Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs

See Informative Annex C for approval dates.

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FOREWORD

This standard method of test (SMOT) was developed to identify and diagnose differences in predictions from whole-building energy simulation software that may be caused by algorithmic differences, modeling limitations, faulty coding, inadequate documentation, or input errors. These tests are part of an overall validation methodology described in Informative Annex B23. The procedures test software over a broad range of parameteric interactions and for a number of different output types, thus minimizing the concealment of algorithmic differences by compensating errors. Different building energy simulation programs, representing different degrees of modeling complexity, can be tested. However, some of the tests may be incompatible with some building energy simulation programs.

The tests are a subset of all the possible tests that could occur. A large amount of effort has gone into establishing a sequence of tests that examines many of the physical and mathematical models relevant to simulating the energy performance of a building and its mechanical equipment. However, because building energy simulation software operates in an immense parameter space, it is not practical to test every combination of parameters over every possible range of function.

The tests consist of a series of carefully described test case building plan, material, and mechanical equipment specifications. Output values for the cases are compared and used in conjunction with diagnostic logic to determine the sources of predictive differences.

The test cases are divided into separate test classes to satisfy different levels of software modeling detail. Such classification allows more convenient citation of specific sections of Standard 140 by other codes and standards and by certifying and accrediting agencies. The Class I test cases (Section 5) are detailed diagnostic tests intended for simulation software capable of hourly or subhourly simulation time steps. The Class II test cases (Section 7) may be used for all types of building load calculation methods, regardless of time-step granularity, and are often favored by those needing to test simplified software for residential buildings. The Class I (Section 5) test cases are designed for more detailed diagnosis of simulation models than the Class II (Section 7) test cases. An overview of the test suites and methodologies that make up Standard 140 follows; Section 4 of the standard provides a detailed road map of the test specifications of Sections 5 and 7, and output requirements of Sections 6 and 8.

Class I Test Procedures (Section 5)

The set of Class I tests included herein consist of

a. software-to-software comparative tests, in which a program's results may be compared to itself or to the results of other programs in a consistent and repeatable manner, and

b. analytical verification tests, in which a program's results may be compared to the results from analytical, quasi-analytical, or verified numerical model solutions (this terminology is elaborated in a subsection below).

In addition to comparative and analytical verification tests, the overall methodology for model validation and testing described in Informative Annex B23, in the 2017 ASHRAE Handbook—Fundamentals (see Chapter 19, Section 8), and elsewhere (as cited in Annex B23, Section B23.1.1) includes empirical validation testing, where tested software models are validated to within the uncertainty of experimental input and output data. Such tests can be accommodated within the current title purpose and scope of Standard 140, and additional research on this topic is recommended, as discussed in Informative Annex B23.

Of the current set of Class I test cases, four test suites were initially developed by the National Renewable Energy Laboratory (NREL) with the International Energy Agency (IEA); one test suite was developed by Natural Resources Canada, also in collaboration with the IEA; and one test suite was based on ASHRAE research and adapted by NREL in collaboration with the ASHRAE Standard 140 project committee (SSPC 140). (See Annex B23, Section B23.1 for reference citations).

For the building thermal envelope and fabric load test cases of Section 5.2, the basic comparative test cases (Sections 5.2.1 and 5.2.2) test the ability of the programs to model such combined effects as thermal mass, direct solar gain windows, window-shading devices, internally generated heat, infiltration, sunspaces, and deadband and setback thermostat control. The in-depth comparative test cases (Section 5.2.3) facilitate diagnosis by allowing extraction of specific heat transfer mechanisms. The ground-coupled slab analytical verification tests of Section 5.2.4 use the results of an analytical solution as a primary mathematical truth standard, and the results from a set of detailed verified numerical models for three-dimensional ground-coupled heat transfer as a secondary mathematical truth standard. These results are then used for comparing to the results of models typically embedded within whole-building energy simulation software. (See Informative Annex B23 for a more complete description of using verified numerical models as a secondary truth standard.) Parametric variations from a steady-state base case include harmonically varying ground surface temperature, floor slab aspect ratio, slab area, water table depth (depth of constant ground temperature), slab interior and ground exterior-surface heat transfer coefficients, and slab and ground thermal conductivity. Informative analytical solution and verified numerical model results are provided for the test cases of this section.

The space-cooling equipment cases of Section 5.3 test the ability of programs to model the performance of unitary space-cooling equipment using manufacturer design data presented as empirically derived performance maps. Many whole-building energy simulation programs are designed to work with this type of data, and there is very little manufacturer's data that would support the alternative of first principles (direct physical system component) modeling. In the steady-state analytical verification cases of Sections 5.3.1
and 5.3.2, which utilize a typical range of performance data, the following parameters are varied: sensible internal gains, latent internal gains, zone thermostat set point (entering dry-bulb temperature), and outdoor dry-bulb temperature. Parametric variations isolate the effects of the parameters singly and in various combinations and isolate the influence of part-loading of equipment, varying sensible heat ratio, dry-coil (no latent load) versus wet-coil (with dehumidification) operation, and operation at typical Air-Conditioning, Heating, and Refrigeration Institute (AHRI) rating conditions. Informative quasi-analytical solution results are provided for the test cases of this section. The comparative test cases of Sections 5.3.3 and 5.3.4 utilize an expanded range of performance data, an outdoor air mixing system, and hourly varying weather data and internal gains. These cases cannot be solved analytically but are more realistic. In these cases, the following parameters are varied: sensible internal gains, latent internal gains, infiltration rate, outdoor air fraction, thermostat set points, and economizer control settings. Through analysis of results, the influence of part-loading of equipment, outdoor dry-bulb (ODB) temperature sensitivity, and dry-coil (no latent load) versus wet-coil (with dehumidification) operation can also be isolated. These cases help to scale the significance of simulation results disagreements more so than the steady-state cases.

The space-heating equipment cases of Section 5.4 test the ability of programs to model the performance of residential fuel-fired furnaces. These tests are divided into two tiers. The Tier 1 analytical verification test cases (Sections 5.4.1 and 5.4.2) employ simplified boundary conditions and test the basic functionality of furnace models. More realistic boundary conditions are used in the Tier 2 comparative test cases (Section 5.4.3), where specific aspects of furnace models are examined. The full set of space-heating test cases is designed to test the implementation of specific algorithms for modeling the following aspects of furnace performance: furnace steady-state efficiency, furnace part-load ratio, furnace fuel consumption, circulating fan operation, and draft fan operation. These cases also test the effects of thermostat setback and undersized capacity. Informative analytical and quasi-analytical solution results are provided for the Tier 1 test cases of this section.

The air-side heating, ventilating, and air-conditioning (HVAC) equipment cases of Section 5.5 test the ability of programs to model fundamental air distribution system mass flow and heat balance. These test cases are complementary to the test cases of Sections 5.3 and 5.4, respectively, which test the ability to apply performance maps for modeling the working heat-transfer-fluid side and combustion side of HVAC equipment as described above. The Section 5.5 test cases are based on ASHRAE research project RP-865 and were adapted by NREL in collaboration with SSPC 140. These are steady-state analytical verification tests at a variety of constant zone and ambient conditions. The test systems include the following in order of increasing complexity: four-pipe fan coil (FC), single-zone air conditioner (SZ), constant-volume terminal reheat (CV), and variable-air-volume terminal reheat (VAV). In these cases, the FC system is a single-zone system with heating and cooling coils, zone air exhaust, and limited outdoor air (no economizer control), and it does not include a return air fan. The SZ system adds an economizer and a return air fan. The CV system further applies multiple (two) zones, system supply-air temperature control, and terminal reheat coils. Finally, the VAV system further applies a variable airflow supply fan and terminal zone supply-air dampers. The test cases are conducted at five different sets of steady-state outdoor and zone conditions in heating, dry-coil cooling, and wet-coil cooling modes and with temperature and enthalpy economizer outdoor air control strategies applied to selected conditions. Informative quasi-analytical solution results are provided.

Class II Test Procedures (Section 7)

The Class II (Section 7) test cases were adapted from HERS BESTEST, developed by the National Renewable Energy Laboratory (as cited in Annex B23, Section B23.1). This set of test cases formally codifies the Tier 1 and Tier 2 tests for certification of residential energy performance analysis tools.

The Section 7 test cases are divided into Tier 1 and Tier 2 tests. The Tier 1 base building plan (Section 7.2.1) is a single-story house with 1539 ft² of floor area, with one conditioned zone (the main floor), an unconditioned attic, a raised floor exposed to air (highly vented crawlspace), and typical glazing and insulation. Additional Tier 1 cases (Section 7.2.2) test the ability of software to model building envelope loads in the base-case configuration with the following variations: infiltration; wall and ceiling R-values; glazing physical properties, area, and orientation; shading by a south overhang; internal loads; exterior surface color; energy inefficient building; raised floor exposed to air; uninsulated and insulated slabs-on-grade; and uninsulated and insulated basements. The Tier 2 tests (Section 7.2.3) consist of the following additional elements related to passive solar design: variation in mass, glazing orientation, east and west shading, glazing area, and south overhang. The Section 7 test cases were developed in a more realistic residential context and have a more complex base building construction than the Section 5 test cases (which have more idealized and simplified construction for enhancement of diagnostic capability). To help avoid user input errors for the Section 7 test cases, the input for the test cases is simple, while remaining as close as possible to typical residential constructions and thermal and physical properties. Typical building descriptions and physical properties published by sources such as the National Association of Home Builders, the U.S. Department of Energy, ASHRAE, and the National Fenestration Rating Council are used for the Section 7 test cases.

Comparing Tested Results

The tests have a variety of uses, including

a. comparing the predictions from other building energy programs to the example results provided in Informative Annexes B8 and B16 for Class I tests, Informative Annex B20 for Class II tests, and/or to other results that were generated using this SMOT;
b. checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted;

c. checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms; and

d. diagnosing the algorithmic sources and other sources of prediction differences. (Diagnostic logic flow diagrams are included in Informative Annex B9.)

Regarding the example simulation results provided for the comparative test results of selected parts of Annex B8, selected parts of Annex B16, and Annex B20, the building energy simulation computer programs used to generate these results have been subjected to a number of analytical verification, empirical validation, and comparative testing studies. However, there is no such thing as a completely validated building energy simulation computer program. All building models are simplifications of reality. The philosophy here is to generate a range of results from several programs that are generally accepted as representing the state of the art in whole-building energy simulation programs. To the extent possible, input errors or differences have been eliminated from the presented results. Thus, for a given case, the range of differences between comparative test results presented in Informative Annexes B8, B16, and B20 represents legitimate algorithmic differences among these computer programs. For any given case, a tested program may fall outside this range without necessarily being incorrect. However, it is worthwhile to investigate the sources of substantial differences, as the collective experience of the authors of this standard is that such differences often indicate problems with the software or its usage, including, but not limited to

a. user input error, where the user misinterpreted or incorrectly entered one or more program inputs;
b. inadequate or faulty documentation;
c. a problem with a particular algorithm in the program; or
d. one or more program algorithms used outside their intended range.

Also, for any given case, a program that yields values in the middle of the range established by the comparative test example results should not be perceived as better or worse than a program that yields values at the borders of the range.

Informative (nonmandatory) Annex B22 provides an example procedure for establishing acceptance range criteria to assess annual or seasonal heating and cooling load results for software undergoing the Class II tests contained in Section 7. Inclusion of this example is intended to be illustrative only and does not imply in any way that results from software tests are required by Standard 140 to be within any specific limits. However, certifying or accrediting agencies using Section 7 may wish to adopt procedures for developing acceptance range criteria for tested software. Informative Annex B22 presents an example statistically based range setting methodology that may be useful for these purposes.

Importance of Analytical Solutions, Quasi-Analytical Solutions, and Verified Numerical Model Results

In general, it is difficult to develop analytical verification test cases, but such cases are extremely useful. Under the classification of "analytical verification," we define three types of test case solutions: "analytical solutions," "quasi-analytical solutions," and "verified numerical models." Analytical solutions represent a "mathematical truth standard," while quasi-analytical solutions and verified numerical models represent "secondary mathematical truth standards" (as described in Informative Annex B23, Section B23.1.1.2). For selected Class I test cases, Informative Annexes B16 and B8 provide analytical verification test results based on the above solution types, along with simulation results.

For analytical solutions, given the underlying simplified physical assumptions in the case definitions, there is a mathematically correct solution for each case. For quasi-analytical solutions, the assumptions can be somewhat more realistic; however, there is also the possibility for human interpretation to yield solutions that are slightly different but with a much smaller range of disagreement than results from different simulation programs. Verified numerical models allow even more realistic assumptions and cases but must be subjected to a rigorous screening procedure to minimize the possibility of errors. Verified numerical models are first compared to all available analytical solutions and then compared to each other for cases that do not have exact analytical solutions. Once verified, these numerical solutions can be used to test other models as implemented within whole-building energy simulation programs. The ground-coupled slab-on-grade heat transfer test cases of Section 5.2.4 utilize an analytical solution and verified numerical models to extend the analytical verification method beyond the constraints inherent in analytical solutions. All three types of analytical verification solutions provide a basis for greater diagnostic capability than the purely software-to-software comparative test method, and the verified numerical models allow more realistic boundary conditions to be used in the test cases than are possible with pure analytical solutions. See Informative Annex B23 for a more complete description of the analytical verification test methodology.

It is important to understand the difference between a "mathematical truth standard" and an "absolute truth standard." When applying mathematical truth standards, we only test the solution process for a model, not the appropriateness of the model itself; that is, we accept the given underlying physical assumptions while recognizing that these assumptions represent a simplification of physical reality. For example a one-dimensional conduction model may be properly solved mathematically, but inappropriate where two-dimensional conduction dominates. By contrast, an "approximate truth standard" from an experiment tests both the solution process and the appropriateness of the model within experimental uncertainty. The ultimate or "absolute" validation truth standard would be comparison of simulation results with data from a perfectly performed empirical validation experiment, with all simulation inputs perfectly defined.

We include simulation results for the cases where analytical verification results (analytical, quasi-analytical, or verified
numerical model solutions) exist. This allows simulationists to compare their relative agreement (or disagreement) versus the analytical verification results to that for other simulation results. Perfect agreement among simulations and analytical verification results is not necessarily expected because sometimes simulations cannot perfectly match the specified simplifying assumptions or boundary conditions required for developing the analytical verification solutions. The provided results give an indication of the degree of agreement that is possible between simulation results and the analytical verification results. Therefore, a tested program may disagree with analytical verification solutions without necessarily being incorrect. However, it is worthwhile to investigate the sources of such differences, as noted previously.

Supporting Files

The supporting electronic files to be used with Standard 140-2017 are called out as described in README-140-2017.docx, provided in the root folder of the accompanying files package. Accompanying files are organized by a separate file folder for each set of tests. Each of the test-set-specific file folders is further subdivided by separate subfolders for normative files and informative files. Normative files include weather data, output report templates, and equipment performance data (for those test cases that apply such data). Informative files include example results, example entries for documentation reports, and other supporting information. Electronic files can be downloaded online at http://www.ashrae.org/140-2017.
1. PURPOSE

This standard specifies test procedures for evaluating the technical capabilities and ranges of applicability of computer programs that calculate the thermal performance of buildings and their HVAC systems.

2. SCOPE

These standard test procedures apply to building energy computer programs that calculate the thermal performance of a building and its mechanical systems. While these standard test procedures cannot test all algorithms within a building energy computer program, they can be used to indicate major flaws or limitations in capabilities.

3. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

3.1 Terms Defined for This Standard

adiabatic: without loss or gain of heat. Informative Note: For example, an adiabatic boundary does not allow heat to flow through it.

adjusted net sensible capacity: the gross sensible capacity less the actual fan power. (See gross sensible capacity.)

adjusted net total capacity: the gross total capacity less the actual fan power. (See gross total capacity.)

altitude: vertical elevation above sea level.

analytical solution: a mathematical solution of a model of reality that has an exact result for a given set of parameters and simplifying assumptions.

analytical verification: where outputs from a program, subroutine, algorithm, or software object are compared to results from a known analytical solution or to results from a set of closely agreeing quasi-analytical solutions or verified numerical models. (See analytical solution, quasi-analytical solution, and verified numerical model.)

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 hourly integrated maximum zone air temperature: the hourly zone temperature that represents the maximum for the one-year simulation period.

annual hourly integrated minimum zone air temperature: the hourly zone temperature that represents the minimum for the one-year simulation period.

annual hourly integrated peak floor conduction: the hourly floor conduction that represents the maximum for the final year of the simulation period; used for tests of Section 5.2.4.

annual hourly integrated peak heating load: the hourly heating load that represents the maximum for the one-year simulation period.

annual hourly integrated peak sensible cooling load: the hourly sensible cooling load that represents the maximum for the one-year simulation period.

annual hourly integrated peak zone load: the hourly zone load that represents the maximum for the final year of the simulation period; used for tests of Section 5.2.4.

annual hourly 1°C zone air temperature bin frequency: the number of hours that the zone air temperature has values within a given bin (1°C bin width) for the one-year simulation period.

annual incident unshaded total solar radiation (diffuse and direct): the sum of direct solar radiation and diffuse solar radiation that strikes a given surface for the entire one-year simulation period when no shading is present. Informative Note: For example, for hourly simulation programs, this is the sum of the hourly total incident solar radiation for the one-year simulation period.

annual mean zone air temperature: the average zone air temperature for the one-year simulation period. Informative Note: For example, for hourly simulation programs, this is the average of the hourly zone air temperatures 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.

annual transmitted solar radiation (diffuse and direct): the sum of direct solar radiation and diffuse solar radiation that passes through a given window for the entire one-year simulation period. This quantity does not include radiation that is absorbed in the glass and conducted inward as heat. Informative Note: This quantity may be taken as the optically transmitted solar radiation through a window that is backed by a perfectly absorbing black cavity.

apparatus dew point (ADP): the effective coil surface temperature when there is dehumidification. On the psychrometric chart, this is the intersection of the condition line and the saturation curve, where the condition line is the line going through entering air conditions with slope defined by the sensible heat ratio (SHR) (ratio of sensible heat transfer to total [sensible + latent] heat transfer for a process). For the test cases of Section 5.3, SHR is calculated as SHR = (Gross sensible capacity)/(Gross total capacity). (See sensible heat ratio, gross sensible capacity, and gross total capacity.) Informative Note: The ADP is the temperature to which all the supply air would be cooled if 100% of the supply air contacted the coil.

aspect ratio (AR): the ratio of the floor slab length to the floor slab width.

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.

bypass factor (BF): the percentage of the distribution air that does not come into contact with the cooling coil; the remaining air is assumed to exit the coil at the average coil temperature (apparatus dew point). (See apparatus dew point.)

cavity albedo: see solar lost through window.
**coefficient of performance (COP):** for a cooling (refrigeration) system, the ratio, using the same units in the numerator as in the denominator, of the net refrigeration effect to the corresponding energy input. For the purpose of calculating COP, corresponding energy input is the related cooling energy consumption, except for Cases CE300 through CE440 (see Sections 5.3.3, 5.3.4.1, and 5.3.4.2) where the indoor air distribution fan energy is included only during times when heat is being extracted by the evaporator coil. (See net refrigeration effect and cooling energy consumption.)

**combined radiative and convective surface coefficient:** a constant of proportionality relating the rate of combined convective and radiative heat transfer at a surface to the temperature difference across the air film on that surface.

**combined surface coefficient:** see combined radiative and convective surface coefficient.

**conductance:** thermal conductance.

**convective surface coefficient:** a constant of proportionality relating the rate of convective heat transfer at a surface to the temperature difference across the air film on that surface.

**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 the 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 the 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 the 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.

**COP:** the ratio, using the same units, of the gross total evaporator coil load to the sum of the compressor and outdoor condenser fan energy consumptions. (See gross total evaporator coil load.)

**COP\(_{\text{SEER}}\):** the seasonal energy efficiency ratio (dimensionless).

**COP degradation factor (CDF):** a multiplier (≤1) applied to the full-load system COP or COP2. CDF is a function of part-load ratio. (See part-load ratio for cooling.)

**deep ground temperature:** the ground temperature at or below a soil depth of 2 m (6.56 ft), except for Section 5.2.4 ground coupling tests where the ground boundary depth varies as specified in the test cases.

**degradation coefficient:** a measure of efficiency loss due to cycling of equipment.

**design nominal zone supply airflow rate:** the maximum zone supply volumetric airflow rate using air conditions at the supply fan inlet. **Informative Note:** The actual design zone supply air volumetric flow varies as supply fan heat and terminal reheat increase the specific volume of the air away from the supply fan inlet.

**design system return airflow rate:** the volumetric return airflow rate calculated from the design system supply airflow rate minus the total zone exhaust airflow rates for the defined zones. This is the volumetric airflow rate at which the return fan pressure rise is specified. **Informative Note:** The actual return fan volumetric flow varies with the return air mass flow and the specific volume of the air entering the return fan.

**design system supply airflow rate:** the maximum system supply volumetric airflow rate at the supply fan inlet. This is the volumetric airflow rate at which the supply fan pressure rise is specified for the VAV system. **Informative Note:** In a VAV system, the supply fan volumetric flow varies to meet the zone terminal airflow requirements.

**detailed ground heat transfer model:** employs transient three-dimensional (3D) numerical-methods (finite-element or finite-difference) heat transfer modeling throughout the modeled domain.

**dew-point temperature:** temperature at which water vapor has reached the saturation point (100% relative humidity; see relative humidity); temperature of the air at which it must be cooled at constant barometric pressure for water vapor to condense.

**diffuse solar radiation:** the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere or other objects such as the ground.

**direct solar radiation:** the solar radiation received from the sun without having been scattered by the atmosphere or other objects such as the ground; this is also called “beam” or “direct beam” radiation.

**economizer:** a control system that conserves energy; for Standard 140, this is a control system designed to conserve cooling energy by increasing outdoor airflow above minimum ventilation requirements when control logic indicates that using more outdoor air will reduce or eliminate cooling-coil loads.

**energy efficiency ratio (EER):** the ratio of net refrigeration effect (in Btu per hour) to cooling energy consumption (in watts) so that EER is stated in units of (Btu/h)/W. (See net refrigeration effect and cooling energy consumption.)
entering dry-bulb temperature (EDB): the temperature indicated by an ordinary thermometer for air entering the evaporator coil. Informative Note: For a draw-through fan configuration with no heat gains or losses in the ductwork and no outdoor air mixed with return air, EDB equals the indoor dry-bulb temperature. For a similar configuration but when outdoor air is mixed with return air, EDB equals the mixed-air dry-bulb temperature.

entering wet-bulb temperature (EWB): the temperature indicated by the wet-bulb portion of a psychrometer when exposed to air entering the evaporator coil. Informative Note: For a draw-through fan with no heat gains or losses in the ductwork and no outdoor air mixed with return air, this would also be the zone air wet-bulb temperature. For a similar configuration but when outdoor air is mixed with return air, EDB equals the mixed-air wet-bulb temperature. For mixtures of water vapor and dry air at atmospheric temperatures and pressures, the wet-bulb temperature is approximately equal to the adiabatic saturation temperature (temperature of the air after undergoing a theoretical adiabatic saturation process). The wet-bulb temperature given in psychrometric charts is really the adiabatic saturation temperature.

evaporator coil loads: the actual sensible heat and latent heat removed from the distribution air by the evaporator coil. Informative Note: These loads include indoor air distribution fan heat for times when the compressor is operating, and they are limited by the system capacity (where system capacity is a function of operating conditions). Sensible evaporator coil load applies only to sensible heat removal. Latent evaporator coil load applies only to latent heat removal. (See sensible heat and latent heat.)

exterior film: as used in Section 7, see combined radiative and convective surface coefficient.

extinction coefficient: the proportionality constant \( K \) in Bouguer’s Law \([dd] = [I K dx]\), where \( I \) is the local intensity of solar radiation within a medium, and \( x \) is the distance the radiation travels through the medium.

fan mechanical efficiency (fan total efficiency \( \eta_f \)): 
\[
\eta_f = \frac{H_o}{H_i}
\]
where
\[
H_o = Q \times P_t \times K_p \times C; \text{ this is the fan power output (causing airflow and pressure rise), W (hp), where}
\]
\[
Q = \text{fan airflow rate, } m^3/s \text{ (cfm)}.
\]
\[
P_t = \text{fan total pressure rise, Pa (in. of water); fan total pressure rise includes static pressure (from compression) and velocity pressure (from rate of motion)}.
\]
\[
K_p = \text{compressibility coefficient, dimensionless. Informative Note: For fan total pressure < 12 in. of water, } K_p \text{ is usually greater than 0.99 and may be taken as unity B-2.}
\]
\[
C = \text{units conversion constant. Informative Note: For Système Internationale (SI) units, } C = 1; \text{ for inch-pound (I-P) units, } C \text{ may be taken as approximately } 1/6343.3 \text{ per the literature B-3}.\]

\( H_i = \) fan power input, W (hp). This is also called “power input to impeller” or “shaf power input” and is the remaining mechanical power after subtracting fan motor and transmission drive power losses from the fan motor input power. (See motor efficiency and transmission drive efficiency.) Informative Note: This parameter is designated as \( W_{sh} \) in Informative Annex B15.

Informative Note: Fan total efficiency and related terminology are further described in the literature B-3,B-4.

film coefficient: see combined radiative and convective surface coefficient.

free float: a condition where mechanical heating and cooling equipment is OFF so that the space or zone temperature varies without constraint.

gross sensible capacity: the rate of sensible heat removal by the cooling coil for a given set of operating conditions. (See sensible heat.) Informative Note: This value varies as a function of performance parameters such as EWB, ODB, EDB, and airflow rate.

gross total capacity: the total rate of both sensible heat and latent heat removal by the cooling coil for a given set of operating conditions. (See sensible heat and latent heat.) Informative Note: This value varies as a function of performance parameters such as EWB, ODB, EDB, and airflow rate.

gross total coil load (or gross total evaporator coil load): the sum of the sensible heat and latent heat removed from the distribution air by the evaporator coil.

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.

heat input ratio (HIR): a ratio that is the inverse of the efficiency.

hemispherical infrared emittance: the average directional infrared emittance over a hemispherical envelope over the surface. (See infrared emittance.)

hourly free-floating zone air temperature: zone air temperature for a given hour during which heating and cooling equipment is OFF or for an unconditioned zone.

hourly heating load: the heating load for a given hour.

hourly incident unshaded solar radiation (direct and diffuse): the sum of direct solar radiation and diffuse solar radiation that strikes a given surface for a given hour.

hourly sensible cooling load: the sensible cooling load for a given hour.

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

incidence angle: the angle defined by the intersection of a line normal to a surface and a ray that strikes that surface.

index of refraction: relates the angle of refraction \( x_2 \) to the angle of incidence \( x_1 \) at the surface interface of two media according to Snell's law \( n_1 \sin(x_1) = n_2 \sin(x_2) \), where \( n_1 \) and \( n_2 \) are indices of refraction for each medium.
infiltration: the leakage of air through any building element. Informative Note: For example, air leakage through walls, windows, and/or doors.

infrared emittance: the ratio of the infrared spectrum radiant flux emitted by a body to that emitted by a blackbody at the same temperature and under the same conditions.

interior film: as used in Section 7, see combined radiative and convective surface coefficient.

interior solar distribution: the fraction of transmitted solar radiation incident on specific surfaces in a room. (See solar distribution fraction.)

internal gains: the heat gains generated inside the space or zone.

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

mathematical truth standard: the standard of accuracy for predicting system behavior based on an analytical solution.

midlevel detailed ground heat transfer model: based on a transient two-dimensional (2D) or three-dimensional (3D) numerical-methods heat transfer model, applying some simplifications for adaptation to a whole-building energy simulation program; such models include correlation methods based on extensive 2D or 3D numerical analysis.

motor efficiency ($\eta_m$):

$$\eta_m = \frac{H_m}{H_e}$$

where

$H_m =$ usable motor shaft output power, W (hp).

$H_e =$ motor electric input power, W (hp). Informative Note: This parameter is designated as $W$ in Informative Annex B15.

net refrigeration effect: the rate of heat removal (sensible + latent) by the evaporator coil, as regulated by the thermostat (not necessarily the full load capacity), after deducting internal and external heat transfers to air passing over the evaporator coil. Informative Note: For the tests of Section 5.3, the net refrigeration effect is the evaporator coil load less the actual air distribution fan heat for the time when the compressor is operating; at full load, this is also the adjusted net total capacity. (See adjusted net total capacity, evaporator coil load, sensible heat, and latent heat.)

net sensible capacity: the gross sensible capacity less the default rate of fan heat assumed by the manufacturer; this rate of fan heat is not necessarily the same as for the actual installed fan (see adjusted net sensible capacity). (Also see gross sensible capacity.)

net total capacity: the gross total capacity less the default rate of fan heat assumed by the manufacturer; this rate of fan heat is not necessarily the same as for the actual installed fan (see adjusted net total capacity). (Also see gross total capacity.)

nominal zone supply airflow rate: the zone supply volumetric airflow rate calculated using conditions of the air at the supply fan inlet. Informative Note: The actual zone supply air volumetric flow rate varies as supply fan heat and terminal reheat increase the specific volume of the air away from the supply fan inlet.

nonproportional-type thermostat: a thermostat that provides two-position (ON/OFF) control.

outdoor dry-bulb temperature (ODB): the temperature indicated by an ordinary thermometer when exposed to outdoor air. Informative Note: For the test cases of Section 5.3, this is the temperature of air entering the condenser coil.

part-load factor (PLF): the ratio of the efficiency at part load to the steady-state efficiency. Informative Note: PLF represents the degradation in efficiency due to part-load operation.

part-load ratio for cooling (PLR): the ratio of the net refrigeration effect to the adjusted net total capacity for the cooling coil. (See net refrigeration effect and adjusted net total capacity.) Informative Note: As shown in Informative Annex B13, for the purpose of calculating the COP degradation factor (CDF), defining PLR as the ratio of gross total evaporator coil load to the gross total capacity produces an equivalent CDF. (See COP degradation factor, gross total evaporator coil load, and gross total capacity.)

part-load ratio for furnace (PLR_f): the ratio of the net heating effect to the adjusted net total capacity for the furnace.

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.

raised floor exposed to air: a floor system where the air temperature below the floor is assumed to equal the outside air temperature, the underside of the conditioned-zone floor has a surface texture and zero wind speed, and the conditioned-zone floor exterior surface (surface facing the raised floor) receives no solar radiation. See Section 7.2.1.5.

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.

relative humidity: (a) the ratio of the mole fraction of water vapor in a given moist air sample to the mole fraction in an air sample that is saturated and at the same temperature and pressure or (b) the ratio of partial pressure of the water vapor in a sample to the saturation pressure at the same dry-bulb temperature and barometric pressure of the ambient air.
seasonal energy efficiency ratio (SEER): the ratio of net refrigeration effect in Btu to the cooling energy consumption in watt-hours for a refrigerating device over its normal annual usage period. (See net refrigeration effect and cooling energy consumption.) Informative Note: This parameter is commonly used for simplified estimates of energy consumption based on a given load and is not generally useful for detailed simulations of mechanical systems. SEER is determined using ANSI/AHRI Standard 210/240-89B-5.

secondary mathematical truth standard: the standard of accuracy for predicting system behavior based on the range of disagreement of a set of closely agreeing verified numerical models or other quasi-analytical solutions, to which other simulations are allowed to be compared. (See verified numerical model and quasi-analytical solution.)

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

sensible heat ratio (SHR): the ratio of sensible heat transfer to total (sensible + latent) heat transfer for a process; alternatively known as "sensible heat factor" (SHF). (See sensible heat and latent heat.)

shortwave: refers to the solar spectrum. Informative Note: For example, in this standard the terms solar absorptance and shortwave absorptance are used interchangeably.

simplified ground heat transfer model: a model based on a one-dimensional (1D) dynamic or steady-state heat transfer model; implementation of such a model usually requires no modification to a whole-building energy simulation program.

solar absorptance: the ratio of the solar spectrum radiant flux absorbed by a body to that incident on it.

solar distribution fraction: the fraction of total solar radiation transmitted through windows that is absorbed by a given surface or retransmitted (lost) back out the windows.

solar fraction: see solar distribution fraction.

solar heat gain coefficient (SHGC): a dimensionless ratio of solar heat gains to incident solar radiation, including transmittance plus inward flowing fraction of absorbed solar radiation. Informative Note: For example, these loads do not include internal gains associated with operating the mechanical system. Informative Note: For example, these loads do not include air distribution fan heat.

solar lost: see solar lost through window.

solar lost through window: the fraction of total solar radiation transmitted through windows that is reflected by opaque surfaces and retransmitted back out the windows.

standard temperature and pressure (STP) conditions: 0°C and 1 atm.

surface coefficient: see combined radiative and convective surface coefficient.

system supply airflow rate: the volumetric airflow rate measured at the supply fan inlet. Informative Note: As the temperature and humidity ratio of the air entering the supply fan change, the specific volume of that air changes; this means that for a given supply volumetric airflow rate, the mass flow rate of supply air varies among the Section 5.5 test cases.

transmission drive efficiency ($\eta_d$): $\eta_d = H_i/H_m$

where

$H_i =$ fan power input, W (hp); see $H_i$ under fan mechanical efficiency.

$H_m =$ usable motor shaft output power, W (hp).

Informative Note: Fan motor shaft power is typically transferred to the fan impeller using belts or direct drive.

verified numerical model: a numerical model with solution accuracy verified by close agreement with an analytical solution and/or other quasi-analytical solution or numerical solutions, according to a process that demonstrates solution convergence in the space and time domains. (See analytical solution and quasi-analytical solution.) Informative Note: Such numerical models may be verified by applying an initial comparison with analytical solutions, followed by comparisons with other numerical models for incrementally more realistic cases where analytical solutions are not available.

zone air temperature: the temperature of just the zone air, not including infrared radiation from the interior surfaces. Informative Note: Such a temperature would be measured by a sensor housed in a well-aspirated containment shielded by a material with a solar and infrared reflectance of one; well-mixed air is assumed.

zone cooling loads: the sensible heat and latent heat loads associated with heat and moisture exchange between the building envelope and its surroundings as well as internal heat and moisture gains within the building. These loads do not include internal gains associated with operating the mechanical system. Informative Note: For example, these loads do not include air distribution fan heat.

zone exhaust airflow rate: the volumetric airflow rate measured at the inlet of a given zone’s exhaust fan. Informative Note: As the temperature and humidity ratio of the air entering an exhaust fan change, the specific volume of that air changes; this means that for a given exhaust volumetric airflow rate, the mass flow rate of exhaust air from each zone varies among the Section 5.5 test cases.

zone latent load: for the test cases of Section 5.5, the rate of heat addition to vaporize the water added to the zone at a temperature of 0°C in the units system used (SI or I-P), plus the energy required to heat that added vapor from 0° to the zone temperature. Informative Note: This definition may be expressed as shown in equation form (also see Part II, Section 2.2.1.8 of the originating test suite adaptation report).
In the above equation, \[ i_{\text{water vapor}} + C_{p_{\text{water vapor}}} \times T_{\text{zone}} \] equals the enthalpy of water vapor \(i_g\) at the given zone temperature, based on ideal gas laws. This approximates the real-gas model values listed in the 2009 *ASHRAE Handbook—Fundamentals* B-7, Chapter 1, Table 3.

**Zone sensible cooling load:** for the test cases of Section 5.5, the rate at which sensible heat must be extracted from the zone to maintain the zone air temperature set point. **Informative Note:** This definition may be expressed as shown in equation form, based on ASHRAE RP-865 B-8.

\[
\text{Zone sensible cooling load} = \frac{\text{[Dry air mass flow rate, kg/s (lb/h)]}}{(T_{\text{zone}} - T_{\text{supply}}) \times (C_{p_{\text{air}}} + C_{p_{\text{water vapor}}} \times W_{\text{supply}})}
\]

where
- \(T_{\text{zone}}\) = zone air temperature, °C (°F).
- \(T_{\text{supply}}\) = zone supply air temperature, °C (°F); for the FC and SZ systems, this is the same as the system supply air temperature.
- \(C_{p_{\text{air}}}\) = specific heat of dry air, kJ/(kg K) (Btu/[lb·°F]).
- \(C_{p_{\text{water vapor}}}\) = specific heat of water vapor, kJ/(kg K) (Btu/[lb·°F]).
- \(W_{\text{supply}}\) = zone supply air humidity ratio (kg water vapor)/(kg dry air) ([lb water vapor]/[lb dry air]); for the FC and SZ systems, this is the same as the system supply air humidity ratio.

**Zone sensible heating load:** for the test cases of Section 5.5, the rate at which sensible heat must be added to the zone to maintain the zone air temperature set point. **Informative Note:** This definition may be expressed as shown in equation form, based on ASHRAE RP-865 B-8.

\[
\text{Zone sensible heating load} = \frac{\text{[Dry air mass flow rate, kg/s (lb/h)]}}{(T_{\text{supply}} - T_{\text{zone}}) \times (C_{p_{\text{air}}} + C_{p_{\text{water vapor}}} \times W_{\text{supply}})}
\]

where
- \(T_{\text{supply}}\) = zone air temperature, °C (°F).
- \(T_{\text{zone}}\) = zone air temperature, °C (°F).
- \(C_{p_{\text{air}}}\) = specific heat of dry air, kJ/(kg K) (Btu/[lb·°F]).
- \(C_{p_{\text{water vapor}}}\) = specific heat of water vapor, kJ/(kg K) (Btu/[lb·°F]).
- \(W_{\text{supply}}\) = zone supply air humidity ratio (kg water vapor)/(kg dry air) ([lb water vapor]/[lb dry air]); for the FC and SZ systems, this is the same as the system supply air humidity ratio.

**Zone supply air mass flow fraction:** the fraction of system supply air mass flow distributed to each zone.

### 3.2 Abbreviations and Acronyms Used in this Standard

- \(\alpha_{\text{ext}}\) = exterior solar absorptance
- 1D = one-dimensional
- 2D = two-dimensional
- 3D = three-dimensional
- \(A\) = area
- \(Abs.\) = absorptance
- \(Abs.\ In\) = absorptance of inner pane
- \(Abs.\ Out\) = absorptance of outer pane
- \(ach\) = air changes per hour
- \(ADP\) = apparatus dew point
- \(AHRI\) = Air-Conditioning, Heating and Refrigeration Institute
- \(AMCA\) = Air Movement and Control Association International, Inc.
- \(ANSI\) = American National Standards Institute
- \(APR\) = April
- \(AR\) = aspect ratio
- \(ARI\) = Air-Conditioning and Refrigeration Institute (now AHRI)
- \(ASHRAE\) = American Society of Heating, Refrigerating and Air-Conditioning Engineers
- \(B\) = floor slab length in north/south direction, m (ft)
- \(Base\) = base case
- \(BESTEST\) = Building Energy Simulation Test and Diagnostic Method
- \(BF\) = bypass factor
- \(BHP\) = brake horsepower
- \(Cd\) = degradation coefficient
- \(CDF\) = coefficient of performance degradation factor
- \(cfm\) = cubic feet per minute
- \(Coef.\) = coefficient
- \(COG\) = center of glass
- \(COP\) = coefficient of performance
- \(COP2\) = alternative coefficient of performance (see Section 3.1)
- \(c_p\) = specific heat, J/(kg·K) (Btu/[lb·°F])
- \(CV\) = constant-volume terminal reheat system, see Section 5.5.3
- \(D\) = door 3 ft. × 6 ft. 8 in.
- \(DBT\) = dry-bulb temperature, °C
- \(Dec.\) = December
- \(Dir.\ Nor.\) = direct normal
- \(DOE\) = United States Department of Energy
- \(E\) = deep-ground depth (Section 5.2.4 only), m
- \(EDB\) = entering dry-bulb temperature
- \(EER\) = energy efficiency ratio
- \(EOG\) = edge of glass
- \(EWB\) = entering wet-bulb temperature
- \(E,W,N,S\) = east, west, north, south
- \(Ext.\) = exterior
- \(F\) = far-field dimension, m (ft)
FC four-pipe fan-coil system, see Section 5.5.1

FF free-floating thermostat control strategy (no heating or cooling)

$h$ convective surface coefficient, $W/(m^2\cdot K)$ (Btu/[h·ft$^2$.°F])

Heatcap heat capacity

Hemis. hemispherical

HERS Home Energy Rating System

$h,ext$ exterior convective surface coefficient, $W/(m^2\cdot K)$ (Btu/[h·ft$^2$.°F])

High-mass heavy mass

$h,int$ interior convective surface coefficient, $W/(m^2\cdot K)$ (Btu/[h·ft$^2$.°F])

HIR heat input ratio

$H_o$ fan output power required to meet specified airflow requirements

HVAC heating, ventilating, and air conditioning


I.D. inside diameter

ID indoor

IDB indoor dry-bulb temperature

IEA International Energy Agency

Int interior

I-P inch-pound

Jan. January

$k$ thermal conductivity, $W/(m\cdot K)$ (Btu/[h·ft·°F])

$k_{soil}$ soil/slab thermal conductivity, $W/(m\cdot K)$ (Btu/[h·ft·°F])

$L$ floor slab length in east/west direction, m (ft)

LCR load to collector area ratio

Low-E low emissivity

Low mass light mass

Mar. March

N/A not applicable

NAHB National Association of Home Builders

NFRC National Fenestration Rating Council

NOAA National Oceanic and Atmospheric Administration

Nov. November

NREL National Renewable Energy Laboratory

NSRDB National Solar Radiation Database

Num. number

OAE outdoor air enthalpy

O.C. on centers

Oct. October

O.D. outside diameter

ODB outdoor dry-bulb temperature

ODB$_{econo,min}$ the outdoor dry-bulb temperature where at the minimum required outdoor airflow rate $T_{zone} = T_{zone}$ thermostat set point

ODP outdoor dew-point temperature

PLF part-load factor

PLR part-load ratio for cooling

PLR$_f$ part-load ratio for furnace property

PROP heat flow, W or Wh/h

QAS quasi-analytical solution

QC$_{latent}$ system cooling-coil latent load, kWh/h

QC$_{sensible}$ system cooling-coil sensible load, kWh/h

QC$_{total}$ system cooling-coil total load, kWh/h

$q_{floor}$ floor conduction, W or Wh/h

$q_{floor,max}$ annual total floor conduction, kWh/y

$q_{zone}$ annual hourly integrated peak floor conduction, W or Wh/h

$q_{zone,max}$ annual hourly integrated peak zone load, W or Wh/h

Quantum heating-coil load, kWh/h; used for single-zone (FC and SZ) system test cases

$QH$ reheat-coil load: Zone 1, kWh/h

$QH_{reheat}$ reheat-coil load: Zone 2, kWh/h

$QH_{preheat}$ system preheat-coil load, kWh/h

$Q_{Z1_{latent}}$ Zone 1 latent load, kWh/h

$Q_{Z2_{latent}}$ Zone 2 latent load, kWh/h

$Q_{Z1_{sensible}}$ Zone 1 sensible cooling load, kWh/h

$Q_{Z2_{sensible}}$ Zone 2 sensible cooling load, kWh/h

$Q_{ZCs}$ zone sensible cooling load, kWh/h; used for single-zone (FC and SZ) system test cases

$Q_{Z1_{sensible}}$ Zone 1 sensible heating load, kWh/h

$Q_{Z2_{sensible}}$ Zone 2 sensible heating load, kWh/h

$Q_{ZH}$ zone latent load, kWh/h; used for single-zone (FC and SZ) system test cases

$Q_{ZH1_{sensible}}$ zone latent load, kWh/h; used for single-zone (FC and SZ) system test cases

$Q_{ZH2_{sensible}}$ zone latent load, kWh/h; used for single-zone (FC and SZ) system test cases

$Q_{Z\_sensible}$ zone latent load, kWh/h; used for single-zone (FC and SZ) system test cases

$R$ unit thermal resistance, $m^2\cdot K/W$ (h·ft$^2$.°F/Btu)

RAE return air enthalpy

RAT return air temperature

Refl. reflectance
**3.3 Subscripts**

- **cco**  system location, cooling-coil outlet
- **hco**  system location, heating-coil outlet
- **ma**  system location, mixed air (recirculated and outdoor) before coils and supply fan
- **oa**  system location, outdoor air inlet
- **pco**  system location, preheating coil outlet
- **ra**  system location, return air
- **rfi**  system location, return fan inlet
- **rfo**  system location, return fan outlet
- **sa**  system location, supply fan outlet
- **z1**  Zone 1 air
- **z1s**  system location, supply air to Zone 1 after terminal reheat-coil
- **z2**  Zone 2 air
- **z2s**  system location, supply air to Zone 2 after terminal reheat-coil
4. METHODS OF TESTING

**Informative Note:** Sections 4.2, 4.3, and 4.4 and their subsections are informative material.

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 below and in greater detail in Informative Section 4.3. Codes and standards that reference Standard 140 shall be permitted to call out specific sections within Standard 140 to specify individual test cases or groups of test cases.

4.1.1 Class I Test Cases. The Class I test cases are detailed diagnostic tests for simulation software capable of hourly or subhourly simulation time steps. The requirements for these test cases are specified in Section 5. Section 6 includes the output requirements for the Class I test cases, as specified in Section 5; Section 6 is placed apart from Section 5 for reasons of convenience.

4.1.2 Class II Test Cases. The Class II test cases are for all types of building load calculation methods regardless of time-step granularity. The requirements for these test cases are specified in Section 7. Section 8 includes the output requirements for the Class II test cases, as specified in Section 7; Section 8 is placed apart from Section 7 for reasons of convenience.

4.1.3 Normative Annexes. The normative annexes to this standard are considered to be integral parts of the mandatory requirements of this standard, which, for reasons of convenience, are placed apart from all other normative elements.

4.1.4 Informative Annexes. The informative annexes and informative notes located within this standard contain additional information and are not mandatory or part of this standard.

**Informative Note:** The remainder of Section 4 is informative material that provides background on the fundamentals and structure of the standard. Users of this standard should review Sections 4.2 through 4.4 before proceeding with this method of test.

4.2 Applicability of Test Method. The method of test is provided for analyzing and diagnosing building energy simulation software using software-to-software, software-to-analytical-solution, software-to-quasi-analytical-solution, and software-to-verified-numerical-model comparisons. The methodology allows different building energy simulation programs, representing different degrees of modeling complexity, to be tested by

- comparing the predictions from other building energy simulation programs to the Class I test example simulation and verified numerical model results provided in Informative Annex B8, to the Class I test example analytical and quasi-analytical solution and simulation results in Informative Annex B16, to the Class II test example simulation results provided in Informative Annex B20, and/or to other results (simulations, analytical and quasi-analytical solutions, or verified numerical model results) that were generated using this standard method of test;
- checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted;
- checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms; and
- diagnosing the algorithmic sources and other sources of prediction differences (diagnostic logic flow diagrams are included in Informative Annex B9).

4.3 Organization of Test Cases. The specifications for determining test case configurations and input values are provided on a case-by-case basis in Section 5 and Section 7. The test cases are divided into two separate test classes to satisfy various levels of software modeling detail. Such classification allows more convenient citation of specific sections of Standard 140 by other codes and standards and by certifying and accrediting agencies, as appropriate. The Class I test cases (Section 5) are detailed diagnostic tests intended for simulation software capable of hourly or subhourly simulation time steps. The Class II test cases (Section 7) may be used for all types of building load calculation methods, regardless of time-step granularity. The Class I (Section 5) test cases are designed for more detailed diagnosis of simulation models than the Class II (Section 7) test cases.

Weather information required for use with the test cases is provided as described in Normative Annex A1. Informative Annex B1 provides an overview for all the test cases and contains information on those building parameters that change from case to case; Annex B1 is recommended for preliminary review of the tests, but do not use it for defining the cases. Additional information regarding the meaning of the cases is shown in Informative Annex B9 on diagnostic logic. In some instances (e.g., Case 620, Section 5.2.2.1.2), a case developed from modifications to a given base case (e.g., Case 600 in Section 5.2.1) will also serve as the base case for other cases. The cases are grouped as follows:

a. Class I Test Procedures

1. Building Thermal Envelope and Fabric Load Tests (see Section 4.3.1.1)
   - Building Thermal Envelope and Fabric Load Base Case (see Section 4.3.1.1.1)
   - Building Thermal Envelope and Fabric Load Basic Tests (see Section 4.3.1.1.2)
     - Low mass (see Section 4.3.1.1.2.1)
     - High mass (see Section 4.3.1.1.2.2)
     - Free float (see Section 4.3.1.1.2.3)
   - Building Thermal Envelope and Fabric Load In-Depth Tests (see Section 4.3.1.1.3)
   - Ground-Coupled Slab-on-Grade Analytical Verification Tests (see Section 4.3.1.1.4)

2. Space-Cooling Equipment Performance Analytical Verification Tests (see Section 4.3.1.2)
   - Space-Cooling Equipment Performance Analytical Verification Base Case (see Section 4.3.1.2.1)
   - Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests (see Section 4.3.1.2.2)

3. Space-Cooling Equipment Performance Comparative Tests (see Section 4.3.1.3)
   - Space-Cooling Equipment Performance Comparative Test Base Case (see Section 4.3.1.3.1)
• Space-Cooling Equipment Performance Comparative Tests (see Section 4.3.1.3.2)

4. Space-Heating Equipment Performance Tests (see Section 4.3.1.4)
• Space-Heating Equipment Performance Analytical Verification Base Case (see Section 4.3.1.4.1)
• Space-Heating Equipment Performance Analytical Verification Tests (see Section 4.3.1.4.2)
• Space-Heating Equipment Performance Comparative Tests (see Section 4.3.1.4.3)

5. Air-side HVAC Equipment Analytical Verification Test Cases (see Section 4.3.1.5)
• Four-Pipe Fan-Coil (FC) System (see Section 4.3.1.5.1)
• Single-Zone (SZ) System (see Section 4.3.1.5.2)
• Constant-Volume Terminal Reheat (CV) System (see Section 4.3.1.5.3)
• Variable-Air-Volume Terminal Reheat (VAV) System (see Section 4.3.1.5.4)

b. Class II Test Procedures
1. Building Thermal Envelope and Fabric Load Base Case (see Section 4.3.2.1)
2. Building Thermal Envelope and Fabric Load Tier 1 Tests (see Section 4.3.2.2)
3. Building Thermal Envelope and Fabric Load Tier 2 Tests (see Section 4.3.2.3)

4.3.1 Class I Test Procedures

4.3.1.1 Building Thermal Envelope and Fabric Load Base Case. The base-building plan is a low-mass, rectangular single zone with no interior partitions. It is presented in detail in Section 5.2.1.

4.3.1.1.2 Building Thermal Envelope and Fabric Load Basic Tests. The basic tests analyze the ability of software to model building envelope loads in a low-mass configuration with the following variations: window orientation, shading devices, setback thermostat, and night ventilation.

4.3.1.1.2.1 The low-mass basic tests (Cases 600 through 650) utilize lightweight walls, floor, and roof. They are presented in detail in Section 5.2.2.1.

4.3.1.1.2.2 The high-mass basic tests (Cases 900 through 960) utilize masonry walls and concrete slab floor and include an additional configuration with a sunspace. They are presented in detail in Section 5.2.2.2.

4.3.1.1.2.3 Free-float basic tests (Cases 600FF, 650FF, 900FF, and 950FF) have no heating or cooling system. They analyze the ability of software to model zone temperature in both low-mass and high-mass configurations with and without night ventilation. The tests are presented in detail in Section 5.2.2.3.

4.3.1.1.3 Building Thermal Envelope and Fabric Load In-Depth Tests. The in-depth cases are presented in detail in Section 5.2.3.

4.3.1.1.3.1 In-depth Cases 195 through 320 analyze the ability of software to model building envelope loads for a nondeadband ON/OFF thermostat control configuration with the following variations among the cases: no windows, opaque windows, exterior infrared emittance, interior infrared emittance, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, window orientation, shading devices, and thermostat set points. These are a detailed set of tests designed to isolate the effects of specific algorithms. However, some of the cases may be incompatible with some building energy simulation programs.

4.3.1.1.3.2 In-depth Cases 395 through 440, 800, and 810 analyze the ability of software to model building envelope loads in a deadband thermostat control configuration with the following variations: no windows, opaque windows, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, and thermal mass. This series of in-depth tests is designed to be compatible with more building energy simulation programs. However, the diagnosis of software using this test series is not as precise as for Cases 195 through 320.

4.3.1.1.4 Ground-Coupled Slab-on-Grade Analytical Verification Tests. These test cases use the results of detailed verified numerical models for ground-coupled heat transfer as a secondary mathematical truth standard for comparing the results of models typically used with whole-building energy simulation software. The test cases use an uninsulated slab-in-grade configuration (slab interior surface level with exterior soil surface). Parametric variations versus a steady-state base case (Case GC30b) include harmonically varying ground surface temperature, floor slab aspect ratio, slab area, water table depth (depth of constant ground temperature), slab-interior and ground-exterior surface heat transfer coefficients, and slab and ground thermal conductivity. The cases use steady-state and harmonic boundary conditions as applied within artificially constructed annual weather data, along with an adiabatic above-grade building envelope to isolate the effects of ground-coupled heat transfer. The test cases are structured within three categories: “b”-series cases (see Section 4.3.1.1.4.1), “a”-series cases (see Section 4.3.1.1.4.2), and “c”-series cases (see Section 4.3.1.1.4.3). The “b”-series cases are presented first because they are likely to be possible for more programs to run than the “a”- or “c”-series cases. If the program being tested can run the “a”-series cases as they are described, run the “a”-series cases before running any of the other cases of Section 5.2.4.

4.3.1.1.4.1 The “b”-series cases (GC30b through GC80b) are for midlevel-detailed and simplified models likely to be used in whole-building simulation programs. These cases are presented in Section 5.2.4.1.

4.3.1.1.4.2 The “a”-series cases (GC10a through GC40a) are for detailed numerical-methods programs (e.g., three-dimensional [3D] numerical models) that are either integrated within or run independently from whole-building energy simulation programs. Within the “a”-series cases, Case GC10a provides a 3D steady-state analytical solution for rectangular surface geometry. These cases are presented in Section 5.2.4.2.

4.3.1.1.4.3 The “c”-series cases (GC30c through GC80c) apply boundary conditions with a fixed interior combined surface coefficient assumption of 7.95 W/m²·K and the exterior ground surface temperature equal to the outdoor dry-
bath temperature. These cases are presented in Section 5.2.4.3.

4.3.1.2 Space-Cooling Equipment Performance Analytical Verification Tests

4.3.1.2.1 Space-Cooling Equipment Performance Analytical Verification Base Case. The configuration of the base-case (Case CE100) building is a near-adiabatic rectangular single zone with only user-specified internal gains to drive steady-state cooling load. Mechanical equipment specifications represent a simple unitary vapor-compression cooling system or, more precisely, a split-system, air-cooled condensing unit with an indoor evaporator coil. Performance of this equipment is typically modeled using manufacturer design data presented in the form of empirically derived performance maps. This case is presented in detail in Section 5.3.1.

4.3.1.2.2 Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests. In these steady-state cases (Cases CE110 through CE200), the following parameters are varied: sensible internal gains, latent internal gains, zone thermostat set point (entering dry-bulb temperature [EDB]), and outdoor dry-bulb temperature (ODB). Parametric variations isolate the effects of the parameters singly and in various combinations and isolate the influence of the following: part-loading of equipment, varying sensible heat ratio, dry coil (no latent load) versus wet coil (with dehumidification) operation, and operation at typical Air-Conditioning, Heating and Refrigeration Institute (AHRI) rating conditions. In this way the models are tested in various domains of the performance map. These cases are presented in detail in Section 5.3.2.

4.3.1.3 Space-Cooling Equipment Performance Comparative Tests

4.3.1.3.1 Space-Cooling Equipment Performance Comparative Test Base Case. The configuration of this base case (Case CE300) is a near-adiabatic rectangular single zone with user-specified internal gains and outdoor air to drive dynamic (hourly varying) loads. The cases apply realistic, hourly varying annual weather data for a hot and humid climate. The mechanical system is a vapor-compression cooling system similar to that described in Section 4.3.1.2, except that it is a larger system and includes an expanded performance data set covering a wider range of operating conditions (i.e., wider range of ODB, EDB, and entering wet-bulb [EWB] temperatures). Also, an air-mixing system is present so that outdoor air mixing and economizer control models can be tested. This case is presented in detail in Section 5.3.3.

4.3.1.3.2 Space-Cooling Equipment Performance Comparative Tests. In these cases (Cases CE310 through CE545), which apply the same weather data as Case CE300, the following parameters are varied: sensible internal gains, latent internal gains, infiltration rate, outdoor air fraction, thermostat set points, and economizer control settings. Results analysis also isolates the influence of part loading of equipment, ODB sensitivity, and dry coil (no latent load) versus wet coil (with dehumidification) operation. These cases help to scale the significance of simulation results disagreements for a realistic context, which is less obvious in the steady-state cases described above. These cases are presented in detail in Section 5.3.4.

4.3.1.4 Space-Heating Equipment Performance Tests

4.3.1.4.1 Space-Heating Equipment Performance Analytical Verification Base Case. The configuration of the base-case (Case HE100) building is a rectangular single zone that is near-adiabatic on five faces with one heat exchange surface (the roof). Mechanical equipment specifications represent a simple unitary fuel-fired furnace with a circulating fan and a draft fan. Performance of this equipment is typically modeled using manufacturer design data presented in the form of empirically derived performance maps. This case is presented in detail in Section 5.4.1.

4.3.1.4.2 Space-Heating Equipment Performance Analytical Verification Tests. In these cases (Cases HE110 through HE170), the following parameters are varied: efficiency, weather (resulting in different load conditions from full load to part load to no load to time-varying load), circulating fan operation, and draft fan operation. In this way the basic functionalities of the models are tested in various domains of the performance map. These cases are presented in detail in Section 5.4.2.

4.3.1.4.3 Space-Heating Equipment Performance Comparative Tests. In these cases (Cases HE210 through HE230), the following parameters are varied: weather (realistic temperature conditions are used), thermostat control strategy, and furnace size (undersized furnace). In this way the models are tested with more realistic conditions in various domains of the performance map. These cases also test the interactions between furnace, control, and zone models. They are presented in detail in Section 5.4.3.

4.3.1.5 Air-Side HVAC Equipment Analytical Verification Tests. These test cases, presented in detail in Section 5.5, are designed to test the ability to model HVAC air distribution system equipment. The cases complement the test cases of Section 5.3, which test the ability to model the working-fluid side of HVAC equipment (also see Sections 4.3.1.2 and 4.3.1.3), and the test cases of Section 5.4, which test the ability to model space heating equipment performance (also see Section 4.3.1.4). Four systems are tested as described in the following subsections.

4.3.1.5.1 Four-Pipe Fan-Coil (FC) System. This is the most simple of the test systems. It is a single-zone system with heating and cooling coils, zone air exhaust, and limited outdoor air (no economizer control), and it does not include a return air fan. The FC system provides a good starting point for testing basic mass flow and heat balance modeling before addressing more complex air systems. The FC system tests include three sets of steady-state outdoor and zone conditions in heating, dry-coil cooling, and wet-coil cooling modes. The FC system cases are presented in detail in Section 5.5.1.

4.3.1.5.2 Single-Zone (SZ) System. The SZ system is based on the FC system but adds a return air fan and economizer outdoor air control. The SZ system tests include five sets of steady-state outdoor and zone conditions in heating, dry-coil cooling, and wet-coil cooling modes, and with temperature and enthalpy economizer outdoor air control strategies applied to selected conditions. The SZ system cases are presented in detail in Section 5.5.2.

4.3.1.5.3 Constant-Volume Terminal Reheat (CV) System. The CV system is based on the SZ system, but adds
multiple (two) zones, system supply air temperature control, and terminal reheat coils. The five sets of CV system test-case conditions are the same as those for the SZ system but applying different zone load and temperature set-point parameters for the second zone. The CV system cases are presented in detail in Section 5.5.3.

4.3.1.5.4 Variable-Air-Volume Terminal Reheat (VAV) System. The VAV system is based on the CV system but applies a variable airflow supply fan and terminal zone supply air dampers (along with terminal reheat coils). The VAV system test-case conditions are the same as those for the CV system. The VAV system cases are presented in detail in Section 5.5.4.

4.3.2 Class II Test Procedures

4.3.2.1 Building Thermal Envelope and Fabric Load Base Case. The building-plan is a 1539 ft² single-story house with one conditioned zone (the main floor), an unconditioned attic, and a raised floor exposed to air. It is presented in detail in Section 7.2.1.

4.3.2.2 Building Thermal Envelope and Fabric Load Tier 1 Tests. The Tier 1 cases test the ability of software to model building envelope loads in the base-case configuration with the following variations: infiltration; wall and ceiling R-value; glazing physical properties, area, and orientation; shading by a south overhang; internal loads; exterior surface color; energy-inefficient building; raised floor exposed to air; unsulated and insulated slab-on-grade; uninsulated and insulated basement. The Tier 1 Tests are presented in detail in Section 7.2.2.

4.3.2.3 Building Thermal Envelope and Fabric Load Tier 2 Tests. The Tier 2 tests consist of the following additional elements related to passive solar design: variation in mass, glazing orientation, east and west shading, glazing area, and south overhang. The Tier 2 tests are presented in detail in Section 7.2.3.

4.4 Comparing Output to Other Results. For Class I test procedures,

a. Informative Annex B8, Section B8.1, gives example simulation results for the building thermal envelope and fabric load tests of Sections 5.2.1, 5.2.2, and 5.2.3;

b. Informative Annex B8, Section B8.2, gives analytical solution, verified numerical model, and example simulation results for the ground-coupled slab-on-grade tests of Section 5.2.4; and

c. Informative Annex B16 gives quasi-analytical solution results and example simulation results for the HVAC equipment performance tests of Sections 5.3, 5.4, and 5.5.

For Class II test procedures (See Section 7), Informative Annex B20 gives example simulation results.

The user may choose to compare output with the example results provided in Informative Annexes B8, B16, and B20 or with other results that were generated using this standard method of test (including self-generated quasi-analytical solutions related to cases where such solutions are provided). For Class I test procedures, information about how the example results were produced is included in Informative Annex B11 for building thermal envelope and fabric load and ground-coupled slab-on-grade tests, and in Informative Annex B17 for HVAC equipment performance tests. For Class II test procedures, information about how the example results were produced is included in Informative Annex B21.

For the convenience of users who wish to plot or tabulate their results along with the example results, electronic versions of the example results are included with the accompanying electronic media: for Informative Annex B8 with the files RESULTS5-2A.XLSX and RESULTS5-2B.XLSX; for Informative Annex B16 with the files RESULTS5-3A.XLSX, RESULTS5-3B.XLSX, RESULTS5-4.XLSX, RESULTS5-5FCSZ.XLSX, and RESULTS5-5CVVV.XLSX; and for Informative Annex B20 with the file RESULTS7-2.XLS. Documentation for navigating these results files is included on the accompanying electronic media and is printed in Informative Annex B10.

4.4.1 Criteria for Determining Agreement between Results. 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. There are no formal criteria for when results agree or disagree with either the example results provided in Informative Annexes B8, B16, or B20, or with other results generated using this method of test. Determination of when results agree or disagree 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. In making this determination, the following should be considered:

a. Magnitude of results for individual cases.

b. Magnitude of difference in results between certain cases (e.g., Case 610 – Case 600).

c. Same direction of sensitivity (positive or negative) for difference in results between certain cases (e.g., Case 610 – Case 600).

d. Whether results are logically counterintuitive with respect to known or expected physical behavior.

e. Availability of analytical solution, quasi-analytical solution, or verified numerical model results (i.e., mathematical or secondary mathematical truth standards as described in Informative Annex B16, Section B16.2, and Informative Annex B8, Section B8.2.1).

f. For analytical verification tests, the degree of disagreement that occurred for other simulation results versus the analytical solution, quasi-analytical solution, or verified numerical model results.

g. Example simulation results do not represent a truth standard.

4.4.2 Diagnostic Logic for Determining Causes of Differences among Results. To help the user identify what algorithm in the tested program is causing specific differences between programs, diagnostic flow charts are provided as Informative Annex B9.
5. CLASS I TEST PROCEDURES

The Class I test procedures shall be applied as specified in Section 5.

**Informative Note:** Class I test procedures are detailed diagnostic tests intended for use with building energy simulation software tools having simulation time-steps of one hour or less. Energy analysis computer tools that do not meet this simulation time-step requirement but produce annual or seasonal results may be evaluated using Section 7, “Class II Test Procedures,” of this standard. The Class I test cases are designed for more detailed diagnosis of simulation models than the Class II test cases.

5.1 Modeling Approach. This modeling approach shall apply to all of the test cases presented in Section 5.

5.1.1 Time Convention. All references to “time” in this specification are to local standard time and assume that hour 1 = the interval from midnight to 1 A.M. Daylight savings time or holidays shall not be used for scheduling.

**Informative Note:** TMY weather data are in hourly bins corresponding to solar time, as specified in Normative Annex A1, Section A1.5. TMY2 and WYEC2 data are in hourly bins corresponding to local standard time.

5.1.2 Geometry Convention. If the program being tested includes the thickness of walls in a three-dimensional (3D) definition of the building geometry, then wall, roof, and floor thicknesses shall be defined such that the interior air volume of the building model remains as specified. The thicknesses shall extend exterior to the currently defined internal volume.

**Informative Notes:** For example, for the building thermal envelope and fabric load test cases of Sections 5.2.1, 5.2.2, and 5.2.3, interior air volume would be calculated as 6 × 8 × 2.7 m = 129.6 m³ (19.7 × 26.2 × 8.9 ft = 4576.8 ft³).

5.1.3 Nonapplicable Inputs. If the specification includes input values that do not apply to the input structure of the program being tested, disregard the nonapplicable inputs and continue.

**Informative Note:** Selected equivalent inputs are included in the test specification for those programs that may need them.

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. The option that is used shall be documented in the Standard Output Report (as specified in Normative Annex A2).

**Informative Note:** 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.

5.1.5 Equivalent Modeling Methods. Where a program or specific model within a program does not allow direct input of specified values, or where input of specified values causes instabilities in a program’s calculations, modelers shall develop equivalent inputs that match the intent of the test specification as nearly as the software being tested allows. Such equivalent inputs shall be developed based on the data provided in the test specification, and such equivalent inputs shall have a mathematical, physical, or logical basis and shall be applied consistently throughout the test cases. The modeler shall document the equivalent modeling method in the Standard Output Report (see Normative Annex A2).

5.1.6 Use of Nonspecified Inputs. Use of nonspecified inputs shall be permitted only for the following specified sections relating to the following topics:

- Interior combined radiative and convective surface coefficients in Sections 5.2.1.10, 5.2.3.2.2, and 5.3.1.9.
- Interior solar distribution in Sections 5.2.1.12, 5.2.2.1.2.2, 5.2.2.2.7.4, 5.2.3.9.3, 5.2.3.10.2, and 5.2.3.12.2.
- Air density given at specific altitudes for the space-cooling and space-heating equipment cases in Sections 5.3.1.4.3, 5.3.3.4.3, and 5.4.1.4.3.

Use of nonspecified inputs shall be permitted only if there is a mathematical, physical, or logical basis for applying them. Where different values are used, they shall be applied consistently throughout the test cases. Use of nonspecified inputs shall be documented in the Standard Output Report specified in Normative Annex A2.

5.1.7 Simulation Initialization and Preconditioning. If the program being tested allows for preconditioning (iterative simulation of an initial time period until temperatures, fluxes, loads, or all of these, stabilize at initial values), that capability shall be used. If the program being tested allows, and if applicable to the model, the simulation initialization process shall begin with zone air conditions that equal the outdoor air conditions.

5.1.8 Simulation Duration

5.1.8.1 Results for the tests of Sections 5.2.1, 5.2.2, 5.2.3, 5.3.3, and 5.3.4 shall be taken from full annual simulations.

5.1.8.2 For the tests of Section 5.2.4, if the program being tested allows multiyear simulations, models shall run for a number of years to satisfy the requirements of specific test cases. If the software being tested is not capable of simulation duration sufficient to satisfy the requirements of specific test cases, the simulation shall be run for the maximum duration allowed by the software being tested.

**Informative Note:** The duration to achieve requirements of specific test cases may vary among the test cases.

5.1.8.3 For the tests of Sections 5.3.1 and 5.3.2, the simulation shall be run for at least the first two months for which the weather data are provided. Provide output for the second month of the simulation (February) in accordance with Section 6.3.1.

**Informative Note:** The first month of the simulation period (January) serves as an initialization period.

5.1.8.4 For the tests of Section 5.4, the simulation shall be run for at least the first three months for which the weather data are provided. Provide output for the first three months of the year (January 1 through March 31) in accordance with Section 6.4.

5.1.8.5 For the tests of Section 5.5, the simulation shall be run until the final hour output agrees with the previous hour output. Provide output in accordance with Section 6.5.

5.1.9 Rules for Modifying Simulation Programs or Simulation Inputs. Modifications to simulation programs or simulation inputs shall have a mathematical, physical, or logical...
basis and shall be applied consistently across tests. Arbitrary modification of a simulation program’s input or internal code solely for the purpose of more closely matching a given set of results shall be prohibited.

If changes are made to the source code of the software for the purpose of performing tests, and these changes are not available in publicly released versions of the software, then the changes shall be documented in sufficient detail, using the modeler report template provided in Normative Annex A2, so that the implications of the changes are assessable.

5.2 Input Specifications for Building Thermal Envelope and Fabric Load Tests

5.2.1 Case 600: Base Case. Begin with Case 600. Case 600 shall be modeled as specified in this section and its subsections.

Informative Note: The bulk of the work for implementing the tests is assembling an accurate base-building model. It is recommended that base-building inputs be double checked and results disagreements be diagnosed before proceeding to the other cases.

5.2.1.1 Weather and Site Data

5.2.1.1.1 Weather Data. The DRYCOLD.TMY weather data provided with the electronic files accompanying this standard shall be used for all cases in Sections 5.2.1, 5.2.2, and 5.2.3. These data are described in Normative Annex A1, Section A1.1.1.

5.2.1.1.2 Site Data. The site parameters provided in Normative Annex A1, Table A1-1 shall be used.

The solar reflectance of the site ground surface = 0.2.

5.2.1.2 Output Requirements. Case 600 requires the following output:

a. All non-free-float case output in accordance with Section 6.2.1.1
b. Case-600-only output in accordance with Section 6.2.1.2
c. Daily hourly output as specified for Case 600 in Section 6.2.1.8
d. General reporting requirements of Section 6.1

Informative Note: In this description, the term “free-float cases” refers to cases designated with “FF” in the case description (i.e., 600FF, 650FF, 900FF, 950FF); non-free-float cases are all the other cases described in Sections 5.2.1, 5.2.2, and 5.2.3. (Informative Annex B1, Tables B1-2 and B1-3, include a summary listing of the cases of Sections 5.2.1, 5.2.2, and 5.2.3).

5.2.1.3 Building Geometry. The base-building plan shall be a 48 m² floor area, single-story, low-mass building with rectangular-prism geometry and 12 m² of south-facing windows as shown in Figure 5-1.

5.2.1.4 Material Properties. For the wall, floor, and roof, the thermal and material properties provided in Table 5-1 shall be used. For programs that automatically calculate interior surface radiation and convection, or that treat interior surface coefficients as specified in Section 5.2.1.10, variation of individual interior surface coefficient U-values and total U- and total UA-values from those specified in Table 5-1 shall be permitted.

5.2.1.5 Ground Coupling. The exterior surface of the floor contacts the ground.

Informative Note: To reduce uncertainty regarding testing the other aspects of simulating the building envelope, the floor insulation described in Table 5-1 has been made very thick to effectively decouple the floor thermally from the ground.

5.2.1.5.1 The underfloor insulation shall have the minimum density and specific heat that the program being tested allows.

5.2.1.5.2 For software that requires input of ground thermal properties, the ground in the vicinity of the building shall be dry-packed soil with the following characteristics:

- Soil thermal conductivity \( k = 1.3 \text{ W/(m·K)} \)
- Soil density = 1500 kg/m³
- Soil specific heat = 800 J/(kg·K)
- Deep ground temperature = 10°C

5.2.1.6 Infiltration. The infiltration rate shall be 0.5 ach, continuously (24 hours per day for the full year). The infiltration rate shall be independent of wind speed, indoor/outdoor temperature difference, and other variables.

5.2.1.6.1 The weather data file represents a high-altitude site with an elevation of 1609 m above sea level. If the program being tested does not use barometric pressure from the weather data or otherwise automatically correct for the change in air density due to altitude, then the specified infiltration rates shall be adjusted to yield mass flows equivalent to those occurring at 1609 m altitude, as shown in Table 5-2.

Informative Note: Air density at 1609 m altitude is roughly 80% of that at sea level. The calculation technique used to develop Table 5-2 is provided as background information in Informative Annex B3.

5.2.1.7 Internally Generated Sensible Heat. The following internal heat gains shall be used:

- Internal gains shall be 200 W, continuously (24 hours per day for the full year).
- Internal gains shall be 100% sensible, 0% latent.
- Internal gains shall be 60% radiative, 40% convective.

Informative Note: Internally generated sensible and latent internal gains are assumed to be distributed evenly throughout
Table 5-1 Material Specifications Lightweight Case

<table>
<thead>
<tr>
<th>Element</th>
<th>( k, \frac{W}{m \cdot K} )</th>
<th>Thickness, m</th>
<th>( U, \frac{W}{m^2 \cdot K} )</th>
<th>( R, \frac{m^2 \cdot K}{W} )</th>
<th>Density, kg/m³</th>
<th>( c_p, \frac{J}{kg \cdot K} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight Case: Exterior Wall (inside to outdoors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Interior surface coefficient</td>
<td></td>
<td></td>
<td>8.290</td>
<td>0.121</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.160</td>
<td>0.012</td>
<td>13.333</td>
<td>0.075</td>
<td>950.000</td>
<td>840.000</td>
</tr>
<tr>
<td>Fiberglass quilt</td>
<td>0.040</td>
<td>0.066</td>
<td>0.606</td>
<td>1.650</td>
<td>12.000</td>
<td>840.000</td>
</tr>
<tr>
<td>Wood siding</td>
<td>0.140</td>
<td>0.009</td>
<td>15.556</td>
<td>0.064</td>
<td>530.000</td>
<td>900.000</td>
</tr>
<tr>
<td>Exterior surface coefficient</td>
<td></td>
<td></td>
<td>29.300</td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total air-air</td>
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<td></td>
<td>0.514</td>
<td>1.944</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total surf-surf</td>
<td></td>
<td></td>
<td>0.559</td>
<td>1.789</td>
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<td>Lightweight Case: Floor (inside to outdoors)</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Interior surface coefficient (^a)</td>
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<td>8.290</td>
<td>0.121</td>
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<td></td>
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<tr>
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<td>1200.000</td>
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<tr>
<td>Insulation</td>
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<td>1.003</td>
<td>0.040</td>
<td>25.075</td>
<td>0 (^b)</td>
<td>0 (^b)</td>
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<tr>
<td>Total air-surf</td>
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<tr>
<td>Total surf-surf</td>
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<td>0.040</td>
<td>25.254</td>
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<tr>
<td>Lightweight Case: Roof (inside to outdoors)</td>
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<tr>
<td>Interior surface coefficient (^a)</td>
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<td></td>
<td>8.290</td>
<td>0.121</td>
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</tr>
<tr>
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<td>0.063</td>
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<tr>
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<td>Component</td>
<td>Area, m²</td>
<td>UA, W/K</td>
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<tr>
<td>Roof</td>
<td>48.000</td>
<td>15.253</td>
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<tr>
<td>South window</td>
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<td>36.000</td>
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</tr>
<tr>
<td>Infiltration</td>
<td>18.440 (^c)</td>
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<td>Total UA (with south glass)</td>
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<tr>
<td>Total UA (without south glass)</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ach</td>
<td>Volume, m³</td>
<td>Altitude, m</td>
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<td></td>
</tr>
<tr>
<td>0.500</td>
<td>129.600</td>
<td>1609.000</td>
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</tr>
</tbody>
</table>

\(^a\) Informative Note: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.

\(^b\) Underfloor insulation has the minimum density and specific heat the program being tested will allow, but not <0.

\(^c\) Informative Note: UA corresponding to infiltration based on ach × volume × (specific heat of air) × (density of air at specified altitude).