criteria for every test in a test group.

To determine the number of range cases for which a software’s results need to be within the acceptance ranges to pass a test group, the number of range cases in the test group is multiplied by 0.9, and the resulting number is rounded down to the nearest integer. E.g., for the thermal fabric low mass test group, there are 21 range cases; $21 \times 0.9 = 18.9$; rounding down yields 18 range cases.

[Note to Reviewers: Annex B13 through Annex C are not shown; that material is unchanged.]