



ASHRAE ADDENDA

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

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FOREWORD

In response to feedback from the code enforcement community, this addendum addresses all the permissive and unenforceable language in Standard 140-2007. With the publication of Addendum c, the standard will be written in an enforceable manner suitable for code adoption.

[Informative Note: Additions are shown in this addendum by underlining and deletions are shown by strikethrough except when an informative note makes it clear that the entire material that follows is to be added or deleted as a whole. The changes shown in this addendum are relative to the 2007 edition of the standard—as modified by published Addenda a and b.]

Addendum c to Standard 140-2007

Change the standard as indicated in the following sections.

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

FOREWORD

This Standard Method of Test can be used for identifying and diagnosing predictive differences from whole building energy simulation software that may possibly be caused by algorithmic differences,

modeling limitations, input differences, or coding errors. The current set of tests included herein consists of

- comparative tests that focus on building thermal envelope and fabric loads and mechanical equipment performance and*
- analytical verification tests that focus on mechanical equipment performance.*

These tests are part of an overall validation methodology described in informative Annex B23. ~~Theis~~ procedures ~~tests~~ software over a broad range of parametric 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 examine many of the thermal 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 plans 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 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 sub-hourly simulation time steps. The Class II (Section 7) test cases 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.

Class I Test Procedures (Section 5)

The set of Class I tests included herein consist of:

- software-to-software comparative tests that focus on building thermal envelope and fabric loads and mechanical equipment performance and.
- analytical verification tests (comparison of software to analytical or quasi-analytical solutions) that focus on mechanical equipment performance.

In addition to comparative and analytical verification tests, the overall methodology for model validation and testing described in informative Annex B23, 2009 ASHRAE Handbook—Fundamentals^{F-1} (see Chapter 19), and elsewhere^{F-2} includes empirical validation testing, where tested software models are validated to within the uncertainty of measured data. Such tests will be considered for Standard 140, and additional research on this topic is recommended, as discussed in Annex B23.

For the building thermal envelope and fabric load cases of Section 5.2, the “basic” 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” cases (Section 5.2.3) facilitate diagnosis by allowing excitation of specific heat transfer mechanisms. 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. 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 setpoint (entering drybulb temperature), and outdoor dry-bulb temperature. Parametric variations isolate the effects of the parameters singly and in various combinations and isolate the influence of partloading of equipment, varying sensible heat ratio, “dry” coil (no latent load) versus “wet” coil (with dehumidification) operation, and operation at typical Air-Conditioning and Refrigeration Institute (ARI) rating conditions. Quasi-analytical solution results are presented for the test cases in this section. The comparative test cases of Sections 5.3.3 and 5.3.4 utilize an expanded

range of performance data, an ~~outside-outdoor~~ air mixing system and hourly varying weather data and internal gains. These cases cannot be solved analytically. In these cases the following parameters are varied: sensible internal gains, latent internal gains, infiltration rate, ~~outside-outdoor~~ air fraction, thermostat setpoints, and economizer control settings. Through analysis of results, the influence of part loading of equipment, ODB 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 in a realistic context, which is less obvious in the steady-state cases of Sections 5.3.1 and 5.3.2. 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 cases (Sections 5.4.1 and 5.4.2—Analytical Verification Tests) employ simplified boundary conditions and test the basic functionality of furnace models. ~~More realistic~~ ~~boundary conditions that are more realistic~~ are used in the Tier 2 cases (Section 5.4.3—Comparative Tests), 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.

~~For consistent numbering of test cases within the standard, case numbers used for the mechanical equipment tests in Sections 5.3 and 5.4 have been changed from the numbering used in the original research reports where the test specifications were developed. For example, in Section 5.3.1, Case CE100 was named Case E100 in the original research.~~

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.^{B-1} This set of test cases formally codifies the Tier 1 and Tier 2 Tests for certification of residential energy performance analysis tools, as described in the 2006 Mortgage Industry National Home Energy Rating Systems Standards.^{B-2}

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, 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-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; un-insulated and insulated slab-on-grade; un-insulated and insulated basement. 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, American Society of Heating Refrigerating and Air Conditioning Engineers, 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 ~~the~~ 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 the informative Annex B9).

Regarding the comparative test results of Annex B8, ~~and~~ 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, ~~and~~ 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 source 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:-

- user input error, where the user misinterpreted or incorrectly entered one or more program inputs;
- a problem with a particular algorithm in the program;
- 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 (non-mandatory) 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 of Standard 140. 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 of Standard 140 may wish to adopt procedures for developing acceptance-range criteria for tested software. Informative Annex B22 presents an example range setting methodology that may be useful for these purposes.

Importance of Analytical and Quasi-Analytical Solution Results

Analytical verification test results for the *Class I* HVAC equipment performance tests include both quasi-analytical solutions and simulation results in selected sections of Informative Annex B16. In general, it is difficult to develop worthwhile test cases that can be solved analytically or quasi-analytically, but such solutions are extremely useful when possible. Analytical or quasi-analytical solutions represent a “mathematical truth standard.” That is, given the underlying physical assumptions in the case definitions, there is a mathematically correct solution for each case. In this context, the underlying physical assumptions regarding the mechanical equipment as defined in Sections 5.3 and 5.4 are representative of typical manufacturer data normally used by building design practitioners. Many “whole-building” simulation programs are designed to work with this type of data. It is important to understand the difference between a “mathematical truth standard” and an “absolute truth standard.” In the former, 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. An approximate truth standard from an experiment tests both the solution process and appropriateness of the model within experimental uncertainty. The ultimate or “absolute” validation truth standard would be comparison of simulation results with a perfectly performed empirical experiment, with all simulation inputs perfectly defined.

The quasi-analytical and analytical solution results presented in selected parts of Annex B16 represent a mathematical truth standard. This allows identification of bugs in the software that would not otherwise be apparent from comparing software only to other software and therefore improves the diagnostic capabilities of the test procedure. The primary purpose of also including simulation results for the cases where analytical or quasi-analytical solutions exist is to allow simulationists to compare their relative agreement (or disagreement) versus the

analytical or quasi-analytical solution results to that for other simulation results. Perfect agreement among simulations and analytical or quasi-analytical solutions is not necessarily expected. The results give an indication of the degree of agreement that is possible between simulation results and the analytical or quasi-analytical solution results. Because the physical assumptions of a simulation may be different from those for analytical or quasi-analytical solutions, a tested program may disagree with such solutions without necessarily being incorrect. However, it is worthwhile to investigate the sources of differences as noted above.

3.1 Terms Defined for This Standard

adjusted net sensible capacity: the gross sensible capacity less the actual fan power. (Also see *gross sensible capacity*.)

adjusted net total capacity: the gross total capacity less the actual fan power. (Also see *gross total capacity*.)

altitude: vertical elevation above sea level.

analytical solution: a mathematical solution of a model of reality that has a deterministic result for a given set of parameters and boundary conditions.

annual heating load: the heating load for the entire one-year simulation period; e.g., 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 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 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; this is the temperature to which all the supply air would be cooled if 100% of the supply air contacted the coil. 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 ([gross sensible capacity]/[gross total capacity]). (Also see *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.

building thermal envelope and fabric: includes the building thermal envelope as defined in *ASHRAE Terminology*, as well as elements of a building which enclose spaces, and which 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): can be thought of as 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 also *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–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. (Also 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.

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.

COP2: 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. (Also see *gross total evaporator coil load*.)

COP_{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 partload ratio. (Also see *part-load ratio*.)

deep ground temperature: the ground temperature at or below a soil depth of two meters.

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

dew-point temperature: the temperature of saturated air at a given humidity ratio and pressure. As moist air is cooled at constant pressure, the dew point is the temperature at which condensation begins. (Also see *humidity ratio*.)

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, usually by using ~~outside-outdoor~~ air and control logic to maintain a fixed minimum of ~~outside-outdoor~~ air when increased ~~outside-outdoor~~-air flow rates are not called for.

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. (Also see *net refrigeration effect* and *cooling energy consumption*.)

entering dry-bulb temperature (EDB): the temperature ~~that indicated by an ordinary~~ thermometer ~~would measure~~ 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 ~~outside-outdoor~~ air mixed with return air, EDB equals the indoor dry-bulb temperature. For a similar configuration but when ~~outside-outdoor~~ air is mixed with return air, EDB equals the mixed-air dry-bulb temperature.

entering wet-bulb temperature (EWB): the temperature ~~that indicated by~~ the wet-bulb portion of a psychrometer ~~would measure if~~ 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 ~~outside-outdoor~~ air mixed with return air, this would also be the zone air wet-bulb temperature. For a similar configuration but when ~~outside-outdoor~~ air is mixed with return air, EWB 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. (Also 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 ($(dI) = (I K dx)$) where I is the local intensity of solar radiation within a medium and x is the distance the radiation travels through the medium.

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

free float: ~~refers to a situation 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. (Also see *sensible heat*.) ***Informative Note:*** This value varies as a function of performance parameters such as EWB, ODB, EDB, and airflow rate. (Also see *sensible heat*.)

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. (Also 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. (~~Also see sensible heat and latent heat.~~)

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.

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. Also see *infrared emittance*.

hourly free-floating zone air temperature: zone air temperature for a given hour; ~~during which~~ when 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.

indoor dry-bulb temperature (IDB): the temperature ~~that indicated by an ordinary thermometer would measure if~~ when exposed to indoor air.

infiltration: the leakage of air through any building element (e.g., walls, windows, and 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. Also 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. (Also see *humidity ratio*.)

net refrigeration effect: the rate of heat removal (sensible + latent) by the evaporator coil, as regulated by the thermostat (~~is~~, 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. (Also 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*.)

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

outdoor dry-bulb temperature (ODB): the temperature ~~that indicated by an ordinary thermometer would measure if~~ when exposed to

outdoor air. **Informative Note:** 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. (Also see *net refrigeration effect* and *adjusted net total capacity*.) **Informative Note:** As shown in 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. (Also see *net refrigeration effect*, *adjusted net total capacity*, *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.

quasi-analytical solution: the mathematical solution of a model of reality for a given set of parameters and boundary conditions. **Informative Note:** Such a result may be computed by generally accepted numerical method calculations, 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 ~~outdoor~~ outside air temperature, the underside of the conditioned-zone floor has an exterior film coefficient consistent with a "rough" surface texture and zero wind speed, and the conditioned-zone floor exterior surface (surface facing the raised floor) receives no solar radiation. **Also see** Section 7.2.1.5.

relative humidity: 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. This is equivalent to the ratio of partial pressure of the water vapor in a sample to the saturation pressure at the same temperature.

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 as determined using ANSI/ARI Standard 210/240-89.² (Also 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. (Also see *net refrigeration effect* and *cooling energy consumption*.)

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): also known as sensible heat factor (SHF), the ratio of sensible heat transfer to total (sensible + latent) heat transfer for a process; also known as sensible heat factor (SHR). (Also see *sensible heat* and *latent heat*.)

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

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 the window(s) that is absorbed by a given surface or retransmitted (lost) back out the window(s).

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 windows, SHGC is dependent on incidence angle.

solar lost: see *solar lost through window*.

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

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

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

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:* (e.g., For example, these loads do not include air distribution fan heat).

4. METHODS OF TESTING

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 sub-hourly 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, providing 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, and software-to-quasi-analytical-solution 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 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 or analytical and quasi-analytical solutions) 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;
- diagnosing the algorithmic sources of prediction differences; diagnostic logic flow diagrams are included in the 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 certifying and accrediting agencies, as appropriate. The Class I tests cases (Section 5) are detailed

diagnostic tests intended for simulation software capable of hourly or sub-hourly 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 the ~~informational~~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:

a. Class I test procedures

1. Building Thermal Envelope and Fabric Load Tests (see Section 4.3.1.1)

~~1-~~ Building Thermal Envelope and Fabric Load Base Case (see Section 4.24.3.1.1.1)

~~2-~~ Building Thermal Envelope and Fabric Load Basic Tests (see Section 4.24.3.1.1.2)

- o ~~1-~~Low mass (see Section 4.24.3.1.1.2.1)
- o ~~1-~~High mass (see Section 4.24.3.1.1.2.2)
- o ~~1-~~Free float (see Section 4.24.3.1.1.2.3)

~~3-~~ Building Thermal Envelope and Fabric Load In-Depth Tests (see Section 4.24.3.1.1.3)

2. Space-Cooling Equipment Performance Analytical Verification Tests (see Section 4.3.1.2)

~~4-~~Space-Cooling Equipment Performance Analytical Verification Base Case (see Section 4.24.3.1.2.14)

~~5-~~Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests (see Section 4.24.3.1.2.25)

3. Space-Cooling Equipment Performance Comparative Tests (see Section 4.3.1.3)

~~6-~~Space-Cooling Equipment Performance Comparative Test Base Case (see Section 4.24.3.1.3.16)

~~7-~~Space-Cooling Equipment Performance Comparative Tests (see Section 4.24.3.1.3.27)

4. Space-Heating Equipment Performance Tests (see Section 4.3.1.4)

~~8-~~ Space-Heating Equipment Performance Analytical Verification Base Case (see Section 4.24.3.1.4.18)

~~9-~~ Space-Heating Equipment Performance Analytical Verification Tests (see Section 4.24.3.1.4.29)

~~10-~~ Space-Heating Equipment Performance Comparative Tests (see Section 4.24.3.1.4.310)

b. Class II test procedures

1. Building Thermal Envelope and Fabric Load Base Case (see Section 4.24.3.2.1)

2. Building Thermal Envelope and Fabric Load Tier-1 Tests (see Section 4.24.3.2.2)

3. Building Thermal Envelope and Fabric Load Tier-2 Tests (see Section 4.24.3.2.3)

4.32.1 Class I Test Procedures.

4.3.1.1 Building Thermal Envelope and Fabric Load Tests

4.32.1.1.1 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.

4.32.1.1.2 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.

4.32.1.1.2.1 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.

4.32.1.1.2.2 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.

4.32.1.1.2.3 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.

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

4.32.1.1.3.1 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 setpoints. 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.

4.32.1.1.3.2 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.

4.3.1.2 Space-Cooling Equipment Performance Analytical Verification Tests

4.32.1.2.1 4-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.

4.32.1.2.25 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 setpoint (entering dry-bulb temperature [EDB]), and ODB. 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 and Refrigeration Institute (ARI) 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

4.32.1.3.16 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 ~~outside-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 4.2.4 4.3.1.2.1, 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 EWB, the entering wet-bulb temperature). Also, an air mixing system is present so that outside-air mixing and economizer control models can be tested. This case is presented in detail in Section 5.3.3.

4.32.1.3.27 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, ~~outside-outdoor~~ air fraction, thermostat setpoints, 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

4.3.2.1.4.18 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.

4.3.2.1.4.29 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.

4.3.2.1.4.310 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.

4.3.2.2 Class II Test Procedures.

4.3.2.2.1 Building Thermal Envelope and Fabric Load Base Case. The base 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.

4.3.2.2.2 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; un-insulated and insulated slab-on-grade; un-insulated and insulated basement. The Tier-1 Tests are presented in detail in Section 7.2.2.

4.3.2.2.3 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.

4.3 Reporting Results

4.3.1 Standard Output Reports. The standard output reports included on the accompanying CD shall be used. Instructions regarding these reports are included in Annex A2. Information required for this report includes

- a. software name and version number;
- b. modeling documentation using "S140outNotes.TXT" on the accompanying CD for:
 - Software identifying information and operating requirements
 - Modeling methods used when alternative methods are available in the software
 - Equivalent modeling methods used when the software does not allow direct input of specified values
 - Omitted test cases and results
 - Changes to source code for the purpose of running the tests, where such changes are not available in publicly released versions of the software
 - Anomalous results
- e. results for simulated cases using the following files on the accompanying CD:
 - See5-2out.XLS for the building thermal envelope and fabric load tests of Section 5.2
 - See5-3Aout.XLS for the space-cooling equipment performance analytical verification tests of Sections 5.3.1 and 5.3.2
 - See5-3Bout.XLS for the space-cooling equipment performance comparative tests of Sections 5.3.3 and 5.3.4
 - See5-4out.XLS for the space-heating equipment performance tests of Section 5.4
 - RESULTS7-2.XLS, sheet tab 'See7-2out' for the building thermal envelope and fabric load tests of Section 7.2

Output quantities to be included in the results report are called out specifically for each case, as they appear in the appropriate subsections of Sections 5.2, 5.3, 5.4, and 7.2.

If a program being tested omits a test case, the modeler shall provide an explanation using the modeler report template provided in Annex A2.

4.3.2 Simulation Input Files. All supporting data required for generating results with the tested software shall be saved, including:

- Input files
- Processed weather data
- Intermediate files containing calculations used for developing inputs
- A “Readme-software-name-yyymmdd.pdf” file that briefly describes the contents of the above files according to their file type (i.e., their “.xyz” file extension).

4.4 Comparing Output to Other Results. For Class I test procedures, Annex B8 gives example simulation results for the building thermal envelope and fabric load tests, and Annex B16 gives quasi-analytical solution results and example simulation results for the HVAC equipment performance tests. For Class II test procedures, Annex B20 gives example simulation results. The user may choose to compare output with the example results provided in Annex B8, Annex B16, and Annex B20 or with other results that were generated using this standard method of test (including self-generated quasi-analytical solutions related to the HVAC equipment performance tests). 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 tests and 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 to users who wish to plot or tabulate their results along with the example results, electronic versions of the example results have been included on with the accompanying CD-electronic media for Annex B8 with the file RESULTS5-2.XLS; for Annex B16 with the files RESULTS5-3A.XLS, RESULTS5-3B.XLS, and RESULTS5-4.XLS; and for Annex B20 with the file RESULTS7-2.XLS. Documentation for navigating these results files has been is included on the accompanying CD electronic media and is printed in 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 that may be running the tests for their own quality assurance purposes. In making this determination, the following should be considered: user should consider the following:

- 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 or quasi-analytical solution results (i.e., mathematical truth standard as described in informative Annex B16, Section B16.2),
- f. for the space-cooling and space-heating equipment performance tests of Sections 5.3 and 5.4, the degree of disagreement that occurred for other simulation results in Annex B16 versus the analytical and quasi-analytical solution 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 ~~informational~~informative Annex B9.

4.4.3 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 just for the purpose of more closely matching a given set of results shall not be allowed.

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 Annex A2, so that the implications of the changes can be assessed.

4.4.4 Discussion of Anomalous Results. At the option of the report author, anomalous test results may be explained using the modeler report template provided in Annex A2.

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 (Section 7) test cases.

5.1 Modeling Approach. This modeling approach shall apply to all the test cases presented in Sections 5.2, 5.3, and 5.4.

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.* ~~Do not use daylight~~ 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 ~~described~~ specified in 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 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 (e.g., for the cases of Section 5.2, $6 \times 8 \times 2.7 \text{ m} = 129.6 \text{ m}^3$). ~~Make these~~ thicknesses shall extend exterior to the currently defined internal volume.

5.1.3 Nonapplicable Inputs. In some instances the specification will include input values that do not apply to the input structure of the program being tested. When this occurs, disregard the nonapplicable inputs and continue.

Informative Note: Such 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. For example, if a software gives a choice of methods for modeling windows, the same window modeling method shall be used for all cases. Document which ~~The~~ option that ~~was~~ is used shall be documented in the Standard Output Report (see as specified in Annex A2).

Informative Note: For example, if a software 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 ~~should~~ develop equivalent inputs that match the intent of the test specification as nearly as the software being tested allows. Such equivalent inputs ~~are to~~ 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 (Annex A2).

5.1.6 Use of Non-Specified Inputs. Use of non-specified 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 non-specified 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 non-specified inputs shall be

documented in the Standard Output Report specified in Annex A2.

5.1.76 Simulation Initialization and Preconditioning. If the program being tested allows, ~~begin~~ the simulation initialization process shall begin with zone air conditions that equal the ~~outside~~ outside air conditions. If the program being tested allows for preconditioning (iterative simulation of an initial time period until temperatures or fluxes, or both, stabilize at initial values), ~~use~~ that capability shall be used.

5.1.87 Simulation Duration

5.1.87.1 Results for the tests of Sections 5.2, 5.3.3, and 5.3.4 ~~are to~~ shall be taken from a full annual simulation.

5.1.87.2 For the tests of Sections 5.3.1 and 5.3.2, ~~run~~ the simulation shall be run for at least the first two months for which the weather data are provided. ~~Give~~ 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.

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

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 just 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 Annex A2, 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 ~~detailed~~ specified in this section and its subsections.

Informative Note: The bulk of the work for implementing the Section 5.2 tests is assembling an accurate base building model. It is recommended that base building inputs be double checked and results disagreements be diagnosed before going on to the other cases.

5.2.1.1 Weather and Site Data. ~~Use~~

5.2.1.1.1 Weather Data. The DRY-COLD.TMY weather data provided ~~on~~ with the CD-electronic files accompanying this standard shall be used for all cases in Section 5.2. These data ~~are~~ described in normative Annex A1, Section A1.1. ~~These weather data shall be used for all cases described in Section 5.2.~~

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 6.4.2.1,
- b. case_600-only output in accordance with Section 6.4.2.2,
- c. daily hourly output as specified for Case 600 in Section 6.2.8,
- 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 Section 5.2 (Tables B1-1a and B1-1b of Annex B1 include an informative summary listing of the cases of Section 5.2).

5.2.1.3 Building Geometry. The base building plan ~~is~~ 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 are 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.

TABLE 5-1 Material Specifications Lightweight Case

Element	k, W/(m·K)	Thickness, m	U, W/(m²·K)	R, (m²·K)/W	Density, kg/m³	C_p, J/(kg·K)
Lightweight Case: Exterior Wall (inside to outside)						
Int Surf Coef	8.290	0.121				
Plasterboard	0.160	0.012	13.333	0.075	950.000	840.000
Fiberglass quilt	0.040	0.066	0.606	1.650	12.000	840.000
Wood Siding	0.140	0.009	15.556	0.064	530.000	900.000
Ext Surf Coef	29.300	0.034				
Total air—air	0.514	1.944				
Total air—surf	0.559	1.789				
Lightweight Case: Floor (inside to outside)						
Int Surf Coef	8.290	0.121				
Timber flooring	0.140	0.025	5.600	0.179	650.000	1200.000
Insulation	0.040	1.003	0.040	25.075	(see Note b)	0 ^b (see Note b)
Total air—air	0.039	25.374				
Total air—surf	0.040	25.254				
Lightweight Case: Roof (inside to outside)						
Int Surf Coef	8.290	0.121				
Plasterboard	0.160	0.010	16.000	0.063	950.000	840.000
Fiberglass quilt	0.040	0.1118	0.358	2.794	12.000	840.000
Roofdeck	0.140	0.019	7.368	0.136	530.000	900.000
Ext. Surf Coef	29.300	0.034				
Total air—air	0.318	3.147				
Total air—surf	0.334	2.992				
Summary: Lightweight Case						
Component Area, m² UA, W/K						
Wall	63.600	32.715				
Floor	48.000	1.892				
Roof	48.000	15.253				
S Window	12.000	36.000				
Infiltration	18.440 ^c					
Total UA (with S Glass)	104.300					
Total UA (without S Glass)	68.300					
ach Volume, m³ Altitude, m						
0.500	129.600	1609.000				

^aThe interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.

^bUnderfloor insulation shall have the minimum density and specific heat the program being tested will allow, but not < 0.

^cUA corresponding to infiltration based on: ach × volume × (specific heat of air) × (density of air at specified altitude).

5.2.1.5 Ground Coupling.

The exterior surface of the floor contacts the ground.

Informative Note: Although heat loss to the ground can have a significant effect on the heating and cooling loads in many types of buildings, the state-of-the-art in ground modeling is not very good even in detailed building energy simulation programs. 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 will allow.

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

- Soil thermal conductivity (k) = 1.3 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 provided in Annex A1 (Section A1.1) represents a high altitude site with an elevation of (1609 m above sea level) with an air density roughly 80% of that at 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 adjust the specified infiltration rates shall be adjusted to yield mass flows equivalent to what would those occurring at the 1609 m altitude, as shown in Table 5-2. The listed infiltration rate is independent of wind speed, indoor/outdoor temperature difference, etc.

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. They are~~ ~~shall be also~~ 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 the zone air. These are internally generated sources of heat (from equipment, lights, people, animals, etc.) that are not related to heating, ventilating, and air conditioning (HVAC).

5.2.1.8 Opaque Surface Radiative Properties. ~~The interior and exterior opaque surfaces solar (visible and ultraviolet wavelengths) absorptances and infrared emittances are included shall be applied to all opaque surfaces as specified in Table 5-3.~~

5.2.1.9 Exterior Combined Radiative and Convective Surface Coefficients. If the program being tested ~~automatically~~ calculates exterior surface radiation and convection ~~automatically, then skip the instructions in this section can be disregarded and proceed to Section 5.2.1.10.~~ If the program being tested does not calculate this effect, then ~~use the information given provided in Table 5-4 shall be used.~~

Informative Note: The exterior combined radiative and convective surface coefficient for the glass and very smooth opaque surfaces (used only in some of the in-depth cases of Section 5.2.3) is specified as equivalent (~~applying infrared emittance of 0.9~~) for convenience of input, even though the infrared emittance for common window glass is usually 0.84.

Informative Note: The calculation technique used to develop Table 5-4 is provided as background information in informative Annex B4. A calculation technique that may be used for comparing combined surface coefficients as a function of infrared emittance is provided as background information in informative Annex B5.

5.2.1.10 Interior Combined Radiative and Convective Surface Coefficients. If the program being tested automatically calculates interior surface radiation and convection, then ~~skip the instructions in this section can be disregarded and proceed to Section 5.2.1.11.~~ If the program being tested does not calculate these effects, then ~~use the constant combined radiative and convective surface~~

~~coefficients given provided in Table 5-5 shall be used.~~

~~The radiative portion of these combined coefficients may be taken as 5.13 W/(m²·K) for cases with an interior infrared emittance of 0.9. The interior combined radiative and convective surface coefficient for the glass is specified as equivalent for convenience of input, even though the infrared emittance for common window glass is usually 0.84.~~

If the program being tested does not allow ~~assignment of values based on the direction of heat flow or other scheduling of these coefficients, then use 8.29 W/(m²·K) shall be used for all horizontal surfaces. If different values can be justified, then use different values.~~ For cases with an interior infrared emittance of 0.9, a radiative portion of 5.13 W/(m²·K) shall be permitted for these combined coefficients.

~~Background information regarding values listed in Table 5-5 is available in Chapter 25 of the 2005 ASHRAE Handbook—Fundamentals.³ Informative Annex B5 includes background information about combined radiative and convective film coefficients. Use of different (non-specified) values shall not be prohibited 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 non-specified values shall be documented in the Standard Output Report described specified in normative Annex A2.~~

Informative Note: The interior combined radiative and convective surface coefficient for the glass is specified as equivalent to that for other vertical surfaces (assuming infrared emittance of 0.9) for convenience of input, even though the infrared emittance for common window glass is usually 0.84. ~~Background information regarding values provided in Table 5-5 is available in Chapter 25 of the 2005 ASHRAE Handbook—Fundamentals.³ Informative Annex B5 includes background information about combined radiative and convective film coefficients.~~

5.2.1.11 Transparent Window. Many programs use different algorithms to calculate window transmittance and therefore require different inputs. For example, SERIRES⁴ calculates transmittance, absorptance, and reflectance for each hourly incidence angle given the index of refraction, extinction coefficient, glazing thickness, and number of panes in the window assembly. BLAST⁵ calculates

~~extinction coefficient, absorptance, reflectance, and angle-dependent transmittance given the direct normal transmittance of a single pane in air, glass thickness, index of refraction, and number of panes. A great deal of information about the window properties has therefore been provided so that equivalent input for the window will be possible for many programs. Use only the information that is relevant to the program being tested.~~

~~Case 600 has 12 m² of south-facing window area, with windows located as shown in Figure 5-1 (Section 5.2.1.4).~~

5.2.1.11.1 Geometry. ~~The windows shall have no sash area; the rough openings shown in Figure 5-1 shall contain only the double-pane glass specified in Tables 5-6 and 5-7.~~

5.2.1.11.2 Window Properties. ~~The basic window properties of the window are provided in Table 5-6 shall be used.~~

5.2.1.11.3 Incidence Angle Dependent Optical Properties. ~~For programs that apply incidence angle-dependent optical properties, are the values given in Table 5-7 shall be used. For programs that need transmittance or reflectance at other angles of incidence, the user may shall be permitted to interpolate between the values in Table 5-7 using the cosine of the incident angle as the basis for interpolation. Where other unspecified data equivalent inputs are needed, then values that are consistent with those quoted are to be calculated specified shall be applied according to the instructions of Section 5.1.5 (Equivalent Modeling Methods).~~

~~For further informational discussion related to calculating angle-dependent glazing optical properties, refer to informative Annex B6.~~

~~The windows have no sash area, so the rough openings shown in Figure 5-1 contain only the double-pane glass described in Tables 5-6 and 5-7.~~

Informative Note: ~~Many programs use different algorithms to calculate window transmittance and therefore require different inputs. For example, SERIRES⁴ calculates transmittance, absorptance, and reflectance for each hourly incidence angle given the index of refraction, extinction coefficient, glazing thickness, and number of panes in the window assembly. BLAST⁵ calculates extinction coefficient, absorptance, reflectance, and angle-dependent~~

transmittance given the direct normal transmittance of a single pane in air, glass thickness, index of refraction, and number of panes. Extensive information about the window properties has therefore been provided so that equivalent input for the window will be possible for many programs. Use only the information that is relevant to the program being tested.

Informative Note: For further informative discussion related to calculating angle-dependent glazing optical properties, refer to informative Annex B6.

5.2.1.12 Interior Solar Distribution. If the program being tested does not calculate this effect internally but requires distribution fractions from the user, then the use of Table 5-8 shall be permitted. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).

Informative Note: then assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Table 5-8 presents an approximate calculation of solar distribution fractions; by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-8, fractional values for the walls with windows (i.e., the south wall) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-8. Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.

5.2.1.13 Mechanical System. The intent of the mechanical system is to produce only pure heating load and sensible cooling load outputs. That is, all equipment is shall be 100% efficient with no duct losses and no capacity limitations.

The mechanical system shall be modeled with the following features as noted below and in Sections 5.2.1.13.1 and 5.2.1.13.2:

- a. 100% convective air system,
- b. the thermostat senses only the air temperature,

- c. nonproportional-type thermostat (~~see as specified in Section 5.2.1.13.1~~),
- d. no latent heat extraction.

Informative Note: The intent of the mechanical system is to produce only pure heating load and sensible cooling load outputs.

5.2.1.13.1 Thermostat Control Strategy. ~~The thermostat is nonproportional in the sense that when the conditioned-zone air temperature exceeds the thermostat cooling setpoint, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment. Likewise, when the conditioned-zone air temperature drops below the thermostat heating setpoint, the heat addition rate equals the maximum capacity of the heating equipment. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by the program being tested).~~

5.2.1.13.1.1 ~~The following thermostat control strategy for Case 600 is~~ shall be used:

- Heat = ON if temperature <20°C; otherwise, Heat = OFF.
- Cool = ON if temperature >27°C; otherwise, Cool = OFF.

Informative Note: ~~“Temperature” refers to conditioned-zone air temperature.~~

5.2.1.13.1.2 The thermostat is nonproportional.

Informative Note: A non-proportional thermostat operates such that when the conditioned-zone air temperature exceeds the thermostat cooling setpoint, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment. Likewise, when the conditioned-zone air temperature drops below the thermostat heating setpoint, the heat addition rate equals the maximum capacity of the heating equipment. A proportional thermostat throttles the heat addition rate (or extraction rate) in proportion to the difference between the zone set point temperature and the actual zone temperature. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by the program being tested).

5.2.1.13.2 Equipment Characteristics. The following inputs shall be used:

- Heating capacity = 1000 kW (effectively infinite).
- Effective efficiency = 100%.
- Cooling capacity = 1000 kW (effectively infinite).
- Effective efficiency = 100%.
- Sensible cooling only; no latent heat load calculation.
- Waste heat from fan = 0.

Equipment efficiency ~~is~~ shall be always 100%, independent of part loading, indoor dry-bulb temperature and humidity ratio, outdoor dry-bulb temperature and humidity ratio, and/or other conditions.

5.2.2 Basic Tests. The basic tests shall be modeled as specified in this section and its subsections.

Informative Note: It is recommended to double check the Case 600 base building inputs and to diagnose Case 600 results disagreements before going on to the other cases.

5.2.2.1 Low Mass Tests. The low mass basic tests shall be modeled as detailed in this section and its subsections. The low mass basic tests include cases 600 through 650. Once an accurate input description for Case 600 has been developed, the remaining low mass basic cases, except Case 630, shall be input by slightly modifying Case 600, as indicated ~~case by case below. Note that Case 630 shall be input by modifying provides the basis for Case 620.~~

5.2.2.1.1 Case 610: South Shading. Case 610 ~~is~~ shall be modeled exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.1.1.1 South Overhang Geometry. The overhang detailed in Figure 5-2 ~~is~~ shall be added. The horizontal overhang for south-facing windows ~~is assumed to~~ shall ~~travel~~ extend across the entire length of the south wall.

5.2.2.1.1.2 Output Requirements. Case 610 requires the following output:

- a. ~~All~~ non-free-float case output in accordance with Section 6.2.1
- b. ~~A~~ additional output in accordance with Section 6.2.3
- c. general reporting requirements of Section 6.1

5.2.2.1.2 Case 620: East/West Window

Orientation. Case 620 ~~is shall be modeled~~ exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.1.2.1 Window Orientation. The window orientation ~~is shall be~~ modified as detailed in Figure 5-3 such that there ~~shall be~~ is 6 m² of window area facing east, 6 m² of window area facing west, and no other windows. Other than the change in orientation, the windows ~~shall be~~ are exactly as in Case 600.

5.2.2.1.2.2 Interior Solar Distribution. If the program being tested does not calculate interior solar distribution internally but requires distribution fractions from the user, then ~~the use of Table 5-9 shall be permitted. assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).~~ the use of Table 5-9 shall be permitted. ~~assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-9, fractional values for the walls with windows (i.e., the east and west walls) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-9. Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.~~

Informative Note: Table 5-9 presents an approximate calculation of solar distribution fractions adjusted for the geometry of Case 620 ~~by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-9, fractional values for the walls with windows (i.e., the east and west walls) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-9. Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.~~

5.2.2.1.2.3 Output Requirements. Case 620 requires the following output:

- a. All non-free-float case output in accordance with Section 6.4.2.1
- b. Additional output in accordance with Section 6.4.2.4
- c. general reporting requirements of Section 6.1

5.2.2.1.3 Case 630: East/West Shading. Case 630 ~~shall be~~ is modeled exactly the same as Case 620 except for changes noted in the subsections below.

5.2.2.1.3.1 East/West Overhang and Fin

Geometry. Shading devices ~~are shall be~~ added to the east and west windows as detailed in Figures 5-4 and 5-5.

5.2.2.1.3.2 Output Requirements. Case 630 requires the following output:

- a. All non-free float case output in accordance with Section 6.4.2.1
- b. Additional output in accordance with Section 6.4.2.5
- c. general reporting requirements of Section 6.1.

5.2.2.1.4 Case 640: Thermostat Setback. Case 640 ~~is shall be modeled~~ exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.1.4.1 Thermostat Control Strategy.

5.2.2.1.4.1.1 The thermostat control is the following setback configuration shall be scheduled as follows:

- From 2300 hours to 0700 hours, heat = ON if temperature < 10°C.
- From 0700 hours to 2300 hours, heat = ON if temperature < 20°C.
- All hours, cool = ON if temperature > 27°C.
- Otherwise, mechanical equipment is OFF.

Informative Note: “Temperature” refers to the conditioned-zone air temperature.

5.2.2.1.4.1.2 A nonproportional thermostat as described specified in Section 5.2.1.13.1.2 is assumed shall be used.

5.2.2.1.4.2 Output Requirements. Case 640 requires the following output:

- a. All non-free float case output in accordance with Section 6.4.2.1
- b. general reporting requirements of Section 6.1.

5.2.2.1.5 Case 650: Night Ventilation. Case 650 ~~is shall be modeled~~ exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.1.5.1 Thermostat and Ventilation Fan Control Strategy.

5.2.2.1.5.1.1 Use of the following configuration schedule shall be applied:

- From 1800 hours to 0700 hours, vent fan = ON.
- From 0700 hours to 1800 hours, vent fan = OFF.
- Heating = always OFF.
- ~~From 1800 hours to 0700 hours, cool = OFF.~~
- From 0700 hours to 1800 hours, cool = ON if temperature >27°C; otherwise, cool = OFF.

~~From 1800 hours to 0700 hours, cool = OFF.~~

Informative Note: "Temperature" refers to the conditioned-zone air temperature.

5.2.2.1.5.1.2 A nonproportional thermostat as ~~described specified~~ in Section 5.2.1.13.1.2 ~~is assumed~~ shall be used.

5.2.2.1.5.2 Ventilation Fan Characteristics

- a. Vent fan capacity = 1703.16 standard m³/h (in addition to specified infiltration rate).
- b. Waste heat from fan = 0.

If the program being tested does not automatically correct for the reduced density of air at altitude, then ~~adjust~~ inputs for the fan capacity shall be adjusted as shown in Table 5-10.

Informative Note: The calculation technique used to develop Table 5-10 is provided as background information in Informative Annex B3.

5.2.2.1.5.3 Output Requirements. Case 650 requires the following output:

- a. All non-freefloat case output in accordance with Section 6.2.1.
- b. general reporting requirements of Section 6.1.

5.2.2.2 High Mass Basic Tests. The high mass basic tests shall be modeled as detailed in this section and its subsections. These tests include cases 900 through 960. ~~Begin with~~ The first case shall be Case 900 (detailed below), which is the start of the high mass basic series. Once an accurate input description for Case 900 has been developed, the remaining high mass cases, except for Case 960, shall be input by modifying each corresponding 600-series case as indicated case by case below. ~~However,~~ Case 960 (sunspace) ~~shall be based on draws from both Case 600,~~ and shall integrate aspects of Case 900 as specified in Section 5.2.2.2.7.

Informative Note: The high mass cases are the same as the corresponding low mass 600-series cases

except that material properties are taken from Table 5-11 rather than Table 5-1. The wall and floor properties are more massive, and the roof properties are unchanged.

5.2.2.2.1 Case 900: High Mass Base Building. Case 900 ~~is~~ shall be modeled exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.2.1.1 Material Properties. ~~The exterior walls and floor are more massive. For the exterior walls and floor, the~~ The materials specifications of Table 5-11 shall be used in replace of the materials specifications of Table 5-1 (see Section 5.2.1.4) for this case. Note ~~†~~ The roof materials do ~~shall not~~ change for any of the 900-series cases.

5.2.2.2.1.2 Output Requirements. Case 900 requires the following output:

- a. All non-free-float case output in accordance with Section 6.2.1
- b. Additional output specified for Case 900 in Section 6.2.8
- c. general reporting requirements of Section 6.1.

5.2.2.2.2 Case 910: High Mass South Shading. Case 910 ~~shall be~~ is modeled exactly the same as Case 610 except for changes noted in the subsections below.

5.2.2.2.2.1 Material Properties. See the requirements of Section 5.2.2.2.1.1.

5.2.2.2.2.2 Output Requirements. Case 910 requires the following output:

- a. All non-freefloat case output in accordance with Section 6.2.1.
- b. general reporting requirements of Section 6.1.

5.2.2.2.3 Case 920: High Mass East/West Window Orientation. Case 920 ~~is~~ shall be modeled exactly the same as Case 620 except for changes noted in the subsections below.

5.2.2.2.3.1 Material Properties. See the requirements of Section 5.2.2.2.1.1.

5.2.2.2.3.2 Output Requirements. Case 920 requires the following output:

- a. All non-freefloat case output in accordance with Section 6.2.1.
- b. general reporting requirements of Section 6.1.

5.2.2.2.4 Case 930: High Mass East/West Shading.

Case 930 shall be modeled exactly the same as Case 630 except for changes noted in the subsections below.

5.2.2.2.4.1 Material Properties. See the requirements of Section 5.2.2.2.1.1.

5.2.2.2.4.2 Output Requirements. Case 930 requires the following output:

- a. All non-free float case output in accordance with Section 6.2.1.
- b. general reporting requirements of Section 6.1.

5.2.2.2.5 Case 940: High Mass Thermostat Setback.

Case 940 shall be modeled exactly the same as Case 640 except that the exterior walls and floor are more massive. The materials specifications of Table 5-11 shall be used in place of the materials specifications of Table 5-1 for this case.

5.2.2.2.6 Case 950: High Mass Night Ventilation.

Case 950 shall be modeled exactly the same as Case 650 except that the exterior walls and floor are more massive. The materials specifications of Table 5-11 shall be used in place of the materials specifications of Table 5-1 for this case.

5.2.2.2.7 Case 960: Sunspace. Case 960 shall

The sunspace consists of two zones (back zone and sun zone) separated by a common wall (as specified in Figure 5-6). The back zone shall be of lightweight construction, and the sun zone shall be of heavyweight construction.

5.2.2.2.7.1 Back Zone.

- a. The geometric and thermal properties of the back zone shall be exactly the same as for Case 600 except that the south wall and windows are replaced with the common wall.
- b. Infiltration in the back zone = 0.5 ach. (If the program being tested does not use barometric pressure from weather data or otherwise automatically correct for the change in air density due to altitude, then see follow the requirements of Section 5.2.1.6.1.)
- c. Internal heat generation in the back zone is in accordance with shall be as specified in Section 5.2.1.7.

5.2.2.2.7.2 Sun Zone/Back Zone Common Wall.

Material properties of the sun-zone/back-zone

common wall are specified in Table 5-12 shall be used.

5.2.2.2.7.3 Sun Zone. The sun zone shall be 2 m

deep by 8 m wide by 2.7 m high. The back (north) wall of the sun zone shall be the common wall. The south wall of the sun zone shall contain two 6 m² windows that shall be the same as the windows in Case 900 except that they are raised 0.3 m higher on the south wall than in Case 900 (see as specified in Figure 5-6). The thermal and physical properties of the sun zone shall be the same as Case 900 with the following exceptions:

- a. Zone depth shall be 2 meters.
- b. The north wall shall be replaced by the common wall.
- c. The south wall shall have two 3 × 2 m windows raised 0.3 m higher on the south wall than in Case 900. These windows shall be double-pane and have the same properties as the windows in Case 900.
- d. The east and west walls of the sun zone (end walls) shall be 5.4 m² each.
- e. The air volume of the sun zone shall be 43.2 m³.
- f. Infiltration in the sun zone shall be 0.5 air changes per hour. If the program being tested does not use barometric pressure from weather data or otherwise automatically correct for the change in air density due to altitude, then see the infiltration rate shall be adjusted according to Section 5.2.1.6.1.
- g. Internal heat gains in the sun zone = 0 W.
- h. The exact geometric details shall be as shown in Figure 5-6.

TABLE 5-11 Material Specification Heavyweight Case

Element	k, W/(m·K)	Thickness, m	U, W/(m ² ·K)	R, m ² ·K/W	Density, kg/m ³	C _p , J/(kg·K)
Heavyweight Case: Exterior Wall (inside to outside)						
Int Surf Coef	8.290	0.121				
Concrete Block	0.510	0.100	5.100	0.196	1400	1000
Foam Insulation	0.040	0.0615	0.651	1.537	10	1400
Wood Siding	0.140	0.009	15.556	0.064	530	900
Ext Surf Coef	29.300	0.034				
Total air—air	0.512	1.952				
Total air—surf	0.556	1.797				
Heavyweight Case: Floor (inside to outside)						
Int Surf Coef	8.290	0.121				
Concrete Slab	1.130	0.080	14.125	0.071	1400	1000
Insulation	0.040	1.007	0.040	25.175	(see Note b)	(see Note b)
Total air—air	0.039	25.366				
Total air—surf	0.040	25.246				
Heavyweight Case: Roof (inside to outside)						
Int Surf Coef	8.290	0.121				
Plasterboard	0.160	0.010	16.000	0.063	950	840

Fiberglass quilt 0.040 0.1118 0.358 2.794 12 840
Roofdeck 0.140 0.019 7.368 0.136 530 900
Ext Surf Coef 29.300 0.034

Total air—air 0.318 3.147

Total air surf—surf 0.334 2.992

Summary: Heavyweight case

Component Area, m² UA, W/K

Wall 63.600 32.580

Floor 48.000 1.892

Roof 48.000 15.253

S. Window 12.000 36.000

Infiltration 18.440d

Total UA (with S. Glass) 104.165

Total UA (without S. Glass) 68.165

ach Volume, m³ Altitude, m

0.500 129.6 1609.0

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 shall have ~~has~~ the minimum density and specific heat the program being tested will allow, but not < 0.

c *Informative Note:* The heavyweight case roof is the same as the lightweight case roof.

d UA corresponding to infiltration based on: ach × volume × (specific heat of air) × (density of air at specified altitude).

5.2.2.2.7.4 Interior Solar Distribution in Sun Zone.

If the program being tested does not calculate this effect internally but requires distribution fractions from the user, ~~then the use of~~ Table 5-13 ~~may be used~~ shall be permitted. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).

Informative Note: Table 5-13 presents an approximate calculation of solar distribution fractions adjusted for the geometry of the Case 960 sun zone, by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-13, fractional values for the walls with windows (i.e., the sun zone south wall) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-13. Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.

5.2.2.2.7.5 Heating and Cooling Control Strategies

a. The sun zone shall not have ~~a~~ has no space conditioning system and the sun zone air temperature shall be ~~(it is allowed to free-float)~~

b. The back zone shall be ~~is~~ controlled the same as for Case 600.

5.2.2.2.7.6 Interzone Mass Transfer. There ~~is~~ shall be no mechanical or natural interzone air exchange.

5.2.2.2.7.7 Output Requirements. Case 960 requires the following output:

a. Back zone only, all non-free-float case outputs in accordance with Section 6.4.2.1

b. Sun zone only, all free-float case outputs in accordance with Section 6.4.2.6

c. general reporting requirements of Section 6.1.

5.2.2.3 Free-Float Cases: Cases 600FF, 650FF, 900FF, and 950FF. If the program being tested has the ability to calculate and output hourly zone air temperatures, the four free-floating cases (600FF, 650FF, 900FF, and 950FF) shall be modeled as detailed in this section and its subsections.

Informative Note: The “FF” cases are based on their corresponding non-FF cases. For all cases where free-float zone air temperature output is required, the free-float zone air temperature is for the zone air only, assuming well-mixed air with no radiant effects (i.e., equivalent to what would be obtained from a hypothetical aspirated temperature sensor perfectly shielded from solar and infrared radiation).

5.2.2.3.1 Case 600FF. Case 600FF ~~is~~ shall be modeled exactly the same as Case 600 except for changes noted in the subsections below.

5.2.2.3.1.1 Mechanical System. There is no mechanical heating or cooling of the building.

5.2.2.3.1.2 Output Requirements. Case 600FF requires the following output:

a. All free-float case output in accordance with Section 6.4.2.6

b. Daily hourly output specified for Case 600FF in Section 6.2.8

c. general reporting requirements of Section 6.1.

5.2.2.3.2 Case 650FF. Case 650FF shall be ~~is~~ modeled exactly the same as Case 650 except for changes noted in the subsections below.

5.2.2.3.2.1 Mechanical System. There is no mechanical heating or cooling of the building. The mechanical venting schedule shall remain as follows:

- From 1800 hours to 0700 hours, vent fan = ON.
- From 0700 hours to 1800 hours, vent fan = OFF.

Ventilation fan characteristics shall remain as follows:

- a. Vent fan capacity = 1703.16 standard m³/h (in addition to specified infiltration rate).
- b. Waste heat from fan = 0.

If the program being tested does not automatically correct for the reduced density of air at altitude, then ~~adjust~~ the inputs for the fan capacity shall be adjusted as described-specified in Table 5-10 (Section 5.2.2.1.5).

5.2.2.3.2.2 Output Requirements, Case 650FF requires the following output:

- a. All free-float case output in accordance with Section 6.+2.6
- b. Daily hourly output specified for Case 650FF in accordance with Section 6.2.8
- c. general reporting requirements of Section 6.1.

5.2.2.3.3 Case 900FF. Case 900FF ~~is~~shall be modeled exactly the same as Case 900 except for changes noted in the subsections below.

5.2.2.3.3.1 Mechanical System. There is no mechanical heating or cooling of the building.

5.2.2.3.3.2 Output Requirements, Case 900FF requires the following output:

- a. All free-float case output in accordance with Section 6.+2.6
- b. Case 900FF only output in accordance with Section 6.+2.7
- c. Daily hourly output specified for Case 900FF in Section 6.2.8
- d. general reporting requirements of Section 6.1.

5.2.2.3.4 Case 950FF. Case 950FF ~~is~~shall be modeled exactly the same as Case 950 except for changes noted in the subsections below.

5.2.2.3.4.1 Mechanical System. See Section 5.2.2.3.2.1 for requirements.

5.2.2.3.4.2 Output Requirements, Case 950FF requires the following output:

- a. All free-float case output in accordance with Section 6.+2.6

- b. Daily hourly output specified for Case 950FF in Section 6.2.8
- c. general reporting requirements of Section 6.1.

5.2.3 In-Depth Tests. The in-depth tests shall be modeled as detailed in this section and the following subsections. The in-depth tests include cases 195 through 320, 395 through 440, 800 and 810. ~~Be careful to use the~~ The proper base case for developing the various in-depth cases as shown in Table 5-14 and Figure 5-7 shall be used.

The in-depth series tests require only non-free-float case output and general reporting requirements in accordance with Sections 6.+2.1 and 6.1, respectively.

5.2.3.1 Case 220: In-Depth Series Base Case. Case 220 ~~is~~shall be modeled exactly the same as Case 600 except for the changes ~~described-specified~~ in the following subsections.

5.2.3.1.1 Infiltration. Infiltration rate = 0 ach, continuously (24 hours per day for the full year).

5.2.3.1.2 Internal Gains. Internal gains = 0 W, continuously (24 hours per day for the full year).

5.2.3.1.3 Opaque Surface Radiative Properties. Interior and exterior opaque surface solar (visible and ultraviolet wavelengths) absorptances and infrared emittances ~~are included~~shall be applied to all opaque surfaces, as specified in Table 5-15.

Where variations to opaque surface radiative properties are specified for other test cases of Section 5.2.3, these variations shall apply to all interior only, exterior only, or interior and exterior opaque surfaces, as specified for a given test case. Where a test case includes a high conductance wall/opaque window, variation of the opaque surface radiative properties shall also be applied there, as specified for a given test case.

Informative Note: Listed infrared emittances are unchanged from Case 600.

5.2.3.1.4 High Conductance Wall/Opaque Window. An element, ~~which may be thought of as a~~ that is either a highly conductive wall or an opaque window shall; replaces the 12 m² of transparent window on the south wall.

The properties of the high-conductance wall shall be as follows:

- a. Shortwave transmittance = 0.
- b. Infrared emittances and solar absorptances ~~are as listed~~ provided in Table 5-15 shall be used.
- c. The exterior surface coefficient is in accordance with Section 5.2.1.9 (Case 600); if combined coefficients are applied, ~~use then~~ 21.0 W/(m²·K) shall be used. The surface texture for the high-conductance wall ~~is~~ shall be very smooth, the same as glass.
- d. The interior surface coefficient ~~is~~ shall be in accordance with Section 5.2.1.10 (Case 600).
- e. Conductance, density, specific heat, and surface texture (very smooth) ~~are~~ shall be the same as for the transparent window listed in Table 5-16.

TABLE 5-16 High Conductance Wall Properties Property Value

Number of opaque panes	2
Opaque pane thickness	3.175 mm
Thermal conductivity of opaque pane	1.06 W/(m·K)
Conductance of each opaque pane	333 W/(m ² ·K) [R-0.003 m ² ·K/W]
Density of opaque pane	2500 kg/m ³
Specific heat of opaque pane	750 J/(kg·K)
Combined radiative and convective heat transfer coefficient of air gap between opaque panes	6.297 W/(m ² ·K) [R-0.1588 m ² ·K/W]
Air gap thickness	13 mm

5.2.3.1.5 Thermostat Control. ~~Use~~

5.2.3.1.5.1 The following “20,20” thermostat control configuration shall be used:

- Heat = ON if temperature < 20°C
- Cool = ON if temperature > 20°C

Informative Note: “temperature” refers to the conditioned-zone air temperature.

5.2.3.1.5.2 ~~The~~ thermostat shall be ~~is a~~ nonproportional thermostat ~~as described~~ specified in Section 5.2.1.13.1.2.

5.2.3.1.6 Output Requirements. Case 220 requires the following output:

- a. Only non-freefloat case output in accordance with Section 6.4.2.1.
- b. general reporting requirements of Section 6.1.

5.2.3.2 Case 210: Interior Infrared Radiation. Case 210 ~~shall be~~ modeled exactly the same as Case 220 except for changes ~~described~~ specified in the following subsections.

5.2.3.2.1 Opaque Surface Radiative Properties.

Interior infrared emittance = 0.1.

5.2.3.2.2 Interior Combined Radiative and Convective Surface Coefficients. If the program being tested calculates interior surface radiation and convection, then ~~disregard~~ skip the instructions in this section. If the program being tested does not calculate these effects, then ~~use~~ the constant combined radiative and convective surface coefficients given in Table 5-17 shall be used.

~~The radiative portion of these combined coefficients may be taken as 0.57 W/(m²·K) for cases with an infrared emittance of 0.1.~~

If the program being tested does not allow scheduling of these coefficients, ~~use then~~ 3.73 W/(m²·K) shall be used for horizontal surfaces. Use of different (non-specified) values shall not be prohibited 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 non-specified values shall be documented in the Standard Output Report specified in normative Annex A2. If different values can be justified, then use different values.

For cases with an infrared emittance of 0.1, a radiative portion of 0.57 W/(m²·K) shall be permitted for these combined coefficients.

Informative Note: Informative Annex B5 includes background information about combined radiative and convective film coefficients.

5.2.3.3 Case 215: Exterior Infrared Radiation.

Case 215 ~~shall be~~ modeled exactly the same as Case 220 except for changes ~~described~~ specified in the following subsections.

5.2.3.3.1 Opaque Surface Radiative Properties.

Exterior infrared emittance = 0.1.

5.2.3.3.2 Exterior Combined Radiative and Convective Surface Coefficients. If the program being tested calculates exterior surface radiation and convection automatically, then ~~disregard~~ skip the instructions in this section. If the program being tested does not calculate this effect, then ~~use~~ the ~~information~~ coefficients given in Table 5-18 shall be used.

Informative Note: The calculation technique used to develop Table 5-18 is provided as background information in Informative Annex B4. A calculation technique that may be used for comparing combined surface coefficients as a function of infrared emittance is provided as background information in Informative Annex B5.

5.2.3.4 Case 200 Surface Convection/Infrared Radiation. Case 200 shall be modeled exactly the same as Case 210 except for changes described specified in the following subsections.

5.2.3.4.1 Opaque Surface Radiative Properties. Exterior infrared emittance = 0.1.

5.2.3.4.2 Exterior Combined Radiative and Convective Surface Coefficients. See Section 5.2.3.3.2 for requirements.

5.2.3.5 Case 195: Solid Conduction Test. Case 195 shall be modeled exactly the same as Case 200 except the 12 m² of high conductance windows are shall be replaced with the lightweight exterior walls with thermal and material properties as described specified in Table 5-1 (see Section 5.2.1.4). These walls shall have a rough exterior surface and shall have surface radiative properties and associated surface coefficients as specified for the lightweight exterior walls of Case 200.

5.2.3.6 Case 230: Infiltration. Case 230 shall be modeled exactly the same as Case 220 except the infiltration rate shall be = 1.0 ach, continuously (24 hours per day for the full year). The infiltration rate shall be independent of wind speed, indoor/outdoor temperature difference, or other variables.

The weather data file provided on the accompanying CD and as described in Annex A1, Section A1.1, is represents a high altitude site with an elevation of (1609 m above sea level,) with an air density roughly 80% of that at 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 adjust the specified infiltration rates shall be adjusted to yield mass flows equivalent to those what would occurring at the specified altitude, as shown in Table 5-19.

Informative Note: Air density at 1609 m altitude is roughly 80% of that at sea level. The calculation technique used to develop Table 5-19 is provided as background information in Informative Annex B3.

5.2.3.7 Case 240: Internal Gains. Case 240 shall be modeled exactly the same as Case 220 except for the following changes to internal gains:

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

Informative Note: Internally generated sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, animals, etc.) that are not related to heating, ventilating, and air conditioning (HVAC).

5.2.3.8 Case 250: Exterior Shortwave Absorbance. Case 250 shall be modeled exactly the same as Case 220 except exterior shortwave absorbance = 0.9.

5.2.3.9 Case 270: South Solar Gains. Case 270 shall be modeled exactly the same as Case 220 except for the changes described specified in the following subsections.

5.2.3.9.1 Opaque Surface Radiative Properties. Interior shortwave absorbance = 0.9.

5.2.3.9.2 Transparent Window. The 12 m² of high conductance walls on the south walls are now shall be windows as in Case 600. Window geometry shall be as shown in see Figure 5-1 (Section 5.2.1.3) and window thermal and optical properties shall be as shown in Section 5.2.1.11 for window geometry and thermal and optical properties. In Exterior and interior surface radiation and convection for windows are as described specified in Sections 5.2.1.9 and 5.2.1.10, respectively.

5.2.3.9.3 Interior Solar Distribution. If the program being tested does not calculate interior solar distribution internally but requires distribution fractions from the user, then the use of Table 5-20 shall be permitted. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).

Informative Note: then assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Table 5-20 presents an approximate calculation of solar distribution fractions corresponding to the interior solar absorptance for Case 270 by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-20, fractional values for the walls with windows (i.e., the south wall) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-20. Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.

5.2.3.10 Case 280: Cavity Albedo. Case 280 shall be modeled exactly the same as Case 270 except for changes described-specified in the following subsections.

5.2.3.10.1 Opaque Surface Radiative Properties. Interior shortwave absorptance = 0.1.

5.2.3.10.2 Interior Solar Distribution. If the program being tested does not calculate interior solar distribution internally but requires distribution fractions from the user, then the use of Table 5-21 shall be permitted. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).

Informative Note: then assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Table 5-21 presents an approximate calculation of solar distribution fractions corresponding to the interior solar absorptance of Case 280 by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Only use these approximations if the program being tested does not provide a more detailed approach. In Table 5-21, fractional values for the walls with windows (i.e., the south wall) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it

initially passes into the building is not included in the values in Table 5-21.

Informative Annex B7 gives background information regarding the calculation technique used for developing these solar fractions.

5.2.3.11 Case 290: South Shading. Case 290 shall be modeled exactly the same as Case 270 except the overhang detailed in Figure 5-2 (Section 5.2.2.1.1.1) is added. The horizontal overhang for south-facing windows is assumed to travel shall extend across the entire length of the south wall.

5.2.3.12 Case 300: East/West Window Orientation. Case 300 shall be modeled exactly the same as Case 270 except for changes described-specified in the following subsections.

5.2.3.12.1 Window Orientation. The window orientation is shall be modified as detailed in Figure 5-3 (Section 5.2.2.1.2.1) such that there are 6 m² of window area facing east and 6 m² of window area facing west and there are no other windows. Other than the change in orientation, the windows are shall be exactly as in Case 270.

5.2.3.12.2 Interior Solar Distribution. If the program being tested does not calculate this effect internally but requires distribution fractions from the user, then the use of Table 5-22 shall be permitted. Use of different (non-specified) values shall not be prohibited 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. The use of non-specified values shall be documented in the Standard Output Report (normative Annex A2).

Informative Note: then assume 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. Table 5-22 presents an approximate calculation of solar distribution fractions adjusted for the geometry of Case 300 by assuming that 100% of the incoming radiation strikes the floor first and that all reflections are diffuse. In Table 5-22, fractional values for the walls with windows (i.e., the east and west walls) include the portion of the solar radiation absorbed by the glass (as it passes back out the window) and conducted back into the zone. Solar radiation absorbed by the glass (and conducted inward) as it initially passes into the building is not included in the values in Table 5-22. Informative Annex B7 gives background information

regarding the calculation technique used for developing these solar fractions.

5.2.3.13 Case 310: East/West Shading. Case 310 ~~shall be modeled~~ exactly the same as Case 300 except shading devices are added to the east and west windows as detailed in Figures 5-4 and 5-5 (Section 5.2.2.1.3.1).

5.2.3.14 Case 320: Thermostat. Case 320 ~~shall be modeled~~ exactly the same as Case 270 except for the changes specified in the following subsections.

5.2.3.14.1 ~~The thermostat shall have~~ the following 20,27 deadband configuration:

- Heat = ON if temperature < 20°C; otherwise, heat = OFF.
- Cool = ON if temperature > 27°C; otherwise, cool = OFF.

Informative Note: "Temperature" refers to the conditioned-zone air temperature.

5.2.3.14.2 ~~The is is a thermostat shall be nonproportional thermostat as described specified in Section 5.2.1.13.1.2.~~

5.2.3.15 Case 400: Opaque Windows with Deadband Thermostat. Case 400 ~~shall be modeled~~ exactly the same as Case 600 except for the changes ~~described specified~~ in the following subsections.

5.2.3.15.1 Infiltration. Infiltration rate = 0 ach, continuously (24 hours per day for the entire year).

5.2.3.15.2 Internal Gains. Internal gains = 0 W, continuously (24 hours per day for the entire year).

5.2.3.15.3 Opaque Surface Radiative Properties. Exterior solar absorptance = 0.1.

5.2.3.15.4 High-Conductance Wall/Opaque Window. An element that ~~is either may be thought of as~~ a highly conductive wall or an opaque window ~~shall replace~~ replaces the 12 m² of transparent window on the south wall.

The properties of the high-conductance wall ~~shall be~~ as follows:

- a. Shortwave transmittance = 0.
- b. Interior and exterior infrared emittances = 0.9.

c. Exterior solar absorptance = 0.1; interior solar absorptance is not applicable.

d. The exterior surface coefficient ~~shall be~~ in accordance with Section 5.2.1.9 (Case 600); if combined coefficients are applied, ~~use then~~ 21.0 W/(m²·K) ~~shall be used~~. The surface texture for the high-conductance wall ~~shall be~~ very smooth, the same as glass.

e. The interior surface coefficient ~~is shall be~~ in accordance with Section 5.2.1.10 (Case 600).

f. Conductance, density, specific heat, and surface texture (very smooth) ~~are shall be~~ the same as for Case 2200 as listed in Table 5-16 (Section 5.2.3.1.4).

5.2.3.15.5 Output Requirements. Case 400 requires the following output:

a. ~~Only~~ non-freefloat case output in accordance with Section 6.2.1.

b. general reporting requirements of Section 6.1.

5.2.3.16 Case 395: Solid Conduction Test. Case 395 ~~shall be modeled~~ exactly the same as Case 400 except the 12 m² of high conductance windows ~~are shall be~~ replaced with the lightweight ~~ease~~ exterior walls that shall have thermal and material properties as described specified in Table 5-1 (see Section 5.2.1.4). These walls ~~shall have~~ a rough exterior surface and ~~shall have~~ surface radiative properties and associated surface coefficients as specified for the lightweight exterior walls of Case ~~200~~400.

5.2.3.17 Case 410: Infiltration. Case 410 ~~shall be modeled~~ exactly the same as Case 400 except infiltration rate = 0.5 ach, continuously (24 hours per day for the full year).

If the program being tested does not use barometric pressure from weather data or otherwise automatically correct for the change in air density due to altitude, then the infiltration rate shall be adjusted as specified in see Section 5.2.1.6.1.

5.2.3.18 Case 420: Internal Gains. Case 420 ~~shall be modeled~~ exactly the same as Case 410 except for the following changes to internal gains:

- ~~Internal gains = 200 W, continuously (24 hours per day for the full year).~~
- Internal gains ~~They are also~~ 100% sensible, 0% latent.
- Internal gains are 60% radiative, 40% convective.

Informative Note: Internally generated sensible and latent internal gains are assumed to be distributed

evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, animals, etc.) that are not related to heating, ventilating, and air conditioning (HVAC).

5.2.3.19 Case 430: Exterior Shortwave

Absorptance. Case 430 shall be modeled exactly the same as Case 420 except exterior shortwave absorptance = 0.6.

5.2.3.20 Case 440: Cavity Albedo. Case 440 shall be modeled exactly the same as Case 600 except for changes described-specified in the following subsections.

5.2.3.20.1 Opaque Surface Radiative Properties.

Interior shortwave absorptance = 0.1.

5.2.3.20.2 Interior Solar Distribution. Interior solar distribution is in accordance with-shall be as specified in Section 5.2.3.10.2 (Case 280).

5.2.3.20.3 Output Requirements. Case 440 requires the following output:

a. Only non-freefloat case output in accordance with Section 6.2.1.

b. general reporting requirements of Section 6.1.

5.2.3.21 Case 800: High Mass without Solar Gains.

Case 800 shall be modeled exactly the same as Case 430 except as follows. ~~The exterior walls and floor are more massive. The materials specifications of Table 5-11 (Section 5.2.2.2.1.1) shall be used in place of replace the materials specifications of Table 5-1 (Section 5.2.1.4) for this case.~~ The roof materials shall ~~do~~ not change, and the high-conductance walls shall also remain as in Case 430.

5.2.3.22 Case 810: High Mass Cavity Albedo.

Case 810 shall be modeled exactly the same as Case 900 except for changes described-specified in the following subsections.

5.2.3.22.1 Opaque Surface Radiative Properties.

Interior shortwave absorptance = 0.1.

5.2.3.22.2 Interior Solar Distribution. Interior solar distribution is in accordance with Section 5.2.3.10.2 (Case 280).

5.2.3.22.3 Output Requirements. Case 810 requires the following output:

a. Only non-freefloat case output in accordance with Section 6.2.1.

b. general reporting requirements of Section 6.1.

5.3 Input Specification for Space-Cooling Equipment Performance Tests

5.3.1 Case CE100: Base Case Building and Mechanical System for Analytical Verification

Tests. ~~Begin with Case CE100.~~ Case CE100 shall be the first case modeled in Section 5.3 as detailed in this section and its subsections.

Informative Note: The bulk of the work for implementing the tests of Sections 5.3.1 and 5.3.2 is assembling an accurate base building model. It is recommended that base building inputs be double-checked and disagreements in results be diagnosed before going on to the other cases.

5.3.1.1 Weather Data. ~~This case requires either the CE100.TMY data (three-month-long TMY data files) or CE100A.TM2 data (year-long TMY2 data files) provided with the on the accompanying electronic files-CD shall be used for Case CE100. These two sets of data files areas described in detail in~~ normative Annex A1, Section A1.2.1.

Informative Note: Other cases described in later sections call for different weather files as needed.

5.3.1.2 Output Requirements. Case CE100 ~~requires shall apply all of the output requirements described specified in~~ Sections 6.1 and 6.3.1.

Informative Note: All of the tests of Sections 5.3.1 and 5.3.2 have the same output requirements.

5.3.1.3 Building Geometry. The base building plan shall be a 48 m² (517 ft²) floor area, single-story, low-mass building with rectangular-prism geometry as shown in Figure 5-8. Zone air volume shall be 129.6 m³ (4577 ft³).

5.3.1.4 Building Envelope Thermal Properties. ~~The base building zone is intended as a near-adiabatic test cell with cooling load driven by user-specified internal gains. For the building envelope, the thermal and material properties listed in Tables 5-23a (SI units) and 5-23b (I-P units) shall be used. All material properties in Systeme Internationale (SI) and inch-pound units, respectively.~~

Informative Note: The base building zone is intended as a near-adiabatic test cell with cooling load driven by user-specified internal gains.

5.3.1.4.1 ~~The building insulation has been made very thick to effectively thermally decouple the zone from ambient conditions. If the software being tested does not allow this as much insulation as Table 23a or 23b specifies, use the thickest insulation the software being tested will permit and reduce floor, roof, and wall areas to achieve the thermal conductance (UA) values listed in Tables 5-23a or 5-23b. The zone air volume shall not be changed from~~ must remain at 129.6 m^3 (4577 ft³).

5.3.1.4.2 Materials of the space shall have no thermal or moisture capacitance, and there is ~~not~~ moisture diffusion through them. If the software being tested requires inputs for thermal capacitance, moisture capacitance, or moisture diffusion, ~~use~~ the minimum values the software being tested allows shall be used.

5.3.1.4.3 If the program being tested automatically calculates air density, skip the instructions in this section and proceed to Section 5.3.1.4.4. The air density at sea level is 1.201 kg/m^3 (0.075 lb/ft^3). Use of different (non-specified) values shall not be prohibited, 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 non-specified values shall be documented in the Standard Output Report specified in normative Annex A2.

5.3.1.4.4 The floor has the same exterior film coefficient as the ~~other~~ walls.

Informative Note: This is, as if the entire zone were suspended above the ground.

5.3.1.4.5 ~~Although the zone is modeled as if suspended above the ground, for software that requires input of ground thermal properties, the ground in the vicinity of the building is dry packed soil with the following characteristics shall be used:~~

- Soil thermal conductivity (k) = $1.3 \text{ W/(m}\cdot\text{K)}$ = $0.751 \text{ Btu/(h}\cdot\text{ft}\cdot\text{°F)}$
- Soil density = 1500 kg/m^3 = 93.64 lb/ft^3
- Soil specific heat = $800 \text{ J/(kg}\cdot\text{K)}$ = $0.191 \text{ Btu/(lb}\cdot\text{°F)}$
- Deep ground temperature = 10°C = 50°F .

Informative Note: This assumes that the ground in the vicinity of the building is dry packed soil.

5.3.1.5 Infiltration. An infiltration rate of 0.0 ach shall be used for the entire simulation period. Infiltration rate = 0.0 ach (air changes per hour) for the entire simulation period.

5.3.1.6 Internal Heat Gains. The following sensible and latent internal heat gains shall be used:

- Sensible internal gains = 5400 W (18430 Btu/h), continuously (24 hours per day for the full simulation period).
- Latent internal gains = 0 W (0 Btu/h), continuously (24 hours per day for the full simulation period).

Sensible internal gains are 100% convective.

Informative Note: For the test cases of Sections 5.3.1 and 5.3.2, ~~Zone-zone~~ sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to the operation of the mechanical cooling system or its air distribution fan.

5.3.1.7 Opaque Surface Radiative Properties. ~~The interior and exterior opaque surface solar (visible and ultraviolet wavelengths) absorptances and infrared emittances listed are included in Table 5-24 shall be used.~~

5.3.1.8 Exterior Combined Radiative and Convective Surface Coefficients. If the program being tested automatically calculates exterior surface radiation and convection, skip the instructions in this section and proceed to Section 5.1.3.9 may be disregarded. If the program being tested does not calculate this effect, then ~~use~~ $29.3 \text{ W/(m}^2\cdot\text{K)}$ [$5.163 \text{ Btu/(h}\cdot\text{ft}^2\cdot\text{°F)}$] shall be used for all exterior surfaces.

Informative Note: This value is based on a mean annual wind speed of 4.02 m/s for a surface with roughness equivalent to rough plaster or brick and is consistent with Informative Annex B4.

5.3.1.9 Interior Combined Radiative and Convective Surface Coefficients. If the program being tested automatically calculates interior surface radiation and convection, then skip the instructions in this section and proceed to Section 5.3.1.10 can be disregarded. If the program being tested does not calculate these effects, then ~~use~~ the constant combined radiative and convective surface coefficients given in Table 5-25 shall be used. If the

program being tested does not allow scheduling of these coefficients, then use 8.29 W/(m²·K) [1.46 Btu/(h·ft²·°F)] for all horizontal surfaces. Use of different (non-specified) values shall not be prohibited; 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 non-specified values shall be documented in the Standard Output Report specified in normative Annex A2.

For cases with an interior infrared emissivity of 0.9, the radiative portion of these combined coefficients may be taken as 5.13 W/(m²·K) [0.90 Btu/(h·ft²·°F)] shall be permitted for these combined coefficients, an interior infrared emissivity of 0.9. If the program being tested does not allow you to schedule these coefficients, then use 8.29 W/(m²·K) [1.46 Btu/(h·ft²·°F)] for all horizontal surfaces. If different values can be justified, then use different values.

Informative Note: Informative Annex B5 includes background information about combined radiative and convective film coefficients.

5.3.1.10 Mechanical System. The mechanical system specified in Figure 5-9 and in the following sections shall be used.

Informative Note: The mechanical system represents a simple vapor compression cooling system, or more precisely, a unitary split air-conditioning system consisting of an air-cooled condensing unit and indoor evaporator coil. See Section 3 for definitions of terminology used in this section. The system has the following characteristics: Figure 5-9 is a schematic diagram of this system. See Section 3 for definitions of terminology used in this section.

5.3.1.10.1 General Information. The system shall have the following characteristics:

- 100% convective air system
- Zone air is perfectly mixed
- No ~~outside-outdoor~~ air; no exhaust air
- Single-speed, draw-through air distribution fan
- Indoor and outdoor fans cycle ON and OFF together with the compressor
- Air-cooled condenser
- Single-speed reciprocating compressor, R-22 refrigerant, no cylinder unloading
- No system hot gas bypass

- The compressor, condenser, and condenser fan are located outside the conditioned zone
- All zone air moisture that condenses on the evaporator coil (latent load) leaves the system through a condensate drain
- Crankcase heater and other auxiliary energy = 0

Informative Note: ~~Note that, in~~ In one of the field-trial simulations, simultaneous use of “0” ~~outside-outdoor~~ air and “0” infiltration caused an error in the simulations. This error was avoided by specifying minimum ~~outside-outdoor~~ air = 0.000001 ft³/min. It is recommended to do a sensitivity test to check that using 0 for both these inputs does not cause a problem.

5.3.1.10.2 Thermostat Control Strategy. The following thermostat control strategy shall be used:

- Heat = OFF
- Cool = ON if zone air temperature > 22.2°C (72.0°F); otherwise cool = OFF.

5.3.1.10.2.1 ~~There is~~ shall be no zone humidity control.

Informative Note: This means that the zone humidity level will float in accordance with zone latent loads and moisture removal by the mechanical system.

5.3.1.10.2.2 The thermostat shall sense only the zone air temperature; the thermostat itself ~~does~~ shall not sense any radiant heat transfer exchange with the interior surfaces.

5.3.1.10.2.3 The controls for this system are ideal in that the equipment ~~is assumed to~~ shall maintain the setpoint exactly when it is operating and not overloaded. There are no minimum ON or OFF time-duration requirements for the unit and no hysteresis control band (e.g., there is no ON at setpoint +x°C or OFF at setpoint -y°C). If the software being tested requires input for these, ~~use the~~ minimum values the software being tested allows shall be used.

5.3.1.10.2.4 The thermostat is nonproportional, ~~in~~ the sense that w

Informative Note: A non-proportional thermostat operates such that W when the conditioned zone air temperature exceeds the thermostat cooling setpoint, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment corresponding to environmental conditions at the

time of operation. A proportional thermostat throttles the heat extraction rate (or heat addition rate) in proportion to the difference between the zone set point temperature and the actual zone temperature. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by the software being tested). A COP = $f(\text{PLR})$ curve is given in Section 5.3.1.10.4 to account for equipment cycling.

5.3.1.10.3 Full-Load Cooling System Performance

Data. Use the eEquipment full-load capacity and full-load performance data from the table in the following list that most closely matches the input requirements of the software being tested: are given in six formats in Tables 5-26a through 5-26f. Before using these tables, read all of the discussion in this section (5.3.1.10.3) and its subsections (5.3.1.10.3.1 through 5.3.1.10.3.6). Use the table that most closely matches the input requirements of the software being tested. The tables contain similar information with the following differences:

- Table 5-26a lists net capacities (SI units)
- Table 5-26b lists net capacities (I-P units)
- Table 5-26c lists gross capacities (SI units)
- Table 5-26d lists gross capacities (I-P units)
- Table 5-26e lists adjusted net capacities (SI units)
- Table 5-26f lists adjusted net capacities (I-P units).

5.3.1.10.3.1 For convenience, aAn electronic file (CE100MAP.XLS) that contains these tables is included on with the accompanying CD electronic media.

Informative Note: Before using these tables it is recommended to read all of the informative notes included with Section 5.3.1.10.3, and the requirements of subsections 5.3.1.10.3.1 and 5.3.1.10.3.2.

5.3.1.10.3.2 Informative Note, Various Ways to Represent System Capacity: The meaning of the various ways to represent system capacity is discussed below; specific terms are also defined in Section 3. These tables use outdoor drybulb temperature (ODB), entering dry-bulb temperature (EDB), and entering wet-bulb temperature (EWB) as independent variables for performance data; the location of EDB and EWB is shown in Figure 5-9. Listed capacities of Tables 5-26a and 5-26b are net values after subtracting manufacturer default fan heat based on 365 W per 1,000 cubic feet per minute

(cfm), so the default fan heat for the 900 cfm fan is 329 W. For example, in Table 5-26a the listed net total capacity at Air-Conditioning and Refrigeration Institute (ARI) rating conditions (EDB = 26.7°C, outdoor drybulb temperature [ODB] = 35.0°C, EWB = 19.4°C) is 7852 W, and the assumed fan heat is 329 W. Therefore, the gross total capacity (see Table 5-26c) of the system at ARI rating conditions—including both the net total capacity and the distribution system fan heat—is 7,852 + 329 = 8,181 W. Similarly, the gross sensible capacity—including both the net sensible capacity and air distribution system fan heat—is 6,040 + 329 = 6,369 W. The unit as described actually uses a 230 W fan. Therefore, the “real” net capacity is actually an adjusted net capacity, (net cap)_{adj}, which is determined by

$$(\text{net cap})_{\text{adj}} = (\text{net cap})_{\text{listed}} + (\text{default fan heat}) - (\text{actual fan power}),$$

so for the adjusted net total (sensible + latent) capacity at ARI conditions and 900 cfm,

$$(\text{net cap})_{\text{adj}} = 7852 \text{ W} + 329 \text{ W} - 230 \text{ W} = 7951 \text{ W}.$$

The technique for determining adjusted net sensible capacities (see Table 5-26e) is similar.

5.3.1.10.3.3 Informative Note, Validity of Listed Data: (VERY IMPORTANT): Compressor kW (kilowatts) and apparatus dew point, along with net total, gross total, and adjusted net total capacities given in Tables 5-26a through 5-26f, are valid only for “wet” coils (when dehumidification is occurring). A dry-coil condition—no dehumidification—occurs when the entering air humidity ratio is decreased to the point where the entering air dew-point temperature is less than the effective coil surface temperature (apparatus dew point). In Tables 5-26a through 5-26f, the dry-coil condition is evident from a given table for conditions where the listed sensible capacity is greater than the corresponding total capacity. For such a dry-coil condition, ~~set~~ total capacity equals ~~to~~ sensible capacity.

For a given EDB and ODB, the compressor power, total capacity, sensible capacity, and apparatus dew point for wet coils change only with varying EWB. Once the coil becomes dry—which is apparent for a given EDB and ODB from the maximum EWB where total and sensible capacities are equal—for a given EDB, compressor power and capacities remain constant with decreasing EWB.⁶

To evaluate equipment performance for a dry-coil condition, establish the performance at the maximum EWB where total and sensible capacities are equal. Make this determination by interpolating or extrapolating with EWB for a given EDB and ODB.

For example, to determine the dry-coil compressor power for ODB/EDB = 29.4°C/26.7°C, find the “maximum EWB” dry-coil condition (net sensible capacity = net total capacity) using the data shown in informative Table 5-27 (extracted from Table 5-26e):
At the dry-coil condition:

- Adjusted net total capacity = adjusted net sensible capacity = 7.66 kW
- Linear interpolation based on adjusted net total capacity gives
Maximum EWB for the dry-coil condition = 16.75°C
- Compressor power = 1.652 kW

Note that in this example linear interpolation was used to find the “maximum EWB” dry-coil condition. Use of other or additional performance data points (e.g., to develop more generalized curve fits) is also possible for the purpose of interpolation or extrapolation. Also see informative Annex B17, Section B17.1.1.2, regarding analytical solution results.

Informative Note, Apparatus Dew Point: Apparatus dew point (ADP) is defined in Section 3. Listed values of ADP may vary somewhat from those calculated using the other listed performance parameters. For more discussion of this, see informative Annex B14 (Cooling Coil Bypass Factor).

Informative Note, SEER: In Tables 5-26a through 5-26f, seasonal energy efficiency ratio (SEER), which is a generalized seasonal efficiency rating, is not generally a useful input for detailed simulation of mechanical systems. SEER (or “COPSEER” in the metric versions) is useful to system designers for comparing one system to another. SEER is further discussed in Section 3 and Informative Annex B13.

5.3.1.10.3.14 Extrapolation of Performance Data.

For Cases CE100–CE200, allow the software being tested to shall perform the necessary extrapolations of the performance data as may be required by these cases, if it has that capability.

Informative Note: Cases CE100, CE110, CE130, and CE140 require some extrapolation of data for EWB <15.0°C (<59°F). Additionally, Case CE180 may require (depending on the model) a small amount of extrapolation of data for EWB >21.7°C (>71°F). Case CE200 may require (depending on the model) some extrapolation of data for EDB >26.7°C (>80°F). In cases where the maximum-EWB dry-coil condition occurs at EWB <15.0°C, extrapolate the

total capacity and sensible capacity to the intersection point where they are both equal. For example, use the data shown in informative Table 5-28 (extracted from Table 5-26e) to find the maximum EWB drycoil condition for ODB/EDB = 29.4°C/22.2°C:

Linear extrapolation of the total and sensible capacities to the point where they are equal gives:

- Adjusted net total capacity = adjusted net sensible capacity = 6.87 kW
- Maximum dry-coil EWB = 13.8°C
- Resulting compressor power = 1.598 kW.

~~Note that in this example linear extrapolation was used to find the “maximum EWB” dry-coil condition.~~ Use of other or additional performance data points (e.g., to develop more generalized curve fits) is also possible for the purpose of interpolation or extrapolation. Also see informative Annex B17, Section B17.1.1.2, regarding analytical solution results.

~~**5.3.1.10.3.5 Apparatus Dew Point.**~~ Apparatus dew point (ADP) is defined in Section 3. Listed values of ADP may vary somewhat from those calculated using the other listed performance parameters. For more discussion of this, see informative Annex B14 (Cooling Coil Bypass Factor).

~~**5.3.1.10.3.26 Values at ARI Rating Conditions.**~~ In Tables 5-26a through 5-26f, nominal values at ARI rating conditions are useful to system designers for comparing the capabilities of one system to those of another. Some detailed simulation programs utilize inputs for ARI rating conditions in conjunction with the full performance maps of Tables 5-26a through 5-26f. For simplified simulation programs and other programs that do not allow performance maps mapping of certain parameters specified in Tables 5-26a through 5-26f, the use of appropriate input values required by the tested program at ARI conditions, may be used and the assumption ed that such values are constant, shall be permitted.

Informative Note: In Tables 5-26a through 5-26f, nominal values at ARI rating conditions are useful to system designers for comparing the capabilities of one system to those of another. Some detailed simulation programs utilize inputs for ARI rating conditions in conjunction with the full performance maps of Tables 5-26a through 5-26f.

~~**5.3.1.10.3.7 SEER.**~~ In Tables 5-26a through 5-26f, seasonal energy efficiency ratio (SEER), which is a generalized seasonal efficiency rating, is not generally a useful input for detailed simulation of

mechanical systems. SEER (or “COPSEER” in the metric versions) is useful to system designers for comparing one system to another. SEER is further discussed in Section 3 and Informative Annex B13.

5.3.1.10.3.38 Cooling Coil Bypass Factor. If the software being tested does not require an input for bypass factor (BF) or automatically calculates it based on other inputs, ~~ignore this information. skip the instructions in this section and proceed to Section 5.3.1.10.3.4.~~

BF at ARI rating conditions is *approximately* 0.049 ≤ BF ≤ 0.080.

Calculation techniques and uncertainty about this range of values are discussed in informative Annex B14. Annex B14 is provided for illustrative purposes; some models may perform the calculation with minor differences in technique or assumptions or both. If the software being tested requires this input, calculate the BF in a manner consistent with ~~its~~ the assumptions of your specific model. If the assumptions of your the model being tested are not apparent from its documentation, use a value consistent with the above range and informative Annex B14.

Calculations based on the listed performance data indicate that ~~If the software being tested allows BF to vary~~ as a function of EDB, EWB, and ODB, ~~incorporate that~~ aspect of equipment performance into your the model, if the software being tested allows it, using a consistent method for developing all points of the BF variation map.

Informative Note: Calculation techniques and uncertainty about the specified range of BF values are discussed in informative Annex B14. Annex B14 is provided for illustrative purposes; some models may perform the calculation with minor differences in technique or assumptions or both.

TABLE 5-27 Determination of Maximum Dry-Coil EWB Using Interpolation
 EWB, °C Adjusted Net Total Capacity, kW Adjusted Net Sensible Capacity, kW Compressor Power, kW
[Informative Note: Table 5-27 is informative material]

15.0 7.19 7.66 1.62
 Maximum dry EWB, 16.75* 7.66* 7.66* 1.652*
 17.2 7.78 7.45 1.66

* Italicized values are not specifically listed with Table 5-26; they are determined based on the accompanying informative discussion note where this table is cited. Other data in this table are from Table 5-26.

TABLE 5-28 Determination of Maximum Dry-Coil EWB Using Extrapolation
 EWB, °C Adjusted Net Total Capacity, kW Adjusted Net Sensible Capacity, kW Compressor Power, kW
[Informative Note: Table 5-28 is informative material]

Maximum dry EWB, 13.8* 6.87* 6.87* 1.598*
 15.0 7.19 6.31 1.62
 17.2 7.78 5.26 1.66

* Italicized values are not specifically listed with Table 5-26; they are determined based on the accompanying informative discussion note where this table is cited. Other data in this table are from Table 5-26.

5.3.1.10.3.49 Minimum Supply Air Temperature. This system is a variable temperature system, meaning that where the supply air temperature varies with the operating conditions. If the software being tested does not require input for minimum supply air temperature, skip the instructions in this section and proceed to Section 5.3.1.10.4. If the software being tested requires an input for minimum allowable supply air temperature, then the following value shall be used:

Minimum supply air temperature ≤ 7.7°C (45.9°F).

Informative Note: This value specified minimum supply air temperature is the lowest value of ADP that occurs in cases CE100–CE200 based on the quasi-analytical solutions for Case CE110 presented in HVAC BESTEST.⁷ If the software being tested does not require this input, ignore this information.

5.3.1.10.4 Part-Load Operation. For building energy simulation programs, defining the part-load performance in terms of a part-load curve as a plot of COP Degradation Factor versus Part Load Ratio, as shown in Figure 5-10, shall be permitted.

5.3.1.10.4.1 COP Degradation Factor. The system efficiency degradation that results from part-load operation is described in Figure 5-10. In this figure the COP degradation factor (CDF) is a multiplier to be applied to the full-load system COP (as defined in Section 3) at a given part-load ratio (PLR), where COP(PLR) = (full load COP(ODB,EWB,EDB)) × CDF(PLR).

Informative Note: This representation is based on information provided by an equipment manufacturer. It might be helpful to think of the efficiency degradation as being caused by additional start-up run time required to bring the evaporator coil temperature down to its equilibrium temperature for the time(s) when the compressor is required to operate during an hour with part load. Simplifying assumptions in Figure 5-10 are as follows:

- There is no minimum ON/OFF time for the compressor and related fans; they may cycle ON/OFF as often as necessary to maintain the setpoint.
- The decrease in efficiency with increased ON/OFF cycling at very low PLR remains linear.

Informative Note: Informative Annex B13, Section B13.1, includes additional details about how Figure 5-10 was derived.

5.3.1.10.4.2 Fractional Run Time. Because the controller is ideal ON/OFF cycling (see Section 5.3.1.10.2.3),
Hourly fractional run time = PLR/CDF.

Informative Note: This is consistent with an ideal ON/OFF cycling controller (see Section 5.3.1.10.2.3).

5.3.1.10.4.3 Calculation of PLR. In Figure 5-10, the PLR is calculated by Equation 5-1, where the net refrigeration effect and the adjusted net total capacity are as defined in Section 3.

$$PLR = \frac{\text{(Net refrigeration effect)}}{\text{(Adjusted net total capacity)}} \text{, (Eq. 5-1)}$$
where the net refrigeration effect and the adjusted net total capacity are as defined in Section 3.

Alternatively, the calculation of PLR shall be permitted as shown in Equation 5-2, where the gross total coil load and gross total capacity are as defined in Section 3.

$$PLR = \frac{\text{(Gross total coil load)}}{\text{(Gross total capacity)}} \text{, (Eq. 5-2)}$$
where the gross total coil load and gross total capacity are as defined in Section 3.

Informative Note: Demonstration of the similarity of these definitions of PLR is included in Annex B13, Section B13.2.

5.3.1.10.4.4 Simplifying assumptions in Figure 5-10 are as follows:

- ~~There is no minimum ON/OFF time for the compressor and related fans; they may cycle ON/OFF as often as necessary to maintain the setpoint.~~
- ~~The decrease in efficiency with increased ON/OFF cycling at very low PLR remains linear.~~

5.3.1.10.4.5 Annex B13, Section B13.1, includes additional details about how Figure 5-10 was derived.

5.3.1.10.4.6 Bypass Factor. If the software being tested utilizes the cooling coil bypass factor, model the BF as independent of (not varying with) the PLR.

5.3.1.10.5 Evaporator Coil. If the software being tested requires input of evaporator coil geometry, the geometry of the evaporator coil is included in Figures 5-11 and 5-12, and Sections 5.3.1.10.5.1 through 5.3.1.10.5.3, shall be applied.

Informative Note: Evaporator coil fins are actually contoured to enhance heat transfer, but further design details about fin geometry are proprietary and therefore unavailable.

5.3.1.10.5.1 Frontal Dimensions (also see as specified in Figure 5-11)

- Height = 68.6 cm (27 in.)
- Width = 61.0 cm (24 in.)
- Frontal area = 0.418 m² (4.50 ft²)
- Depth = 9.53 cm (3.75 in.)

5.3.1.10.5.2 Tubes

- 130 tubes total
- (5 tubes per row, 26 rows)
- Tube outside diameter = 9.53 mm (0.375 in.)
- Tube inside diameter = 8.81 mm (0.347 in.)
- Exposed tube surface area = 2.229 m² (23.99 ft²).

5.3.1.10.5.3 Fins

- 12 fins per inch
- Fin thickness = 0.13 mm (0.005 in.)
- 288 fins total
- Exposed fin surface area = 32.085 m² (345.36 ft²).

5.3.1.10.6 Fans

The indoor air and outdoor condenser fans shall be modeled as specified in Sections 5.3.1.10.6.1 and 5.3.1.10.6.2, respectively.

5.3.1.10.6.1 Indoor Air Distribution Fan

- Indoor fan power = 230 W
- Airflow rate = 0.425 m³/s = 1529 m³/h = 900 cfm
- Total combined fan and motor efficiency = 0.5

- Total fan pressure = 271 Pa = 1.09 in. w.g. (water gauge)
- Supply air temperature rise from fan heat = 0.44°C = 0.8°F
- Air distribution efficiency = 100% (adiabatic ducts)

Informative Note: For further discussion of these inputs, see Annex B15, Section B15.1.

5.3.1.10.6.1.1 The draw-through indoor air distribution fan cycles ON and OFF with the compressor.

5.3.1.10.6.1.2 For calculating additional heating of the distribution air related to waste heat from the indoor distribution fan, assume that the distribution fan motor ~~is~~ shall be mounted in the distribution airstream so that 100% of the heat from fan energy use goes to the distribution (supply) air.

5.3.1.10.6.2 Outdoor Condenser Fan

- Outdoor fan power = 108 W.
- The draw-through outdoor condenser fan cycles ON and OFF with the compressor.

5.3.2 Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests

5.3.2.1 Additional Dry Coil Test Cases

~~It is recommended to double check the Case CE100 base case inputs and to diagnose Case CE100 results disagreements before going on to the other test cases.~~

~~This section describes~~ Additional dry coil test cases shall be modeled as sequential revisions to the base case ~~required to model additional dry coil cases.~~ The dry-coil cases shall have no latent load in the zone. ~~In many instances the base case for a given case is not Case CE100; appropriate b~~Base cases for a given dry-coil case shall be:

Case	Basis for That Case
CE110	CE100
CE120	CE110
CE130	CE100
CE140	CE130

Informative Note: It is recommended to double check the Case CE100 base case inputs and to diagnose Case CE100 results disagreements before going on to the other test cases.

5.3.2.1.1 Case CE110: Reduced Outdoor Dry-Bulb Temperature. Case CE110 ~~is~~ shall be modeled

exactly the same as Case CE100 except ~~that the applicable weather data file is~~ shall be

CE110.TMY or CE110A.TM2.

These data are provided ~~on in with the CD electronic files~~ accompanying this standard ~~and areas~~ described in normative Annex A1, Section A1.2.1.

5.3.2.1.2 Case CE120: Increased Thermostat Setpoint. Case CE120 ~~is~~ shall be modeled exactly the same as Case CE110 except the thermostat control strategy ~~is~~ shall be:

- Heat = OFF
- Cool = ON if zone air temperature >26.7°C (80.0°F); otherwise cool = OFF.

All other features of the thermostat shall remain as before.

5.3.2.1.3 Case CE130: Low Part-Load Ratio. Case CE130 ~~is~~ shall be modeled exactly the same as Case CE100 except the internal heat gains ~~are~~ shall be:

- Sensible internal gains = 270 W (922 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 0 W (0 Btu/h), continuously (24 hours per day for the full simulation period).

Sensible internal gains shall remain as 100% convective.

~~Zone sensible internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to the operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.1.4 Case CE140: Reduced Outdoor Dry-Bulb Temperature at Low Part-Load Ratio. Case CE140 ~~is~~ shall be modeled exactly the same as Case CE130 except ~~that the applicable weather data file is~~ shall be

CE110.TMY or CE110A.TM2.

These data are provided ~~in~~ with the electronic files accompanying this standard ~~and areas~~ described in normative Annex A1, Section A1.2.1.

5.3.2.2 Humid Zone Test Cases. ~~In this section, the sequential revisions required to model humid zone cases are described. The humid zone cases shall have latent load in the zone as specified in the following subsections, and, therefore, have moisture removed by the evaporator coil. All condensed moisture is assumed to leave the system through a condensate drain. Humid zone test cases shall be developed as sequential revisions to base case models. The appropriate base cases for a given case are shall be as follows:~~

Case	Basis for That Case
CE150	CE110
CE160	CE150
CE165	CE160
CE170	CE150
CE180	CE170
CE185	CE180
CE190	CE180
CE195	CE190
CE200	CE150

5.3.2.2.1 Case CE150: Latent Load at High Sensible Heat Ratio. Case CE150 ~~is~~ shall be modeled exactly as Case CE110 except ~~that~~ the internal heat gains ~~are~~ shall be:

- Sensible internal gains = 5400 W (18430 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 1100 W (3754 Btu/h), continuously (24 hours per day for the full simulation period)

Sensible gains remain as 100% convective.

~~Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.2.1.1 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains, then to convert the listed latent internal gains to water vapor mass flow rate, ~~use~~ a heat of vaporization (h_{fg}) that approximates the value of h_{fg}

for condensation at the coil ~~used~~ applied by the software being tested shall be used.

5.3.2.2.1.2 If the software being tested requires input of total internal gains, then ~~use~~ the sum of listed sensible + latent internal gains shall be used.

5.3.2.2.2 Case CE160: Increased Thermostat Setpoint at High Sensible Heat Ratio. Case CE160 ~~shall be~~ modeled exactly the same as Case CE150 except ~~that~~ the thermostat control strategy shall be:

- Heat = OFF
- Cool = ON if zone air temperature > 26.7°C (80.0°F); otherwise cool = OFF₁

All other features of the thermostat shall remain as before.

5.3.2.2.3 Case CE165: Variation of Thermostat Setpoint and Outdoor Dry-Bulb Temperature at High Sensible Heat Ratio. Case CE165 ~~is~~ shall be modeled exactly the same as Case CE160 except the thermostat control strategy and weather data ~~are~~ shall be changed as ~~noted below~~ follows.

5.3.2.2.3.1 Weather Data. The weather data file shall be CE165.TMY or CE165A.TM2₁

These data are provided ~~with~~ the electronic files accompanying this standard ~~and areas~~ described in normative Annex A1, Section A1.2.1.

5.3.2.2.3.2 Thermostat Control Strategy

- Heat = OFF
- Cool = ON if zone air temperature > 23.3°C (74.0°); otherwise cool = OFF₁

All other features of the thermostat shall remain as before.

5.3.2.2.4 Case CE170: Reduced Sensible Load. Case CE170 ~~shall be~~ modeled exactly the same as Case CE150 except the internal heat gains shall be:

- Sensible internal gains = 2100 W (7166 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 1100 W (3754 Btu/h), continuously (24 hours per day for the full simulation period)₁

Sensible gains shall remain as 100% convective.

~~Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.2.4.1 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains, then to convert the listed latent internal gains to water vapor mass flow rate, use a heat of vaporization (h_{fg}) that approximates the value of h_{fg} for condensation at the coil used applied by the software being tested shall be used.

5.3.2.2.4.2 If the software being tested requires input of total internal gains, then use the sum of listed sensible + latent internal gains shall be used.

5.3.2.2.5 Case CE180: Increased Latent Load.

Case CE180 shall be modeled exactly the same as Case CE170 except the internal heat gains shall be:

- Sensible internal gains = 2100 W (7166 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 4400 W (15018 Btu/h), continuously (24 hours per day for the full simulation period).

Sensible gains shall remain as 100% convective.

~~Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.2.5.1 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains, then to convert the listed latent internal gains to water vapor mass flow rate, use a heat of vaporization (h_{fg}) that approximates the value of h_{fg} for condensation at the coil used applied by the software being tested shall be used.

5.3.2.2.5.2 If the software being tested requires input of total internal gains, then use the sum of listed sensible + latent internal gains shall be used.

5.3.2.2.6 Case CE185: Increased Outdoor Dry-Bulb Temperature at Low Sensible Heat Ratio.

Case

CE185 shall be modeled exactly the same as Case CE180 except the applicable weather data file shall be:

CE100.TMY or CE100A.TM2.

These data are provided with the electronic files accompanying this standard and areas described in normative Annex A1, Section A1.2.1.

5.3.2.2.7 Case CE190: Low Part-Load Ratio at Low Sensible Heat Ratio. Case CE190 is shall be modeled exactly the same as Case CE180 except that the internal heat gains shall be:

- Sensible internal gains = 270 W (922 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 550 W (1877 Btu/h), continuously (24 hours per day for the full simulation period).

Sensible gains remain as 100% convective.

~~Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.2.7.1 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains, then to convert the listed latent internal gains to water vapor mass flow rate, use a heat of vaporization (h_{fg}) that approximates the value of h_{fg} for condensation at the coil used applied by the software being tested shall be used.

5.3.2.2.7.2 If the software being tested requires input of total internal gains, then use the sum of listed sensible + latent internal gains shall be used.

5.3.2.2.8 Case CE195: Increased Outdoor Dry-Bulb Temperature at Low Sensible Heat Ratio

and Low Part-Load Ratio. Case CE195 ~~is~~ shall be modeled exactly the same as Case CE190 except the applicable weather data file shall be CE100.TMY or CE100A.TM2.

These data are provided ~~with~~ the electronic files accompanying this standard ~~and areas~~ described in normative Annex A1, Section A1.2.1.

5.3.2.2.9 Case CE200: Full-Load Test at ARI Conditions. ~~This case compares simulated performance of mechanical equipment to the manufacturer's listed performance at full load and at ARI-specified operating conditions. Case CE200 shall be modeled exactly the same as Case CE150 except for the following changes noted below.~~

Informative Note: ~~This case compares simulated performance of mechanical equipment to the manufacturer's listed performance at full load and at ARI-specified operating conditions.~~

5.3.2.2.9.1 Weather Data. ~~The weather data file shall be CE200.TMY or CE200A.TM2.~~

These data are provided ~~with~~ the electronic files accompanying this standard ~~and areas~~ described in normative Annex A1, Section A1.2.1.

5.3.2.2.9.2 Internal Heat Gains. ~~The internal gains shall be~~

- Sensible internal gains = 6120 W (20890 Btu/h), continuously (24 hours per day for the full simulation period)
- Latent internal gains = 1817 W (6200 Btu/h), continuously (24 hours per day for the full simulation period).

Sensible gains shall remain as 100% convective.

~~Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat (from equipment, lights, people, etc.) that are not related to operation of the mechanical cooling system or its air distribution fan.~~

5.3.2.2.9.2.1 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains, then to convert the listed latent internal

gains to water vapor mass flow rate, ~~use~~ a heat of vaporization (h_{fg}) that approximates the value of h_{fg} for condensation at the coil ~~used~~ applied by the software being tested shall be used.

5.3.2.2.9.2.2 If the software being tested requires input of total internal gains, then ~~use~~ the sum of listed sensible + latent internal gains shall be used.

5.3.2.2.9.3 Thermostat Control Strategy

- Heat = OFF.
- Cool = ON if zone air temperature > 26.7°C (80.0°F); otherwise cool = OFF.

All other features of the thermostat shall remain as before.

5.3.3 Case CE300: Comparative Test Base Case Building and Mechanical System. ~~Begin with Case CE300. Case CE300 shall be modeled as detailed in this section and its subsections.~~

Informative Note: ~~CE300 is the base case for the CE-300 series cases, and Cases CE400 and CE500. The bulk of the work for implementing the tests of Sections 5.3.3 and 5.3.4 is assembling an accurate base building model. It is recommended that base Case CE300 building inputs be double-checked and disagreements in results be diagnosed before going on to the other cases.~~

5.3.3.1 Weather Data. ~~This case requires the weather data file shall be CE300.TM2.~~

~~These data are provided with the electronic files accompanying this standard and is~~ described in normative Annex A1, Section A1.2.2.

5.3.3.2 Output Requirements. Case CE300 requires the following output:

- a. Annual summation, mean, and hourly-integrated maximum and minimum results in accordance with Section 6.3.2.1
- b. Additional annual and hourly outputs only applicable to case CE300 in accordance with Section 6.3.2.2-
- c. general reporting requirements of Section 6.1.

5.3.3.3 Building Geometry. The base building ~~is~~ shall be a 196 m² (2110 ft²) floor area, single-story building with rectangular-prism geometry as shown

in Figure 5-13. ~~The zone air volume is~~ shall be 588 m³ (20765 ft³).

5.3.3.4 Building Envelope Thermal Properties. ~~The base building zone is intended as a near-adiabatic test cell with cooling load driven by user-specified scheduled internal gains. For the building envelope, the thermal and material properties listed in Tables 5-29a (SI units) and 5-29b (I-P units) shall be used; list material properties in Systeme Internationale (SI) and English (I-P) units, respectively; abbreviations used in these tables are listed defined in Section 3.2.~~

Informative Note: ~~The base building zone is intended as a near-adiabatic test cell with the cooling load driven by user-specified scheduled internal gains.~~

5.3.3.4.1 ~~The building insulation has been made very thick to effectively thermally decouple the zone from ambient conditions. If the software being tested does not allow as this much insulation as specified in Table 5-29a (SI) or 5-29b (I-P), use the thickest insulation that the software will permit and reduce the floor, roof, and wall areas to achieve the thermal conductance (UA) values listed in Table 5-29a (SI) or 29b (I-P). The zone air volume must shall remain at 588 m³ (20765 ft³).~~

5.3.3.4.2 Materials of the space shall have no thermal or moisture capacitance and ~~there is no~~ moisture diffusion through them. If the software being tested requires inputs for thermal capacitance, moisture capacitance, or moisture diffusion, ~~use the~~ minimum values the software allows shall be used.

5.3.3.4.3 ~~If the program being tested automatically calculates air density, skip the instructions in this section and proceed to Section 5.3.3.4.4. Air density at sea level is 1.201 kg/m³ (0.075 lb/ft³). Use of different (non-specified) values shall not be prohibited, 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 non-specified values shall be documented in the Standard Output Report specified in normative Annex A2.~~

5.3.3.4.4 The floor has the same exterior film coefficient as the ~~other~~ walls.

Informative Note: ~~This is as if the entire zone were suspended above the ground.~~

5.3.3.4.5 For software that requires input of ground thermal properties, ~~use the~~ values of Section 5.3.1.4.5 shall be used.

5.3.3.5 Infiltration. ~~An infiltration rate of 0.0 air changes per hour (ach) shall be used for the entire simulation period.~~

5.3.3.6 Internal Heat Gains. Sensible and latent internal heat gains ~~are as~~ indicated in Table 5-30 shall be used.

5.3.3.6.1 Informative Note: Table 5-30 lists hourly values for a given period. In the first row of values, for example, the 2931 W of sensible gains and 0 W of latent gains are applied for each hour from 12 A.M. until 8 A.M. for the entire period from January 1 through March 10. Similarly, the second row of values indicates 2931 W of sensible gains and 366 W of latent gains for each hour from 8 A.M. until 8 P.M. for the same period. Values are provided in both SI and I-P units. Additionally, the corresponding fraction of a given hourly value relative to the maximum hourly value for the year is given for the convenience of users who may need to provide input in such a format. In the first row of values for sensible gains, for example, the “frac v. max” value of 0.15625 is the result of: (10,000 British thermal units [Btu]/h) / (64,000 Btu/h). Note that 64,000 Btu/h, which is the hourly sensible heat gain for the period from 14:00 until 16:00 for the period beginning April 21 and ending October 12 (and October 19 through November 5), is the maximum hourly sensible internal gain input for the year.

5.3.3.6.1.5.3.3.6.2 Sensible gains ~~are~~ shall be 100% convective.

5.3.3.6.3 Informative Note: Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat that are not related to the operation of the mechanical cooling system or its air distribution fan.

5.3.3.6.4.2 If the software being tested requires input of water vapor mass flow rate rather than latent internal gains ~~then to convert the listed latent internal gains to water vapor mass flow rate, use the~~ heat of vaporization (h_{fg}) that approximates the value of h_{fg} for condensation at the coil applied by the software being tested shall be used ~~the software assumes for condensation at the coil to convert the latent gains to~~

water vapor mass flow rate for for each listed time period.

5.3.3.6.53 If the software being tested requires input of total internal gains, ~~use~~ the sum of sensible + latent internal gains for each listed time period shall be used.

5.3.3.7 Opaque Surface Radiative Properties.

These shall be the same as for cases CE100-CE200, see as specified in Section 5.3.1.7.

5.3.3.8 Exterior Combined Radiative and Convective Surface Coefficients. These shall be the same as for cases CE100-CE200, see as specified in Section 5.3.1.8.

5.3.3.9 Interior Combined Radiative and Convective Surface Coefficients. These shall be the same as for cases CE100-CE200, see as specified in Section 5.3.1.9.

5.3.3.10 Mechanical System. The mechanical system specified in Figure 5-14 and in the following sub-sections shall be modeled.

Informative Note: The mechanical system represents a simple unitary vapor compression cooling system or, more precisely, a split-system, air-cooled condensing unit with an indoor evaporator coil and with an ~~outside-outdoor~~ air mixing system. ~~Figure 5-14 is a schematic diagram of this system. See Section 3 for definitions of the terminology used in this section.~~

5.3.3.10.1 General Information. The mechanical system shall have the following characteristics:

- 100% convective air system.
- Zone air perfectly mixed.
- An outside-air mixing system ~~is included~~ (as shown in Figure 5-14).
- Single-speed draw-through indoor-air distribution fan, continuous operation.
- Outdoor condenser fan, cycling ON and OFF with the compressor.
- Air-cooled condenser.
- Single-speed reciprocating compressor, R-22 refrigerant, no cylinder unloading.
- No system hot-gas bypass.
- The compressor, condenser, and condenser fan are located outside the conditioned zone.
- All moisture that condenses on the evaporator coil (latent load) leaves the system through a condensate drain.

- Crankcase heater and other auxiliary energy = 0.

5.3.3.10.2 Thermostat Control Strategy. The following thermostat control strategy shall be used:

- Heat = OFF
- Cool = ON if temperature > 25.0°C (77.0°F); otherwise Cool = OFF.

~~All other~~ The thermostat control strategy characteristics shall be the same as for cases CE100-CE200, see as specified in Sections 5.3.1.10.2.1 through 5.3.1.10.2.4.

5.3.3.10.3 Full-Load Cooling System Performance Data. Equipment full-load capacity and full-load performance data from Tables 5-31a (SI units) and/or 5-31b (IP units) shall be used. give a sample expanded set of data for equipment full load capacity and full-load performance data. An electronic file (CE300MAP.XLS) containing Tables 5-31a and 5-31b is included with the electronic files accompanying this standard.

Informative Note: Before using these tables, it is recommended to read all of the informative notes included with Section 5.3.3.10.3; and the discussion in Subsection 5.3.3.10.3.1.

Informative Note, Tables 5-31a and 5-31b: Tables 5-31a and 5-31b give a sample expanded set of data for equipment full load performance. The tables contain gross capacity data, which are the full capacities of the unit without any fan heat subtracted out. Table 5-31a is in SI units; Table 5-31b is in IP units. Notes that also include specific units for various quantities presented in the tables are given on the last page of each table. Data are included for 2.78°C (5°F) increments of EDB and EWB and 5.56°C (10°F) increments of ODB. Data are also included for typical rating conditions of ODB/EDB/EWB = 35.00°C/26.67°C/19.44°C (95°F/80°F/67°F).

5.3.3.10.3.1 For convenience, an electronic file (CE300MAP.XLS) containing Tables 5-31a and 5-31b is included on the accompanying CD.

5.3.3.10.3.2 These tables use ODB, EDB, and EWB as independent variables for performance data; the locations of EDB and EWB are shown in Figure 5-14. In these tables each block of data represents an (EDB, EWB) data set for a different ODB. The data

set includes ranges where the HVAC equipment manufacturer recommends only limited system operation ~~is recommended~~. These ranges are indicated by background shading in the upper-left and lower-right regions of the tables (see the electronic version of CE300MAP.XLS). The data set assumes that the refrigerant charge is always optimal at each listed full-load operating point. For the purpose of the test cases, assume that the refrigerant charge is always optimal.

The unit as described actually uses a 1242 W fan. So the adjusted net capacity is
(net cap)_{adj} = (gross cap)_{listed} – (fan power).

For example, for the net total (sensible + latent) capacity at ODB = 95°F, EDB = 75°F, and EWB = 65°F and 4000 cfm:

$$(\text{net cap})_{\text{adj}} = 32,122 \text{ W} - 1242 \text{ W} = 30,880 \text{ W}.$$

The technique for determining net sensible capacities is similar.

5.3.3.10.3.3 Informative Note: Validity of Listed Data (VERY IMPORTANT). EWB given for the listed compressor kW (kilowatts) and gross capacities given in Tables 5-31a and 5-31b are valid only for “wet” coils (when dehumidification is occurring). A dry-coil condition—no dehumidification—occurs when the entering air humidity ratio is decreased to the point where the entering air dew-point temperature is less than the effective coil surface temperature (apparatus dew point). In Tables 5-31a and 5-31b, the dry-coil data (indicated with *italics*) are evident for conditions where the listed sensible capacity is equal to the corresponding total capacity. For a given EDB and ODB, the compressor power, total capacity, and sensible capacity for wet coils change with varying EWB. Once the coil becomes dry, for a given EDB, compressor power and capacities remain constant with decreasing EWB.⁶

For the purpose of interpolating data between listed wet-coil and dry-coil data points, it is necessary to evaluate the maximum EWB for the occurrence of the listed dry-coil data point. One method for establishing the maximum EWB where total and sensible capacities are equal is to linearly extrapolate EWB for a given EDB and ODB. For example, the data shown in informative Table 5-32a (extracted from Table 5-31a, SI units) and informative Table 5-32b (extracted from Table 5-31b, I-P units) can be used to determine that the dry-coil compressor power for ODB/EDB = 35.00°C/26.67°C (95.0°F/80°F).

At the dry-coil condition:

Gross total capacity = gross sensible capacity
= 31.05 kW thermal (105.9 kBtu/h)
where these data are listed in the row in Tables 5-31a and 5-31b (for ODB = 35.00°C [95°F]) for EWB = 15.56°C (60°F).

Linear extrapolation based on gross total capacity gives

Maximum EWB for the dry-coil condition
= 17.11°C (62.77°F).

Linear extrapolation based on gross sensible capacity gives

Maximum EWB for the dry-coil condition
= 17.00°C (62.63°F).

Therefore, maximum dry-coil EWB = 17.05°C (62.7°F).

(The difference in values of maximum EWB based on extrapolation using total capacity versus sensible capacity may be attributable to a small amount of error associated with assuming linearity in this determination, or there may be some uncertainty in the listed values. The listed compressor power data were not used for extrapolating EWB because they have fewer significant digits than the capacity data.)

5.3.3.10.3.4-1 Extrapolation of Performance Data.

~~Allow the~~ The software being tested shall~~to~~ perform any necessary extrapolations of performance data, if it has that capability.

Informative Note: ~~(The need for doing extrapolations has been minimized by the inclusion of an expanded performance data set and by specifying reduced internal gains during cooler weather.)~~

5.3.3.10.3.5-2 Cooling Coil Bypass Factor. If the software being tested does not require an input for bypass factor (BF), or automatically calculates it based on other inputs, then skip the instructions in this section and proceed to Section 5.3.3.10.3.3. ignore this information.

For this system,

- BF = 0.070.

Informative Note: This value was provided by the manufacturer. For this system, BF varies only with airflow rate, which is constant for these test cases.

5.3.3.10.3.6-3 Minimum Supply Air Temperature.

This system shall be a variable temperature system, meaning that where the supply air temperature varies with the operating conditions. If the software being tested does not require input for minimum supply air temperature, then skip the instructions in this section and proceed to Section 5.3.3.10.4. If the software being tested requires an input for minimum allowable supply air temperature, then the following value shall be used:

- Minimum supply air temperature ≤ 1.46°C (34.6°F).

Informative Note: Calculation of minimum supply air temperature is presented in HVAC BESTEST, Volume 2.⁸

If the software being tested does not require this input, ignore this information.

TABLE 5-32a Determination of Maximum Dry-Coil EWB Using Extrapolation (SI Units)

[Informative Note: Table 5-32a is informative material]

EWB,
°C

Gross Total Capacity,
kW thermal

Gross Sensible Capacity,
kW thermal

Compressor Power,
kW

17.11 (on TC); 17.00 (on SHC) 31.05 31.05 9.7

18.33 32.26 28.28 9.9

21.11 35.02 22.48 10.3

Note: Italicized values are not specifically listed with the original performance data; they are determined based on the accompanying discussion/informative note where this table is cited. Data in normal font are from the original performance data.

TABLE 5-32b Determination of Maximum Dry-Coil EWB Using Extrapolation (I-P Units)

[Informative Note: Table 5-32b is informative material]

EWB,
°F

Gross Total Capacity,
kBtu/h

Gross Sensible Capacity,
kBtu/h

Compressor Power,
kW

62.77 (on TC); 62.63 (on SHC) 105.9 105.9 9.7

65 110.1 96.5 9.9

70 119.5 76.7 10.3

Note: Italicized values are not specifically listed with the original performance data; they are determined based on the informative note where

this table is cited, accompanying discussion. Data in normal font are from the original performance data.

5.3.3.10.4 Part-Load Operation Part-load operation shall be the same as for ~~Ceases CE100-CE200~~ as specified in Section 5.3.1.10.4, with comments and exceptions as follows.

5.3.3.10.4.1 COP Degradation Factor (CDF). See Section 5.3.1.10.4.1 for requirements.

5.3.3.10.4.2 COP2 at Part Load. When the simplifying assumption is made that continuous operation of the air distribution fan has a negligible effect on the compressor's part-load energy use, For calculating COP2 at part load, CDF from Figure 5-10 (Section 5.3.1.10.4.1) shall apply to COP2 as follows, as well as to COP (see Section 3 for definitions). That is,

$$(\text{COP2 at part load}) = (\text{CDF}) \times (\text{COP2 at full load})_{5.7}$$

Informative Note: When the simplifying assumption is made that continuous operation of the air distribution fan has a negligible effect on the compressor's part-load energy use, CDF applies to COP2 in a similar manner as it applies to COP (see Section 3 for definitions).

Because the compressor controller is assumed to provide ideal ON/OFF cycling (see Section 5.3.1.10.2.3), **5.3.3.10.4.3 Fractional Run Time.** Hourly fractional compressor and outdoor fan run time = PLR/CDF.

Informative Note: This assumption is consistent with the performance expected from an ideal ON/OFF cycling controller (see Section 5.3.1.10.2.3).

5.3.3.10.4.3 Calculation of PLR. See Section 5.3.1.10.4.3 for requirements.

5.3.3.10.4.4 See Section 5.3.1.10.4.4.

5.3.3.10.4.5 Informative Note: Because there is a continuously operating indoor air fan in the CE300 and CE400 series cases, the definition of PLR (as in see Section 5.3.1.10.4.3) applying gross total evaporator coil load and gross total capacity is more convenient to apply. If the software being tested is defining PLR based on net refrigeration effect and adjusted net capacity, then for the CE300 and CE400 series cases, indoor air distribution fan operation for times when the evaporator coil is not removing heat

~~must~~ is still be considered in the overall simulation. Indoor air distribution fan operation for times when the evaporator coil is not removing heat does not affect the net refrigeration effect or the adjusted net total capacity.

5.3.3.10.4.56 For cases CE300–CE440, the CDF (defined in Section 5.3.1.10.4.1) ~~is~~ shall not be applicable to the continuously operating indoor air distribution fan energy consumption.

5.3.3.10.4.7 See Section 5.3.1.10.4.5.

5.3.3.10.4.68 Bypass Factor. See Section 5.3.1.10.4.64 for requirements.

5.3.3.10.5 Fans

5.3.3.10.5.1 Indoor Air Distribution Fan. The indoor distribution fan shall be a draw-through fan with the following operating characteristics:

- Airflow rate = $1.888 \text{ m}^3/\text{s} = 6796 \text{ m}^3/\text{h} = 4000 \text{ cfm}$
- Indoor fan electric power = 1242 W
- Indoor fan mechanical shaft power = 1167 W (1.565 brake horsepower [BHP])
- External static fan pressure = $74.7 \text{ Pa} = 0.3 \text{ in. w.g.}$ (water gauge)
- Fan static efficiency = 0.121
- Motor/drive efficiency = 0.940
- Supply air temperature rise from fan heat = $0.54^\circ\text{C} = 0.97^\circ\text{F}$
- Air distribution efficiency = 100% (adiabatic ducts).

Informative Note: For further discussion of these inputs, see Annex B15, Section B15.2.

5.3.3.10.5.1.1 The draw-through indoor air distribution fan shall operate continuously at 4000 cfm ($6796.0 \text{ m}^3/\text{h}$) for the entire simulation period.

5.3.3.10.5.1.2 For calculating additional heating of the distribution air related to waste heat from the indoor distribution fan, ~~assume that~~ the distribution fan motor shall be ~~is~~ mounted in the distribution airstream so that 100% of the heat from fan energy use goes to the distribution (supply) air.

5.3.3.10.5.2 Outdoor Condenser Fan

- Outdoor fan power = 930 W.
- The draw-through outdoor condenser fan shall cycle ON and OFF with the compressor.

5.3.3.10.6 Outside Outdoor Air. ~~The indoor air distribution fan operates continuously at 4000 cfm ($6796.0 \text{ m}^3/\text{h}$).~~ Outdoor air shall be 15% of total supply air and return air shall be 85% of total supply air, continuously. ~~Dampers are adjusted to continuously supply 15% outside air mixed with the return air.~~ That is, of the 4000 cfm ($6796.0 \text{ m}^3/\text{h}$) of mixed supply air, 600 cfm ($1019.4 \text{ m}^3/\text{h}$) ~~is~~ shall be outside-outdoor air and 3400 cfm ($5776.6 \text{ m}^3/\text{h}$) ~~is~~ shall be return air. As fresh air is introduced from the outside, a corresponding amount of zone air shall exits through the relief damper (see shown in Figure 5-14).

5.3.4 Space-Cooling Equipment Performance Comparative Tests.

Sequential variations shall be modeled as specified in the following subsections.

Informative Note: It is recommended to double check the Case CE300 base-case inputs and to diagnose Case CE300 results disagreements before going on to the other test cases.

5.3.4.1 Basic Tests (CE300 Series). Case CE300 shall be the base case for all test cases in this series. ~~This section describes sequential revisions to the base case required to model additional CE300 series cases. Case CE300 is the base case for all the CE300 series cases.~~

5.3.4.1.1 Case CE310: High Latent Gains. Case CE310 ~~shall be~~ is modeled exactly the same as Case CE300 except for the following changes as follows.

5.3.4.1.1.1 Internal Heat Gains. ~~The latent internal heat gains are revised.~~ shall be scheduled according to Table 5-33. Only the latent internal gains ~~are~~ shall be changed; sensible internal gains shown here ~~are~~ shall be the same as for Case CE300. ~~5.3.4.1.1.1 All other modeling details for internal gains shall be exactly the same as of Case CE300, also apply here; see as specified in Sections 5.3.3.6.2-1 through 5.3.3.6.53.~~

5.3.4.1.1.2 Output Requirements. ~~The Case CE310 requires the following output: s for these cases are the same as for Case CE300, except that they exclude the outputs of Section 6.3.2.2 (annual weather data checks and June 28 hourly outputs).~~ a. Annual summation, mean, and hourly-integrated maximum and minimum results in accordance with the requirements of Section 6.3.2.1
b. general reporting requirements of Section 6.1.

5.3.4.1.2 Case CE320: High Infiltration. Case CE320 ~~is shall be modeled~~ exactly the same as Case CE300 except for the following changes as follows.

5.3.4.1.2.1 Infiltration Schedule. ~~See below~~The infiltration rate shall be scheduled as follows:

Time Period Infiltration Rate

Jan. 1—April 20 1.734 ach (1019.4 m³/h, 600 cfm)
April 21—Oct. 12
 00:00 to 08:00 1.734 ach (1019.4 m³/h, 600 cfm)
 08:00 to 20:00 11.558 ach (6796.0 m³/h, 4000 cfm)
 20:00 to 24:00 1.734 ach (1019.4 m³/h, 600 cfm)
Oct. 13—Dec. 31 1.734 ach (1019.4 m³/h, 600 cfm)

Note: Informative Note: Infiltration is leakage of air through any building element (e.g., walls, windows, and doors). The listed infiltration rates are independent of factors such as wind speed and indoor/outdoor temperature difference.

5.3.4.1.2.2 Outside-Outdoor Air. ~~No~~ Outside outdoor air shall be introduced by the system (outdoor air fraction = 0.0) (no outside air) for the full annual simulation period.

5.3.4.1.2.3 Output Requirements. These shall be the same as for Case CE310, see as specified in Section 5.3.4.1.1.2.

5.3.4.1.3 Case CE330: High Outside-Outdoor Air. Case CE330 ~~shall be modeled~~ exactly the same as Case CE300 except for the following changes as follows.

5.3.4.1.3.1 Outside-Outdoor Air. The Outside outdoor air fraction (as a percentage of total fan flow; (OA%)) is shall be scheduled as follows:

Time Period OA Fraction

Jan. 1—April 20 15%
April 21—Oct. 12
 00:00 to 08:00 15%
 08:00 to 20:00 100%
 20:00 to 24:00 15%
Oct. 13—Dec. 31 15%

Note: Informative Note: An ~~outside-outdoor~~ air fraction of 15% corresponds to 4000 cfm (6796.0 m³/h) of mixed air containing 600 cfm (1019.4 m³/h) of ~~outside-outdoor~~ air and 3400 cfm (5776.6 m³/h) of return air.

return air. Similarly, an ~~outside-outdoor~~ air fraction of 100% corresponds to 4000 cfm (6796.0 m³/h) of mixed air containing 4000 cfm (6796.0 m³/h) of ~~outside-outdoor~~ air and 0 cfm (0 m³/h) of return air.

5.3.4.1.3.2 Output Requirements. These shall be the same as for Case CE310; see Section 5.3.4.1.1.2.

5.3.4.1.4 Case CE340: Infiltration and Outside Outdoor Air Interaction.

Case CE340 ~~shall be modeled~~ exactly the same as Case CE300 except for the following changes as follows.

5.3.4.1.4.1 Infiltration Schedule. ~~See below~~The infiltration rate shall be scheduled as follows:

Time Period Infiltration Rate

Jan. 1—April 20 0 ach
April 21—Oct. 12
 00:00 to 08:00 0 ach
 08:00 to 20:00 5.779 ach (3398.0 m³/h; 2000 cfm)
 20:00 to 24:00 0 ach
Oct. 13—Dec. 31 0 ach

Note: Informative Note: Infiltration is leakage of air through any building element (e.g., walls, windows, and doors). The listed infiltration rates are independent of factors such as wind speed and indoor/outdoor temperature difference.

5.3.4.1.4.2 Outside-Outdoor Air. ~~See below~~ The outdoor air fraction as a percentage of total fan flow (OA%) shall be scheduled as follows:

Time Period OA Fraction

Jan. 1—April 20 15%
April 21—Oct. 12
 00:00 to 08:00 15%
 08:00 to 20:00 50%
 20:00 to 24:00 15%
Oct. 13—Dec. 31 15%

Note: Informative Note: An ~~outside-outdoor~~ air fraction of 15% corresponds to 4000 cfm (6796.0 m³/h) of mixed air containing 600 cfm (1019.4 m³/h) of ~~outside-outdoor~~ air and 3400 cfm (5776.6 m³/h) of return air. Similarly, an ~~outside-outdoor~~ air fraction of 50% corresponds to 4000 cfm (6796.0 m³/h) of mixed air containing 2000 cfm (3398.0 m³/h) of ~~outside-outdoor~~ air and 2000 cfm (3398.0 m³/h) of return air.

5.3.4.1.4.3 Output Requirements. ~~These shall be the same as for Case CE310, see as specified in Section 5.3.4.1.1.2.~~

5.3.4.1.5 Case CE350: Thermostat Setup. Case CE350 ~~is shall be modeled~~ exactly the same as Case CE300 except for the following changes as follows.

5.3.4.1.5.1 Thermostat Control Strategy Schedule. The thermostat cooling setpoint shall be scheduled as follows ~~for the entire year:~~

Time Period Cooling Setpoint

Jan. 1—April 20 25°C (77°F)

April 21—Oct. 12

00:00 to 07:00 35°C (95°F)

07:00 to 20:00 25°C (77°F)

20:00 to 24:00 35°C (95°F)

Oct. 13—Dec. 31 25°C (77°F)

~~Note:~~ **Informative Note:** For April 21 through October 12, the cooling setpoint is lowered at 07:00, which is 1 hour before the internal gains increase.

5.3.4.1.5.2 Output Requirements. ~~These shall be the same as for Case CE310, see as specified in Section 5.3.4.1.1.2.~~

5.3.4.1.6 Case CE360: Undersized System. Case CE360 ~~is shall be modeled~~ exactly the same as Case CE300 except for the changes as in the following subsections.

5.3.4.1.6.1 Internal Heat Gains. The internal heat gains ~~are revised~~ shall be scheduled according to Table 5-34. Only the sensible internal gains shall be changed from the base case for the period from April 21 through October 12; the latent internal gains and other sensible internal gains shown in the table shall be the same as for Case CE300. ~~5.3.4.1.6.1.1 All other modeling details for internal gains of shall be the same as for Case CE300 also apply here, see as specified in Sections 5.3.3.6.1 through 5.3.3.6.35.~~

5.3.4.1.6.2 Output Requirements. ~~These shall be the same as for Case CE310, see as specified in Section 5.3.4.1.1.2.~~

5.3.4.2 Economizer Series (CE400 Series). ~~This section describes sequential revisions to the base case required to model the CE400-series economizer-series cases shall be implemented by applying the-~~

~~Base cases for a given economizer case are as follows:~~

Case	Basis for that Case
CE400	CE300
CE410	CE400
CE420	CE400
CE430	CE400
CE440	CE430

5.3.4.2.1 Case CE400: Economizer with ODB/IDB Control and Integrated Compressor Control. Case CE400 ~~shall be modeled~~ exactly the same as Case CE300 except for the following changes as follows.

5.3.4.2.1.1 Economizer and Compressor Control Strategy (CE400). The ~~outside-outdoor air and relief dampers (see shown in Figure 5-14) are shall be~~ adjusted using economizer control based on ODB and return air temperature as described specified below. ~~Because these cases assume no thermal losses or gains in the ducts, so that the return air temperature and the zone air temperature (IDB) may be assumed to be are equal.~~

Economizer = ON AND Compressor = OFF IF IDB > 25.0°C (77.0°F) AND ODB ≤ IDB AND all cooling load for the given hour ~~is are~~ compensated by the economizer.

Economizer = ON AND Compressor = ON IF IDB > 25.0°C (77.0°F) AND ODB ≤ IDB AND all cooling load for the given hour ~~is are~~ NOT compensated by the economizer. ~~(In this configuration outside outdoor air is shall be at the 100% maximum setting for the full hour.)~~

Economizer = OFF AND Compressor = ON IF IDB > 25.0°C (77.0°F) AND ODB > IDB.

Economizer = OFF AND Compressor = OFF IF IDB ≤ 25.0°C (77.0°F),

where for

Economizer = ON, outside-outdoor air shall be provided as needed up to 100% outside-outdoor air for the entire hour, but not less than the 15% minimum outside-outdoor air setting for any time during the hour.

Economizer = OFF, ~~outside-outdoor air is~~ shall be provided at the 15% minimum ~~outside-outdoor air~~ setting for that hour.

Compressor = ON, the compressor and condenser fan shall ~~will~~ operate only as long as necessary to handle the sensible cooling load not compensated by the economizer.

Compressor = OFF, the compressor and condenser fan shall ~~do~~ not operate for the hour.

Informative Note: ~~Note that~~ There is no lower limit temperature, which means that the economizer control strategy is not affected by how cold the ~~outside-outdoor air~~ may become.

5.3.4.2.1.2 Output Requirements. These shall be the same as for Case CE310, see as specified in Section 5.3.4.1.1.2.

5.3.4.2.2 Case CE410: Economizer with ODB/IDB Control and Nonintegrated Compressor. Case CE410 shall be modeled exactly the same as Case CE400 except while the economizer is operating, the compressor shall ~~is~~ not be allowed to operate. The economizer takes precedence over the compressor but is only allowed to operate whenever it ~~can~~ is capable of satisfying the entire cooling load by itself.

5.3.4.2.2.1 Economizer and Compressor Control Strategy (CE410).

Economizer = ON AND Compressor = OFF IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $ODB \leq IDB$ AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON NOT allowed.

Economizer = OFF AND Compressor = ON IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $\{(ODB > IDB) \text{ OR (all cooling load for the given hour CANNOT be compensated by the economizer)}\}$.

Economizer = OFF AND Compressor = OFF IF $IDB \leq 25.0^{\circ}\text{C}$ (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case CE400.

5.3.4.2.3 Case CE420: Economizer with ODB Limit Control. Case CE420 shall be modeled exactly the same as Case CE400 except when $ODB > 20^{\circ}\text{C}$ (68°F), the ~~outside-outdoor air~~ and relief dampers shall be ~~are~~ maintained at 15% ~~outside outdoor air~~.

5.3.4.2.3.1 Economizer and Compressor Control Strategy (CE420).

Economizer = ON AND Compressor = OFF IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $ODB \leq 20.0^{\circ}\text{C}$ (68.0°F) AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $ODB \leq 20.0^{\circ}\text{C}$ (68.0°F) AND all cooling load for the given hour is NOT compensated by the economizer. (In this configuration ~~outside-outdoor air is~~ shall be at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $ODB > 20.0^{\circ}\text{C}$ (68.0°F).

Economizer = OFF AND Compressor = OFF IF $IDB \leq 25.0^{\circ}\text{C}$ (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case CE400.

5.3.4.2.4 Case CE430: Enthalpy Economizer with Integrated Compressor Control.

Case CE430 is shall be modeled exactly the same as Case CE400 except the ~~outside-outdoor air~~ and relief dampers are adjusted using economizer control based on outdoor air enthalpy (h_{amb}) and return air enthalpy (h_{ra}) as described ~~specified~~ below. ~~Because~~ These cases assume no thermal losses or gains in the ducts, so that the return air enthalpy and the zone air enthalpy ~~may be assumed to be~~ are equal.

Informative Note: Enthalpy has units of energy per mass of dry air.

5.3.4.2.4.1 Economizer and Compressor Control Strategy (CE430).

Economizer = ON AND Compressor = OFF IF $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} \leq h_{ra}$ AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
 $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} \leq h_{ra}$ AND all cooling load for the given hour is NOT compensated by the economizer. (In this configuration ~~outside~~ outdoor air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
 $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} > h_{ra}$.

Economizer = OFF AND Compressor = OFF IF
 $IDB \leq 25.0^{\circ}\text{C}$ (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case CE400.

5.3.4.2.5 Case CE440: Economizer with Enthalpy Limit Control. Case CE440 shall be modeled exactly the same as Case CE430 except when $h_{amb} > 47.25$ kJ/kg (28.0 Btu/lb), the ~~outside-outdoor~~ air and relief dampers ~~are~~ shall be maintained at 15% ~~outside~~ outdoor air.

5.3.4.2.5.1 Economizer and Compressor Control Strategy (CE440).

Economizer = ON AND Compressor = OFF IF
 $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} \leq 47.25$ kJ/kg (28.0 Btu/lb) AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
 $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} \leq 47.25$ kJ/kg (28.0 Btu/lb) AND all cooling load for the given hour is NOT compensated by the economizer. (In this configuration ~~outside-outdoor~~ air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
 $IDB > 25.0^{\circ}\text{C}$ (77.0°F) AND $h_{amb} > 47.25$ kJ/kg (28.0 Btu/lb).

Economizer = OFF AND Compressor = OFF IF
 $IDB \leq 25.0^{\circ}\text{C}$ (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case CE400.

5.3.4.3 Cases with No ~~Outside-Outdoor~~ Air, Annual Simulation Context (CE500 Series). ~~This section describes s~~ Sequential revisions to the base case required to model the CE500-series cases shall

be implemented by applying the: Base cases for a given case are as follows:

Case	Basis for that Case
CE500	CE300
CE510	CE500
CE520	CE500
CE522	CE520
CE525	CE520
CE530	CE500
CE540	CE530
CE545	CE540

5.3.4.3.1 Case CE500: Base Case with No ~~Outside~~ Outdoor Air. Case CE500 shall be modeled exactly the same as Case CE300 except for the changes ~~as in the following subsections.~~

5.3.4.3.1.1 Internal Heat Gains. The hourly internal gains ~~are~~ shall be as indicated in Table 5-35. For this case the “frac v. max” values in Table 5-35 are the same for both sensible and latent loads.

5.3.4.3.1.1.1 All other m- Modeling details for internal gains shall be exactly the same as of for Case CE300, ~~also apply here; see~~ as specified in Sections 5.3.3.6.2 1 through 5.3.3.6.53.

5.3.4.3.1.2 Indoor Fan Control and Part-Load Operation. The indoor air distribution fan cycles ON and OFF with the compressor.

Informative Note: For this type of control, CDF applies to the indoor fan energy consumption (see Section 5.3.1.10.4). Although the fan now cycles rather than operating continuously, the equivalence ~~still holds~~ applies for using gross total capacity to calculate PLR as an alternative to using net refrigeration effect and adjusted net capacity; see Annex B13, Section B13.2.

5.3.4.3.1.3 ~~Outside-Outdoor~~ Air. No outdoor air shall be introduced to the zone by the system (~~Outside-outdoor~~ air fraction = 0.0) (~~no outside air~~) for the full annual simulation period.

Note/Informative Note: ~~that~~ In one of the field-trial simulations for Case CE100, simultaneous use of “0” ~~outside-outdoor~~ air and “0” infiltration caused an error in the simulations. This error was avoided by specifying minimum ~~outside-outdoor~~ air = 0.000001 ft³/min. It is recommended to do a sensitivity test to check that using 0 for both these inputs does not cause a problem.

5.3.4.3.1.4 Output Requirements, Case CE500

requires the following output:

- a. Annual summations according to Section 6.3.2.1.1
- b. Annual means according to Section 6.3.2.1.2
- c. Annual hourly-integrated maximum values according to Section 6.3.2.1.3
- d. Annual hourly-integrated maxima and minima according to Section 6.3.2.3
- e. PLR sensitivity results according to Section 6.3.2.4
- f. ODB sensitivity results according to Section 6.3.2.5
- g. general reporting requirements of Section 6.1.

5.3.4.3.2 Case CE510: High Part-Load Ratio. Case CE510 shall be modeled exactly the same as Case CE500 except for the following changes as follows.

5.3.4.3.2.1 Internal Heat Gains. The hourly internal gains shall be scheduled as indicated in Table 5-36. The loads are only changed from Case CE500 for the period of April 21 through October 11. This results in changes to the listed “frac v. max” multipliers for the other time periods. For this case the “frac v. max” values in Table 5-36 are the same for both sensible and latent loads.

5.3.4.3.2.1.1 All other Modeling modeling details for internal gains shall be exactly as of Case CE300, also apply here; see as specified in Sections 5.3.3.6.2-1 through 5.3.3.6.53.

5.3.4.3.2.2 Output Requirements, Case CE510

requires the following output:

- a. Annual hourly-integrated maximum values according to Section 6.3.2.1.3
- b. Annual hourly-integrated maxima and minima according to Section 6.3.2.3
- c. PLR sensitivity results according to Section 6.3.2.4
- d. general reporting requirements of Section 6.1.

5.3.4.3.3 Case CE520: Reduced Thermostat Set Point (EDB = 15°C). Case CE520 shall be modeled exactly the same as Case CE500 except for the following changes as follows.

5.3.4.3.3.1 Thermostat Control Strategy

- Heat = OFF.
- Cool = ON if zone air temperature > 15.0°C (59.0°F); otherwise Cool = OFF.

All other features of the thermostat shall remain as before.

5.3.4.3.3.2 Output Requirements, Case CE520

requires the following output:

- a. Annual summations according to Section 6.3.2.1.1
- b. Annual means according to Section 6.3.2.1.2
- c. Annual hourly-integrated maximum values according to Section 6.3.2.1.3
- d. Annual hourly-integrated maxima and minima according to Section 6.3.2.3
- e. general reporting requirements of Section 6.1.

5.3.4.3.4 Case CE522: Reduced Thermostat Set Point (EDB = 20°C). Case CE522 shall be modeled exactly the same as Case CE520 except the thermostat control strategy shall be as described specified below.

- Heat = OFF.
- Cool = ON if zone air temperature > 20.0°C (68.0°F); otherwise Cool = OFF.

All other features of the thermostat shall remain as before.

5.3.4.3.5 Case CE525: Increased Thermostat Set Point (EDB Sensitivity). Case CE525 shall be modeled exactly the same as Case CE520 except the thermostat control strategy shall be as described below.

- Heat = OFF.
- Cool = ON if zone air temperature > 35.0°C (95.0°F); otherwise Cool = OFF.

All other features of the thermostat shall remain as before.

5.3.4.3.6 Case CE530: Dry Coil. Case CE530 shall be modeled exactly the same as Case CE500 except for the following changes as follows.

5.3.4.3.6.1 Internal Gains. The latent internal gains shall be 0 for the entire annual simulation period. The sensible internal gains remain as in Case CE500.

If the software being tested requires input of total internal gains, the sensible internal gains for each listed time period shall be used.

5.3.4.3.6.2 Output Requirements, Case CE530

requires the following output:

- a. Annual summations according to Section 6.3.2.1.1
- b. Annual means according to Section 6.3.2.1.2

- c. Annual hourly-integrated maximum values according to Section 6.3.2.1.3
- d. Annual hourly-integrated maxima and minima according to Section 6.3.2.3
- e. ODB sensitivity results according to Section 6.3.2.5-
- f. general reporting requirements of Section 6.1.

5.3.4.3.7 Case CE540: Reduced Thermostat Setpoint (EDB Sensitivity). Case CE540 shall be modeled exactly the same as Case CE530 except for the following changes as follows.

5.3.4.3.7.1 Thermostat Control Strategy

- Heat = OFF.
- Cool = ON if zone air temperature > 15.0°C (59.0°F); otherwise Cool = OFF.

All other features of the thermostat remain as before.

5.3.4.3.7.2 Output Requirements. Case CE540 requires the following output:

- a. Annual summations according to Section 6.3.2.1.1
- b. Annual means according to Section 6.3.2.1.2
- c. Annual hourly-integrated maximum values according to Section 6.3.2.1.3
- d. Annual hourly-integrated maxima and minima according to Section 6.3.2.3
- e. general reporting requirements of Section 6.1.

5.3.4.3.8 Case CE545: Increased Thermostat Setpoint (EDB Sensitivity). Case CE545 shall be modeled exactly the same as Case CE540 except the thermostat control strategy shall be as described below.

- Heat = OFF.
- Cool = ON if zone air temperature > 35.0°C (95.0°F); otherwise Cool = OFF.

All other features of the thermostat shall remain as before.

5.4 Input Specification for Space-Heating Equipment Performance Tests. Cases HE100 through HE230 shall be modeled as specified in this section and its subsections.

Informative Note: The test cases isolate the furnace performance by simplifying the zone-side energy transfers. The simulation method isolates a single facet of the furnace model in each test case, starting

with the simplest case and progressively adding complexity.

5.4.1 Case HE100: Base Case Building and Mechanical Systems. ~~Begin with Case HE100.~~ Case HE100 shall be the first case modeled as detailed in this section and its subsections.

Informative Note: The bulk of the work for implementing these cases is assembling an accurate base building and mechanical system. It is recommended that building inputs be double-checked and results disagreements be diagnosed before going on to the other cases. When diagnosing the results, it is important to compare results differences for building loads along with mechanical system results because disagreements for building loads influence the mechanical systems results.

5.4.1.1 Weather Data. The weather data used for this simulation ~~are Weather File~~ shall be the data file HE100W.WY2. ~~This file is provided with~~ the electronic files ~~CD~~ accompanying this standard as described in normative Annex A1, Section A1.3.

~~Note:~~ *Informative Note:* Other cases call for different weather files as needed.

5.4.1.2 Output Requirements. ~~Case HE100 requires~~ All of the output described specified in Sections 6.1 and 6.4 shall be reported for Case HE100 and the other cases of Section 5.4.

~~Note:~~ All of the Section 5.4 tests have the same output requirements.

5.4.1.3 Building Geometry. The base case building shall be a 48 m² floor area, single-story, low mass building with rectangular prism geometry and internal measurements as shown in Figure 5-15. The zone air volume shall be 129.6 m³.

5.4.1.4 Building Envelope Thermal Properties. The base case building ~~is designed~~ shall be as a near-adiabatic test cell except for one heat transfer surface. Energy shall be transferred to the outdoors through the heat transfer surface, with the furnace used to maintain the interior setpoint temperature.

5.4.1.4.1 ~~The M~~ Material properties for the exterior wall, floor, and roof are listed in Table 5-37 shall be used. The roof ~~will~~ shall be modeled as the heat transfer surface. ~~The insulation in the walls and floors has been made very thick and resistant to heat~~

~~transfer to effectively thermally decouple the zone from ambient conditions; i.e., they are made to be near-adiabatic. If the software being tested does not allow the specified insulation levels, use the thickest insulation the software being tested will permit shall be used and reduce the floor and wall areas shall be reduced to achieve the same UA values as defined in Table 5-37. The zone air volume must shall remain as 129.6 m³.~~

Informative Note: The insulation in the walls and floors has been made very thick and resistant to heat transfer to effectively thermally decouple the zone from ambient conditions; i.e., they are made to be near-adiabatic.

5.4.1.4.2 Materials shall have no thermal or moisture capacitance and there is shall have no moisture diffusion through them. If the software being tested requires inputs for thermal capacitance, moisture capacitance, and/or moisture diffusion, use the minimum values the software being tested allows shall be used.

5.4.1.4.3 If the program being tested automatically calculates air density, skip the instructions in this section and proceed to Section 5.4.1.4.4. Air density at 115 m altitude is 1.185 kg/m³. Use of different (non-specified) values shall not be prohibited, 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 non-specified values shall be documented in the Standard Output Report specified in normative Annex A2. For software that automatically calculates air density, the air density may have a different value.

5.4.1.4.4 Although the zone is modeled as if suspended above the ground, for For these software programs that require input of ground thermal properties, the ground in the vicinity of the building is shall be dry packed soil with the following characteristics:

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

Informative Note: Although the zone is modeled as if suspended above the ground, some programs require input for ground thermal properties.

5.4.1.5 Infiltration. ~~There shall will be no internal infiltration accounted for in the base case model:~~

- Infiltration rate = 0.0 ach (air changes per hour) for the entire simulation period.

5.4.1.6 Internal Heat Gains. ~~There shall be no internal heat gains (sensible or latent) will not be accounted for in the base case model.~~

- Sensible internal gains = 0 W, continuously.
- Latent internal gains = 0 W, continuously.

5.4.1.7 Surface Convective Heat Transfer

Coefficients. ~~If the software being tested does not allow for the definition direct input of convection coefficients, skip the instructions in this section and Section 5.4.1.8, and follow the approach described specified in Section 5.4.1.9.~~

Surface convection coefficients ~~will shall~~ approach zero for all interior and exterior surfaces except for the roof, which will have a constant surface convection coefficient.

The following surface convection coefficients (h_c) ~~will shall~~ be defined for all internal and external surfaces:

- internal and external $h_c = 20$ W/(m²·K) for the roof;
- internal and external $h_c \rightarrow 0$ for other surfaces.

If the software being tested does not allow a definition of zero for h_c , then set these coefficients to as small a value as possible the software allows.

5.4.1.7.1 The floor ~~has shall have~~ the same exterior film coefficient as the ~~other walls;~~

Information Note: This assumes that as if the entire zone were is suspended above the ground.

5.4.1.7.2 If the software being tested models radiation and convection together, then ~~set~~ the combined heat transfer coefficient for the roof heat transfer surface ~~shall be to~~ 20 W/(m²·K). For all other surfaces, ~~set~~ this value ~~shall be to~~ zero. If the software being tested ~~program~~ requires a non-zero value for the combined heat transfer coefficient, then set it to as small a value as ~~is~~ allowed by the software.

5.4.1.8 Surface Radiative Heat Transfer

Coefficients. ~~Solar absorptivity and longwave~~

~~emissivity coefficients will approach zero for all interior and exterior opaque surfaces.~~

The following longwave emissivity (λ) and solar absorptivity (α) ~~will~~ shall be used for all internal and external surfaces:

- longwave emissivity, $\lambda \rightarrow 0$ (shall approach zero) at all internal and external surfaces
- solar absorptivity, $\alpha \rightarrow 0$ (shall approach zero) at all internal and external surfaces.

If the software being tested does not allow a definition of zero for λ or for α , then set them to as small a value as ~~possible~~ the software allows.

5.4.1.9 Heat Exchange by Infiltration. For programs that do not allow for the definition of convection coefficients, the heating loads ~~are~~ shall be driven by infiltration of outdoor air through the zone as defined in this section and its subsections.

Informative Note: The configuration of the base case building is a single near-adiabatic rectangular zone where ~~energy is transferred to~~ heating load is generated in the zone air by means of regulated infiltration ~~to maintain the interior setpoint temperature.~~ The setpoint temperature of the zone and outdoor air temperatures and the amount of outdoor air infiltration drives the furnace operation. The furnace will run continuously at capacity, and this case is designed to ensure the furnace output is correctly represented in the zone energy balance.

5.4.1.9.1 Building Zone Description. See Figure 5-16 for requirements.

5.4.1.9.2 Building Envelope Thermal Properties. Material properties for the exterior wall, floor, and roof ~~are~~ shall be as listed specified in Table 5-38.

5.4.1.9.3 Infiltration

Infiltration mass flow rate = 0.2 kg/s for entire simulation period.

Informative Note: It is up to the user to determine the correct combination of volumetric flow rate (ach) and air density to generate the required mass flow rate of air through the building for the software being tested.

5.4.1.10 Mechanical System. The mechanical system ~~represents~~ shall be a simple sealed combustion, fuel-fired furnace heating system as defined in the following subsections.

5.4.1.10.1 General Information. The ~~general test conditions for the mechanical system~~ shall be modeled as follows:

- The furnace shall injects heat directly to the zone air (i.e., a 100% convective heating system).
- The zone air shall be fully mixed.
- The furnace shall draws its combustion air from outdoors.
- The furnace flue shall ~~does not~~ extract air from the zone.
- There shall be ~~is~~ no pilot light.
- There shall be ~~are~~ no air or thermal losses from the distribution ducts.
- The heat from the circulation fan energy shall go ~~goes~~ entirely to the distribution (supply) air.
- The draft fan heat shall be exhausted in the flue; none of the draft fan heat shall be introduced into the zone.

5.4.1.10.2 Thermostat Control Strategy. Control settings ~~are as follows~~ shall be:

- Heat = ON if temperature < 20°C; otherwise Heat = OFF
- Cool = OFF

5.4.1.10.2.1 There shall be no zone humidity control.

5.4.1.10.2.2 The thermostat shall sense only the zone air temperature; the thermostat itself shall not sense any radiative heat transfer exchange with the interior surfaces.

5.4.1.10.2.3 The controls for this system are ideal in that ~~the equipment is assumed to~~ shall maintain the setpoint exactly when it ~~is~~ operates ~~d~~ and is not overloaded. There are no minimum ON or OFF time duration requirements for the unit, and no hysteresis control band; i.e., there is no ON at setpoint $-x^\circ\text{C}$ or OFF at setpoint $+y^\circ\text{C}$. If the software being tested requires input for these settings, then ~~use~~ the minimum allowable values allowed by the software shall be used.

~~There is no zone humidity control.~~

~~The thermostat senses only the zone air temperature; the thermostat itself does not sense any radiative heat transfer exchange with the interior surfaces.~~

5.4.1.10.2.4 The thermostat shall be nonproportional in the sense that

Informative Note: A non-proportional thermostat operates such that when the zone air temperature drops below the thermostat heating setpoint, the heat generation rate is assumed to equal the maximum capacity of the heating equipment corresponding to environmental conditions at the time of operation. A proportional thermostat throttles the heat addition rate (or heat extraction rate) in proportion to the difference between the zone set point temperature and the actual zone temperature. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by the software being tested). A $PLF = f(PLR_f)$ curve is described in Section 5.4.1.10.4 to account for equipment cycling.

5.4.1.10.3 Full-load Heating System Performance Data. The equipment full-load capacity and full-load performance data for the natural gas furnace are shall be as follows:

- Furnace capacity = 10 kW (this capacity does not include fan heat)
- Furnace full-load efficiency = 100%

5.4.1.10.4 Part-Load Operation. The Residential furnaces shall cycle ON and OFF to meet their load at off-design conditions. The part-load ratio (PLR) is used to predict the energy use of a furnace under part-load conditions and is defined as

$$PLR_f = \frac{\text{Load Placed on Furnace}}{\text{Furnace Capacity}}$$

where *Load Placed on Furnace* is integrated over the simulation time step and *Furnace Capacity* is the capacity of the furnace to supply heat for that time step.

The part-load factor (PLF) represents the degradation in furnace efficiency due to part-load operation:

$$PLF = \frac{\text{Part - Load Efficiency}}{\text{Steady - State Efficiency}} = \frac{\eta_{partload}}{\eta}$$

For building energy simulation programs, defining the part-load performance can be defined in terms of a part-load curve, as a plot of PLF vs. PLR_f shall be permitted. The part-load curve chosen for this suite of test cases shall be as is illustrated in Figure 5-17. The equation for this curve is

$$PLF = \frac{PLR_f}{HIR(PLR_f)}$$

where

$$HIR(PLR_f) = a + b \times PLR_f + c \times PLR_f^2 + d \times PLR_f^3$$

Henderson⁹ defines the HIR coefficients for a condensing gas furnace are defined as:⁹

$$\begin{aligned} a &= 0.0080472574 \\ b &= 0.87564457 \\ c &= 0.29249943 \\ d &= -0.17624156 \end{aligned}$$

Informative Note: $HIR(PLR_f)$ is the correlation factor applied to the heat input ratio (HIR) at full load to correct for the effect of part-load performance. Note that these PLFs were evaluated for one-hour time steps and that their use with different time steps may introduce some differences.

Informative Note: For the base case (Case HE100) and Case HE110, the furnace runs continuously at full-load capacity. Therefore, part-load operation is not examined. However, if the software being tested requires input for the part-load operation, then use the above equation. For the remaining furnace test cases (HE120 through HE230), the furnace operates at part load all or most of the time.

5.4.1.10.5 Fuel Higher Heating Value (HHV). The amount of heat generated by the combustion of a unit of fuel—including the latent heat of vaporization—is known as the higher heating value (HHV). For these tests, the higher heating value (HHV) of natural gas shall be 38 MJ/m³. The HHV shall be used to calculate the rate of fuel consumption.

The fuel flow rate and HHV are reported at standard temperature and pressure (STP = 0°C and 1 atm) conditions, and, therefore, the altitude and density of air at the building site will not affect the results.

Informative Note: The amount of heat generated by the combustion of a unit of fuel—including the latent heat of vaporization—is known as the higher heating value (HHV). The fuel flow rate and HHV are reported at standard temperature and pressure (STP = 0°C and 1 atm) conditions, and therefore the altitude and density of air at the building site will not affect the results.

5.4.1.10.6 Fans. There ~~is~~ shall be no fan power and no heat generated by the fans for the base case. The circulating fan and draft fan are simulated, but their power draw ~~is set to~~ shall be zero.

- Circulating fan power draw = 0 W, runs continuously.
- Draft fan power draw = 0 W, cycles with burner operation.

5.4.2 Space-Heating Equipment Performance Analytical Verification Tests

5.4.2.1 Case HE110: Efficiency Test. ~~The objective of this test case is to test a program's ability to model heating equipment performance under controlled load and weather conditions.~~ Case HE110 ~~shall be~~ modeled exactly the same as Case HE100 except:

- Furnace full-load efficiency = 80%

Informative Note: The objective of this test case is to test a program's ability to model heating equipment performance under controlled load and weather conditions.

5.4.2.2 Case HE120: Steady Part-Load Test.

~~The objective of this test case is to test a program's ability to model heating equipment part load performance under controlled load and weather conditions in situations where the furnace will not run at full load capacity because the indoor-outdoor temperature difference has been reduced. This case is designed to ensure that the furnace part-load curves are properly implemented.~~

Case HE120 ~~shall be~~ modeled exactly the same as Case HE110, except that the ~~applicable~~ weather file ~~shall be~~ HE120W.WY2. These data are provided ~~with~~ the electronic files accompanying this standard and are described in normative Annex A1, Section A1.3.

Part-load performance ~~data are~~ shall be as ~~described~~ specified before (~~see previously in~~ Section 5.4.1.10.4).

Informative Note: The objective of this test case is to test a program's ability to model heating equipment part-load performance under controlled load and weather conditions in situations where the furnace will not run at full-load capacity, because the indoor-outdoor temperature difference has been reduced.

This case is designed to ensure that the furnace part-load curves are properly implemented.

5.4.2.3 Case HE130: No Load Test. ~~The objective of this test case is to test a program's ability to accurately respond to zero heat loads on the heating equipment. As the outdoor temperature is kept at a constant value of 20°C and the setpoint temperature is 20°C, then the heating system should never turn on.~~

Case HE130 ~~shall be~~ modeled exactly the same as Case HE110 except that the ~~applicable~~ weather file ~~is~~ shall be HE130W.WY2. These data are provided ~~with~~ the electronic files accompanying this standard and are described in normative Annex A1, Section A1.3.

Informative Note: The objective of this test case is to test a program's ability to accurately respond to zero heat loads on the heating equipment. Because the outdoor temperature is kept at a constant value of 20°C and the setpoint temperature is 20°C, then the heating system should never turn on.

5.4.2.4 Case HE140: Periodically Varying Part-Load Test. ~~The objective of this test case is to examine a program's ability to accurately respond to variations in load. In Case HE140, a weather file with a sinusoidally varying outdoor temperature is used. This case is designed to ensure that the model operates over the full range of the part-load curve. This represents a more challenging test on whether the part-load ratio is properly implemented.~~ Case HE140 ~~is~~ shall be modeled exactly the same as Case HE110 except that the ~~applicable~~ weather file ~~shall be~~ HE140W.WY2. These data are provided ~~with~~ the electronic files accompanying this standard and are described in normative Annex A1, Section A1.3.

The weather data are represented by Figure 5-18, which is a plot of the outdoor temperature varying over the range of +20°C to -20°C over a 24-hour period. The equation of the sinusoid is

$$T = 20 \times \left(\sin\left(\frac{\pi}{12} \times t \right) \right),$$

where T is the resulting outdoor dry-bulb temperature and t is the corresponding time (hour) of day.

Informative Note: The objective of this test case is to examine a program's ability to accurately respond to variations in load. In Case HE140, a weather file with

a sinusoidally varying outdoor temperature is used. This case is designed to ensure that the model operates over the full range of the part-load curve. This represents a more challenging test on whether the part-load ratio is properly implemented.

5.4.2.5 Case HE150: Circulating Fan Test. The objective of this case is to test a program's ability to model circulating fan operation. This case is designed to ensure that the fan electrical consumption is properly calculated and that the heat output of the circulating fan is correctly reflected in the zone energy balance.

Case HE150 shall be modeled exactly the same as Case HE140; except that a circulating fan shall operate as follows, runs continuously:

- Circulating fan power draw = 200 W
- Circulating fan, runs continuously
- Circulating fan flow rate = 0.355 m³/s
- Circulating fan motor shall be mounted in the airstream such that 100% of the heat from fan energy goes to the distribution (supply) air.

For calculating additional heating of the distribution air related to waste heat from the indoor air distribution fan, assume that the distribution fan motor is mounted in the airstream such that 100% of the heat from fan energy goes to the distribution (supply) air.

Informative Note: The objective of this case is to test a program's ability to model circulating fan operation. This case is designed to ensure that the fan electrical consumption is properly calculated and that the heat output of the circulating fan is correctly reflected in the zone energy balance.

5.4.2.6 Case HE160: Cycling Circulating Fan Test.

The objective of this test case is to test a program's ability to model cyclic circulation fan operation. This case is designed to ensure that the impact of fan cycling is properly considered in the calculation of circulation fan electrical consumption. Case HE160 is shall be modeled exactly the same as Case HE150; except that the circulating fan shall cycle with burner operation (i.e., burner ON → fan ON; burner OFF → fan OFF).

Informative Note: The objective of this test case is to test a program's ability to model cyclic circulation

fan operation. This case is designed to ensure that the impact of fan cycling is properly considered in the calculation of circulation fan electrical consumption.

5.4.2.7 Case HE170: Draft Fan Test. The objective of this test case is to test a program's ability to model draft fan operation. It is designed to ensure that the impact of the draft fan is properly considered in calculation of electrical consumption but not accounted for in the fuel consumption. The heat output of the draft fan should not be added to the zone energy balance. Case HE170 shall be modeled exactly the same as Case HE150; except that the draft fan electrical consumption shall be incorporated as follows. The circulating fan operates exactly as before (continuously):

- Draft fan power draw = 50 W
- Draft fan cycles with burner operation (i.e., burner ON → fan ON; burner OFF → fan OFF).
- Draft fan heat shall be exhausted in the flue; none of the draft fan heat shall be introduced into the zone.

The circulating fan operates exactly as in Case HE150 (continuously), as specified in Section 5.4.2.5.

Informative Note: The objective of this test case is to test a program's ability to model draft fan operation. It is designed to ensure that the impact of the draft fan is properly considered in calculation of electrical consumption but not accounted for in the fuel consumption. The heat output of the draft fan should not be added to the zone energy balance.

5.4.3 Space-Heating Equipment Performance Comparative Tests.

These tests shall be modeled as specified in the following subsections.

Informative Note: The objective of these cases is to test the interactions between furnace, control, and zone models. The approach taken is to use the same zone configuration as in cases HE100-HE170; except that realistic boundary conditions are incorporated.

5.4.3.1 Case HE210: Realistic Weather Data. The objective of this test case is to test a program's ability to model heating equipment part-load performance under controlled load and typical dynamic weather conditions. This case is designed to test the combined effects of circulating fan, draft fan, and realistic load profile. The output of interest is a comparison of the

~~circulation and draft fan electrical energy consumption and fuel consumption.~~ Case HE210 shall be modeled exactly the same as Case HE170; except that the weather data and circulating fan control strategy shall be ~~are~~ changed as ~~noted below.~~ specified in the following subsections.

Informative Note: The objective of this test case is to test a program's ability to model heating equipment part-load performance under controlled load and typical dynamic weather conditions. This case is designed to test the combined effects of circulating fan, draft fan, and realistic load profile. The output of interest is a comparison of the circulation and draft fan electrical energy consumption and fuel consumption.

5.4.3.1.1 Weather Data. For this test case, use ~~W~~ weather data provided in file ~~File-HE210W.WY2~~ shall be used ~~of weather data.~~ These data are provided ~~with~~ the electronic files ~~CD~~ accompanying this standard and ~~areas~~ described in normative Annex A1, Section A1.3.

5.4.3.1.2 Fans. The fans ~~are~~ shall be as follows:

- Circulating fan power draw = 200 W
- ~~Circulating fan,~~ cycles with burner operation (i.e., burner ON → fan ON, burner OFF → fan OFF)
- Draft fan operation shall be ~~is~~ the same as in case HE170 as specified in Section 5.4.2.7.

5.4.3.2 Case HE220: Setback Thermostat. ~~The objective of this test case is to test the effects of setback temperatures on furnace fuel consumption. Since the zone and building fabric have very low thermal mass, the zone air temperature should follow the setpoint schedule.~~

Case HE220 ~~is~~ shall be modeled exactly the same as Case HE210; except that the zone setpoint temperature ~~follows the relationship illustrated in Figure 5-19;~~ shall be scheduled as defined below, and illustrated in Figure 5-19.

For $6h00 \leq \text{time of day} \leq 23h00$, then

- Heat = ON if temperature < 20°C; otherwise Heat = OFF
- Cool = OFF

For $23h00 < \text{time of day} < 6h00$, then

- Heat = ON if temperature < 15°C; otherwise Heat = OFF

- Cool = OFF

Informative Note: The objective of this test case is to test the effects of setback temperatures on furnace fuel consumption. Since the zone and building fabric have very low thermal mass, the zone air temperature should follow the setpoint schedule.

5.4.3.3 Case HE230: Undersized Furnace. The objective of this test case is to test the behavior of the furnace algorithm when the system is undersized. For this purpose, the zone temperature will fluctuate throughout the simulation.

Case HE230 ~~is~~ shall be modeled exactly the same as Case HE220; except that:

- furnace capacity = 5 kW (this capacity does not include fan heat).

Furnace full-load efficiency and efficiency variation with part load shall remain as in ~~e~~Case HE220.

Informative Note: The objective of this test case is to test the behavior of the furnace algorithm when the system is undersized. For this purpose, the zone temperature will fluctuate throughout the simulation.

6. CLASS I OUTPUT REQUIREMENTS

Class I output requirements listed in Section 6 shall be applied as specified in Section 5.

4.36.1 Reporting Results

4.36.1.1 Standard Output Reports. The standard output reports included on the accompanying ~~CD~~ electronic media shall be used. Instructions regarding these reports are included in Annex A2. Information required for this report includes:

- a. software name and version number,
- b. modeling documentation using "S140outNotes.TXT" on the accompanying ~~CD~~ electronic media for:
 - Software identifying information and operating requirements
 - Modeling methods used when alternative methods are available in the software (as specified in Section 5.1.4)
 - Equivalent modeling methods used when the software does not allow direct input of specified values (as specified in Section 5.1.5)
 - Non-specified inputs (as specified in Section 5.1.6)

- Changes to source code for the purpose of running the tests, where such changes are not available in publicly released versions of the software (as specified Section 5.1.9)
 - Omitted test cases and results (as specified in Section 6.1.3)
 - Anomalous results (as specified in Section 6.1.4)
- c. results for simulated cases using the following files on the accompanying ~~CD~~ electronic media:
- Sec5-2out.XLS for the building thermal envelope and fabric load tests of Section 5.2
 - Sec5-3Aout.XLS for the space-cooling equipment performance analytical verification tests of Sections 5.3.1 and 5.3.2
 - Sec5-3Bout.XLS for the space-cooling equipment performance comparative tests of Sections 5.3.3 and 5.3.4
 - Sec5-4out.XLS for the space-heating equipment performance tests of Section 5.4
 - ~~RESULTS7-2.XLS, sheet tab 'See7-2out' for the building thermal envelope and fabric load tests of Section 7.2~~
- ~~For the specific output quantities to be included required in the results report are called out specifically for each case, as they appear in refer to the appropriate subsections of Sections 5.2, 5.3, and 5.4, and 7.2.~~

~~If a program being tested omits a test case, the modeler shall provide an explanation using the modeler report template provided in Annex A2.~~

~~4.36.1.2 Simulation Input Files.~~ All supporting data required for generating results with the tested software shall be saved, including:

- Input files
- Processed weather data
- Intermediate files containing calculations used for developing inputs
- A "Readme-software-name-yymmdd.pdf" file that briefly describes the contents of the above files according to their file type (i.e., their ".xyz" file extension).

6.1.3 Omitted Test Cases. If a program being tested omits a test case, the modeler shall provide an explanation of the omission using the modeler report template provided in Annex A2.

~~4.4.46.1.4 Discussion of Anomalous Results.~~ At the option of the report author, Explanation of anomalous test results may be explained using the

modeler report template provided in Annex A2 shall be permitted, but is not required.

6.21 Annual Outputs Requirements for Building Thermal Envelope and Fabric Load Tests of Section 5.2

Required output shall be as specified in the sections below.

6.21.1 All Non-Free-Float Cases. ~~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 Section 5.2 (Tables B1-1a and B1-1b of Annex B1 include an informational summary listing of the cases of Section 5.2). Required outputs for the non-free-float cases shall be as designated in Sections 6.2.1.1 through 6.2.1.5. are:~~

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 Section 5.2 (Tables B1-1a and B1-1b of Annex B1 include an informative summary listing of the cases of Section 5.2).

6.21.1.1 Annual heating load (MWh).

6.21.1.2 Annual sensible cooling loads (MWh).

6.21.1.3 Annual hourly integrated peak heating load (kW) with date and hour of occurrence.

6.21.1.4 Annual hourly integrated peak sensible cooling load (kW) with date and hour of occurrence.

6.21.1.5 All heating and cooling loads listed in Sections 6.2.1.1 through 6.2.1.4 shall be entered into the appropriate standard output report (~~see as specified in Annex A2~~) as positive values (≤ 0).

6.21.2 Case 600 Only

6.21.2.1 Annual incident unshaded total solar radiation (diffuse and direct) on north, east, west, south, and horizontal surfaces (kWh/m^2).

6.21.2.2 Unshaded annual transmitted solar radiation (diffuse and direct) through south windows (kWh/m^2). 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.

6.2.1.3 Case 610 Only

6.2.1.3.1 Annual transmitted solar radiation through the shaded south window with a horizontal overhang (kWh/m^2).

6.2.1.4 Case 620 Only

6.2.1.4.1 Unshaded annual transmitted solar radiation (diffuse and direct) through the west window (kWh/m^2). 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.

6.2.1.5 Case 630 Only

6.2.1.5.1 Annual transmitted solar radiation through the shaded west window with horizontal overhang and vertical fins (kWh/m^2).

6.2.1.6 All Free-Float Cases. Required outputs for the freefloat cases shall be as designated in Sections 6.2.6.1 through 6.2.6.3. *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 and for just the sun zone in Case 960). ~~Required outputs for the freefloat cases are:~~

6.2.1.6.1 Annual hourly integrated maximum zone air temperature ($^{\circ}\text{C}$) with date and hour of occurrence.

6.2.1.6.2 Annual hourly integrated minimum zone air temperature ($^{\circ}\text{C}$) with date and hour of occurrence.

6.2.1.6.3 Annual mean zone air temperature ($^{\circ}\text{C}$). *Informative Note:* For all cases where free-float-zone air temperature output is required, the free-float-zone air temperature is for the zone air only, assuming well-mixed air with no radiant effects (i.e., equivalent to what would be obtained from an aspirated temperature sensor perfectly shielded from solar and infrared radiation).

6.2.1.7 Case 900FF Only

6.2.1.7.1 Annual hourly 1°C zone air temperature bin frequencies from -20°C to 70°C , where “bin

frequency” ~~bins~~ are is the number of hours a given zone air temperature has values within given bins (1°C bin width) ~~occurs~~ during the annual simulation. Zone air temperature bins are defined by an integer value of temperature as the lower bound (inclusive) of the range, the upper bound of the range being less than the next highest integer value.

Informative Notes:

For example, the zone air temperature (T) bin defined by 20°C is $20^{\circ}\text{C} \leq T < 21^{\circ}\text{C}$; and similarly the bin defined by -2°C is $-2^{\circ}\text{C} \leq T < -1^{\circ}\text{C}$.

Output Example: Output from an annual simulation (8760 hours) might indicate 400 hours when the zone air temperature (T) is 25°C ($25^{\circ}\text{C} \leq T < 26^{\circ}\text{C}$), and 430 hours when the zone air temperature is 28°C ($28^{\circ}\text{C} \leq T < 29^{\circ}\text{C}$), with temperatures for remaining hours distributed among other bins as appropriate.

Additional information regarding this calculation is provided in informative Annex B12.

~~6.2.82~~ **Daily Hourly Output for Building Thermal Envelope and Fabric Load Tests of Section 5.2.** If the program being tested is capable of producing ~~produce~~ hourly outputs, then ~~produce~~ the following hourly values for the specified days shall be provided. To produce this output, ~~run the program for a~~ the simulation period shall be a typical normal annual run, as specified in Sections 5.1.7 and 5.1.8. ~~Do not just run~~ Running the simulation for only the required days specified in the output requirements shall be prohibited, because the results could contain temperature history errors. Required outputs ~~are~~ shall be as listed for specific cases in Table 6-1.5-39.

6.3 Output Requirements for Space-Cooling Equipment Performance Tests of Section 5.3.

Required output shall be as specified in the sections below. See Section 3 for definitions of terms used below.

6.3.1 Analytical Verification Tests of Sections 5.3.1 and 5.3.2. The outputs listed immediately below ~~are~~ shall include loads or consumptions (as appropriate) for the entire month of February (the second month in the weather data sets).

6.3.1.1 Cooling energy consumptions (kWh)

- Total consumption (compressor and fans)
- Disaggregated compressor consumption

- c. Disaggregated indoor air distribution fan consumption
- d. Disaggregated outdoor condenser fan consumption

6.3.1.2 Evaporator coil loads (kWh)

- a. Total evaporator coil load (sensible + latent)
- b. Disaggregated sensible evaporator coil load
- c. Disaggregated latent evaporator coil load

6.3.1.3 Zone cooling loads (kWh)

- a. Total cooling load (sensible + latent)
- b. Disaggregated sensible cooling load
- c. Disaggregated latent cooling load

6.3.1.4 The outputs listed immediately below ~~are to~~ shall include the mean value for the month of February and the hourly integrated maximum and minimum values for the month of February.

- a. Calculated coefficient of performance (COP) (dimensionless) [(Net refrigeration effect) / (total cooling energy consumption)]
- b. Zone dry-bulb temperature (°C)
- c. Zone humidity ratio (kg moisture/kg dry air)

6.3.2 Comparative Tests of Sections 5.3.3 and 5.3.4.

6.3.2.1 Cases CE300 – CE545 (for output period January 1 – Dec 31)

6.3.2.1.1 Annual Summations (except Case CE510). The outputs listed immediately below ~~are to~~ shall include summed loads or consumptions (as appropriate) for the full annual simulation (full year).

6.3.2.1.1.1 Cooling energy consumption (kilowatt-hours [kWh])

- a. Total consumption (compressor + outdoor condenser fan + indoor air distribution fan)
- b. Disaggregated compressor consumption
- c. Disaggregated outdoor condenser fan consumption
- d. Disaggregated indoor air distribution fan consumption

6.3.2.1.1.2 Evaporator coil loads (kWh)

- a. Total evaporator coil load (sensible + latent)
- b. Disaggregated sensible evaporator coil load
- c. Disaggregated latent evaporator coil load.

6.3.2.1.2 Annual Means (except Case CE510). The outputs listed immediately below ~~are to~~ shall include the mean value for the full annual simulation.

- a. Zone indoor dry-bulb temperature (IDB; °C)
- b. Zone humidity ratio (kg moisture/kg dry air)
- c. Zone relative humidity (%)
- d. Coefficient of performance excluding indoor fan energy consumption (COP2).

The mean value for COP2 ~~is~~ shall be calculated as

$$COP2_{mean} = \Sigma (\text{total evaporator coil load}) / [\Sigma (\text{compressor consumption}) + \Sigma (\text{outdoor fan consumption})],$$

where Σ indicates annual summation of the given value.

Informative Note: For example, if for an annual simulation

Total coil load (sensible + latent) = 28500 kWh thermal and
Combined compressor and outdoor-fan consumption = 240 kWh electric, then

$$COP2_{mean} = 28500 \text{ kWh} / 6240 \text{ kWh} = 4.567.$$

6.3.2.1.3 Annual Hourly Maximum Values Only.

The outputs listed immediately below ~~are to~~ shall include the hourly-integrated maximum values for the full annual simulation. Maximum values ~~are to~~ shall include date and hour of occurrence; if there are multiple hours of occurrence for the maximum value, ~~give~~ the time and date for the first hour of the maximum value occurrence shall be provided.

6.3.2.1.3.1 Total cooling energy consumption (compressor and both fans) (Wh)

6.3.2.1.3.2 Evaporator coil loads (Wh)

- a. Total evaporator coil load (sensible + latent)
- b. Disaggregated sensible evaporator coil load
- c. Disaggregated latent evaporator coil load.

6.3.2.1.4 Annual Maxima and Minima (Except Cases CE500-CE545). The outputs listed immediately below ~~are to~~ shall include the hourly-integrated maximum and minimum values for the full annual simulation. Maximum and minimum values ~~are to~~ shall include date and hour of occurrence. If there are multiple hours of occurrence for the

maximum and/or minimum values, ~~give~~ the time and date for the first hour of the occurrence shall be provided.

- a. Zone indoor dry-bulb temperature (IDB, °C)
- b. Zone humidity ratio (kg moisture/kg dry air)
- c. Zone relative humidity (%)
- d. Coefficient of performance excluding indoor fan energy consumption (COP2)

Informative Note: If the software being tested does not output enough significant digits, maximum and minimum values for COP2 can be generated by rounding uncertainty. If this is the case, when determining maximum and minimum COP2, it will be necessary to filter out lower part-load ratio (PLR) outputs (e.g., for PLR < 0.01).

Table 5-39 6-1 Daily Hourly Output Requirements for Building Thermal Envelope and Fabric Load Tests of Section 5.2

Case Hourly Outputs* Day

- 600 Hourly incident unshaded solar radiation (direct and diffuse) on south and west surfaces (Wh/m²) March 5
- 600 Hourly incident unshaded solar radiation (direct and diffuse) on south and west surfaces (Wh/m²) July 27
- 600 Hourly heating (+) and sensible cooling (-) loads (kWh, designate cooling with a (-) sign) ~~July 27~~ January 4
- 900 Hourly heating (+) and sensible cooling (-) loads (kWh, designate cooling with a (-) sign) January 4
- 600FF Hourly free-floating zone air temperature (°C) January 4
- 650FF Hourly free-floating zone air temperature (°C) July 27
- 900FF Hourly free-floating zone air temperature (°C) January 4
- 950FF Hourly free-floating zone air temperature (°C) July 27

*Hourly data to consist of 24 values for each day. The first hour (hour 1) is defined to run from 0000 to 0100 hours

6.3.2.2 Additional Outputs for Case CE300 Only

6.3.2.2.1 Annual Means and Maximum Values

(Weather Data Checks). The outputs listed immediately below ~~are to~~ shall include the mean value for the full annual simulation and the hourly-integrated maximum values for the full annual simulation. Maximum values ~~are to~~ shall include date and hour of occurrence. If there are multiple hours of occurrence for the maximum value, ~~give~~ the time and date for the first hour of the occurrence shall be provided.

- a. ODB (°C)
- b. Outdoor humidity ratio (kg/kg)

6.3.2.2.2 Hourly Outputs for June 28 (all 24 Hours):

- a. Compressor electric consumption (Wh)
- b. Outdoor condenser fan electric consumption (Wh)
- c. Total evaporator coil load (sensible + latent) (Wh)
- d. Sensible evaporator coil load (Wh)
- e. Latent evaporator coil load (Wh)
- f. COP2
- g. Zone humidity ratio (kg/kg)
- h. ODB (°C)
- i. Entering dry-bulb temperature (EDB), same as mixed air dry-bulb temperature (°C)
- j. Entering wet-bulb temperature (EWB), same as mixed air wet-bulb temperature (°C)
- k. Outdoor humidity ratio (kg/kg)

The hourly data are to consist of 24 values for each day. The first hour (hour 1) is defined to run from midnight (0:00) to 1 a.m. (1:00). To produce this output, ~~run the program- simulation period shall be for a normal-typical annual run, as specified in Sections 5.1.7 and 5.1.8. Do not run-Running the simulation only~~ for the required days specified in the output requirements shall be prohibited, because the results could contain temperature history errors.

6.3.2.3 Cases CE500-CE545 Annual Maxima and Minima.

The outputs listed immediately below ~~are to~~ shall include the hourly-integrated maximum and minimum values from a full annual simulation. Maximum and minimum values ~~are to~~ shall include date and hour of occurrence. If there are multiple hours of occurrence for the maximum and/or minimum values, ~~give~~ the time and date for the first hour of the occurrence shall be provided.

6.3.2.3.1 For Output Period January 1–December 31

- a. Maximum zone indoor dry-bulb temperature (IDB, °C)
- b. Maximum zone humidity ratio (kg moisture/kg dry air)
- c. Maximum COP2
- d. Minimum COP2

Informative Note: If the software being tested does not output enough significant digits, maximum and minimum values for COP2 can be generated by rounding uncertainty. If this is the case, when determining maximum and minimum COP2, it will be necessary to filter out lower part-load ratio (PLR) outputs (e.g., for PLR < 0.01).

6.3.2.3.2 For Output Period April 1–December 31

- Minimum zone indoor dry-bulb temperature (IDB, °C)
- Minimum zone humidity ratio (kg moisture/kg dry air)
- Maximum zone relative humidity (%)
- Minimum zone relative humidity (%)

~~Extract~~ This output shall be extracted from a normal typical annual simulation run, as specified in Sections 5.1.7 and 5.1.8. ~~Do not do~~ Running an additional simulation beginning on April 1 shall be prohibited, because the above results could contain temperature history errors. *Informative Note:* These four values are selected after the first three months of simulation to avoid differences in results that could be caused by differences in zone initialization techniques.

6.3.2.4 PLR Sensitivity, Cases CE500 and CE510 Only (for Output Period May 1 – September 30).

~~For a sensitivity test of performance as a function of PLR, include~~ For cases CE500 and CE510, only the following outputs for the period of May 1 through September 30 shall be provided. ~~Extract~~ This output shall be extracted from a normal typical annual simulation run, as specified in Sections 5.1.7 and 5.1.8. ~~Do not run~~ Running only the required months specified in the output requirements is prohibited, because the results could contain temperature history errors. *Informative Note:* This output provides a sensitivity test of performance as a function of PLR.

6.3.2.4.1 Summed Values

- Total cooling energy consumption (compressor + outdoor condenser fan + indoor air distribution fan, kWh)
- Compressor electric consumption (kWh)
- Outdoor condenser fan electric consumption (kWh)
- Indoor air distribution fan electric consumption (kWh)
- Total evaporator coil load (sensible + latent), (kWh)
- Sensible evaporator coil load (kWh)
- Latent evaporator coil load (kWh)

6.3.2.4.2 Mean Values

- $COP2 = \Sigma (\text{total coil load}) / [\Sigma (\text{compressor energy}) + \Sigma (\text{outdoor fan energy})]$, for May through September 30
- Zone IDB (°C)
- Zone humidity ratio (kg/kg)

- Zone relative humidity (%)

6.3.2.5 ODB Sensitivity, Cases CE500 and CE530 Only, Average Daily Outputs for April 30 and June 25 Only.

For a sensitivity test of performance as a function of ODB, include The following daily average per hour outputs (consumptions and coil loads are full-day sums divided by 24 [hours]) for April 30 and June 25 (0:00–24:00) shall be provided:

- Total cooling energy consumption (compressor + outdoor condenser fan + indoor air distribution fan, Wh)
- Compressor electric consumption (Wh)
- Outdoor condenser fan electric consumption (Wh)
- Indoor air distribution fan electric consumption (Wh)
- Total evaporator coil load (sensible + latent), (Wh)
- Sensible evaporator coil load (Wh)
- Latent evaporator coil load (Wh)
- $COP2 = \Sigma (\text{total coil load}) / [\Sigma (\text{compressor energy}) + \Sigma (\text{outdoor fan energy})]$, for the given day
- Zone humidity ratio (kg/kg)
- ODB (°C)
- EDB (°C)

Informative Note: This output provides a sensitivity test of performance as a function of ODB.

6.4 Output Requirements for Space-Heating Equipment Performance Tests of Section 5.4. All these The values listed below shall be provided, and entered into the appropriate standard output report; see Sec5-4out.xls included with the accompanying electronic media as specified in (see Annex A2).

The outputs listed immediately below shall include cumulative consumptions or average loads, as specified, (as appropriate) for the three-month simulation period: January 1 through March 31. Sections 6.4.1–6.4.3 detail specify the required outputs for each test case.

6.4.1 All cases HE100–HE170, HE210–HE230

6.4.1.1 Cumulative (Total) Energy Delivered to the Space (GJ). In Sec5-4out.xls, this is the Total Furnace Load, which refers to the load at the furnace coil.

6.4.1.2 Cumulative (Total) Energy Delivered to the Furnace (GJ). In Sec5-4out.xls, this is the Total Furnace Input, which refers to the combustion energy of the fuel consumed by the furnace.

6.4.1.3 Average Rate of Fuel Consumption (m³/s).

~~In Sec5-4out.xls, this is the Fuel Consumption,~~ which corresponds to the ratio of the Total Furnace Input (GJ, see Section 6.4.1.2) to the fuel HHV (38 MJ/m³, see Section 5.4.1.10.5) to the time of the simulation (3 months = 7.776 × 10⁶ s) as shown in the following equation:

$$\text{Fuel Consumption} = \frac{\text{Furnace Input}}{\text{HHV} \times 7.776 \times 10^6} \times 1000$$

6.4.2 Cases with Fan: HE150-HE170 and HE210-HE230

6.4.2.1 Cumulative Fan Energy (kWh). Electricity consumed by the draft fan and the circulating fan.

6.4.3 Cases with More Complex Controls: HE210-HE230

6.4.3.1 Mean Zone Temperature (°C)

6.4.3.2 Maximum Zone Temperature (°C)

6.4.3.3 Minimum Zone Temperature (°C)

7. CLASS II TEST PROCEDURES

Class II test procedures shall be applied as specified in Section 7. **Informative Note:** Class II test procedures may be used for all types of building load calculation methods, regardless of time-step granularity. Informative Annex B22 provides an example procedure for developing acceptance-range criteria for Section 7 test cases.

7.1 Modeling Approach. This modeling approach shall apply to all the test cases presented in Section 7.2.

7.1.1 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.* ~~Do not use 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 described in normative Annex A1, Section A1.5.

7.1.2 Geometry Convention. If the program being tested includes the thickness of walls in a three-dimensional 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. ~~Make the~~ These thicknesses shall extend exterior to the currently defined internal volume.

7.1.3 Nonapplicable Inputs. In some instances the specification will include input values that do not apply to the input structure of the program being tested. When this occurs, disregard the non-applicable inputs and continue. **Informative Note:** ~~Such Selected~~ inputs are included in the test specification for those programs that may need them.

7.1.4 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. ~~For example, if software gives a choice of methods for modeling windows, the same window modeling method shall be used for all cases. Document the~~ The option used shall be documented in the Standard Output Report (see as specified in normative Annex A2).

Informative Note: For example, if the software being tested gives a choice of methods for modeling windows, the same window modeling method is to be applied for all cases.

7.1.5 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 ~~should~~ shall develop equivalent inputs that match the intent of the test specification as nearly as the software being tested allows. Such equivalent inputs ~~are to~~ 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 (normative Annex A2).

7.1.6 Simulation Initialization and Preconditioning. If the program being tested allows, ~~begin~~ the simulation initialization process shall begin with zone air conditions that equal the ~~outdoor~~ outside air conditions. If the program being tested allows for preconditioning (iterative simulation of an initial time period until temperatures or fluxes, or both, stabilize at initial values), ~~use that~~ capability shall be used.

7.1.7 Simulation Duration Results for the tests of Section 7.2 shall ~~are to~~ be taken either from a full annual simulation or from a seasonal simulation(s), as allowed by the program being tested.

7.1.8 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 just 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 Annex A2, that the implications of the changes are clear.

7.1.9 Example Acceptance-Range Criteria. ~~For certifying or accrediting agencies that may wish to consider adopting acceptance ranges, example criteria are~~ Use of informative example acceptance-range criteria provided in informative Annex B22 shall be permitted, but is not mandatory. Where application of the criteria leads to identification of a disagreement(s) result that requires correction, that a software developer may wish to correct, the rules of Section 4.4.3-7.1.8 for modifying simulation programs or inputs shall be applied.

Informative Note: Example acceptance range criteria are provided for certifying or accrediting agencies that may wish to consider adopting acceptance ranges.

7.2 Input Specifications. The test cases shall be modeled as specified in this section.

Informative Note: The test cases are described in a manner that allows many different residential modeling tools, representing different degrees of modeling complexity, to be tested. Within this structure, figures and tables are grouped as summary data and supplemental data. The summary data, which are based on the supplemental data, are figures and tables that contain information that should cover most of the input requirements for most users. The supplemental tables contain more detailed information that was ~~required~~ applied for generating a consistent set of inputs to the programs used to

generate example results provided in informative Annex B20. Such data include: material properties for modeling thermal mass and modeling the attic as a separate zone, interior solar distribution fractions, combined convective and radiative surface coefficients, hourly internal gains schedules, and detailed window optical properties. Use the supplemental data as needed, according to the inputs allowed by the tool being tested.

~~Apply the modeling rules of Section 7.1 for all test cases.~~

Informative Note: Abbreviations used in the tables, figures, and text, are defined in the acronyms and abbreviations of Section 3.

7.2.1 The Base Case Building (Case L100A). Begin with Case L100A. Case L100A shall be modeled as detailed in this section and its subsections.

Informative Note: The bulk of the work for implementing the Section 7.2 tests is assembling an accurate base building model. It is recommended that base building inputs be double-checked and results disagreements be diagnosed before going on to the other cases. Informative Annex B20 includes example simulation results for the test procedures of Section 7.

7.2.1.1 Weather Data. This case requires the use of both the Colorad.TMY and Lasvega.TMY weather data provided on the electronic media accompanying this standard, as ~~described~~ specified in normative Annex A1, Section A1.4. Colorad.TMY (a clear, cold climate) shall be used for developing heating loads, and Lasvega.TMY (a hot, dry climate) shall be used for developing cooling loads. If the program being tested uses a different representation of weather, such as degree days, bin method, ~~etc.~~ or other representation, then the above weather data shall be processed with the tested program's weather data processor so that the tested program's output will be based on the above data.

Informative Note: All of the Section 7 tests use the same weather data, except the following cases do not require the use of the Lasvega.TMY data: L302A, L304A, L322A, L324A, P100A, P105A, P110A, P140A and P150A.

7.2.1.1.1 Ground Reflectance. The solar reflectance of the site ground surface = 0.2.

7.2.1.2 Output Requirements. Case L100A requires the following:

- a. general reporting requirements of Section 8.1
- b. annual or seasonal heating load and sensible cooling load output as ~~described~~ specified in Section 8.2.14. **Informative Note:** All of the Tier-1 tests (defined in Sections 7.2.1 and 7.2.2) have the same output requirements, except for ~~e~~ Cases L302A, L304A, L322A, and L324A.

7.2.1.3 Building Geometry and Material Properties. The base building plan shall be a 1,539 ft² floor area, single-story house with one conditioned zone (the main floor), an unconditioned attic, and a raised floor exposed to air. The building model shall apply information in the following figures and tables, as required by the program being tested: ~~contain information that is applicable to most users.~~

- Figure 7-1 Base Building Axonometric
- Figure 7-2 Floor Plan - Case L100A
- Figure 7-3 East Side Elevation - Case L100A
- Figure 7-4 Exterior Wall Plan Section - Case L100A
- Figure 7-5 Raised Floor Exposed to Air, Section – Case L100A
- Figure 7-6 Ceiling/Attic/Roof Section - Case L100A
- Figure 7-7 Interior Wall Plan Section - Case L100A
- Figure 7-8 Window Detail, Vertical Slider (NFRC AA) with 2-3/4" Wide Frame - Case L100A
- Table 7-1 Building Thermal Summary - Case L100A
- Table 7-2 Other Building Details - Case L100A.

For models requiring Relevant supplementary tables that include more detailed information, are the supplementary information in the following tables shall be applied, as required by the program being tested:

- Table 7-3 Component Surface Areas and Solar Fractions - Case L100A
- Table 7-4 Material Descriptions, Exterior Wall, Door and Window - Case L100A
- Table 7-5 Material Descriptions, Raised Floor Exposed to Air - Case L100A
- Table 7-6 Material Descriptions, Ceiling, Attic and Roof - Case L100A
- Table 7-7 Material Descriptions, Ceiling/Attic/Roof, Attic as Material Layer - Case L100A (for calculating equivalent ceiling/attic/roof composite R-value.)
- Table 7-8 Material Descriptions, Interior Wall – Case L100A
- Table 7-9 Internal Loads Schedule - Case L100A
- Table 7-10 Window Summary, Single Pane Aluminum Frame with Thermal Break - Case L100A

Table 7-11 Glazing Summary, Single Pane Center of Glass Values - Case L100A

Table 7-12 Optical Properties as a Function of Incidence Angle for Single-Pane Glazing - Case L100A.

Other details not described in these figures and tables shall be modeled as specified ~~are discussed~~ topically in the following subsections.

7.2.1.4 Attic. ~~For Many residential energy analysis tools that input an attic by specifying it within a menu of roof types; and then specifying the insulation-only R-value corresponding to the insulation installed on the attic floor. If this is the ease for the software being tested, then the information provided in Figure 7-6 shall be used will be sufficient.~~

For programs that apply more detailed modeling, the attic shall be modeled as a separate zone using information provided in Table 7-6, or as a layer of thermal resistance between ceiling and roof materials using information provided in Table 7-7.

As with other components, except where explicitly varied by the test specification, the attic shall be modeled consistently for all test cases such that the modeling rules of Section 7.1 are applied.

For programs such as those used for developing the example results, more detailed information is required. The detailed information for modeling an attic as a separate zone is supplied in Table 7-6. Table 7-7 gives similar information as Table 7-6, except in Table 7-7 the attic space is modeled as a layer of thermal resistance between ceiling and roof materials.

Informative Note: Table 7-7 is included to document the calculation of ceiling/attic/roof composite air-air R-value noted in the building thermal summary of Table 7-1. In Table 7-7, the equivalent resistance for the attic is based on values from the Cooling and Heating Load Calculation Manual;^{B-3} typical ventilation by natural effects and roof solar absorptance of 0.6 were assumed. The equivalence of the one-zone model versus the two-zone base case was verified with sensitivity tests using BLAST and SERIRES/SUNCODE.^{B-4, B-5}

As with other components, except where explicitly varied by the test specification, the attic must be modeled consistently for all test cases such that the modeling rules of Section 7.1 are applied.

7.2.1.5 Raised Floor Exposed to Air. ~~The floor shall be modeled as follows: To simulate a raised floor exposed to air, the test cases require the following assumptions:~~

- ~~the air temperature below the raised floor is assumed to~~ shall be equal to the outdoor-outside air temperature
- the underside of the conditioned-zone floor ~~shall have~~ has an exterior film coefficient of 2.2 Btu/(h·ft²·°F), consistent with a "rough" surface texture and zero windspeed; if the program being tested ~~cannot is not capable of setting~~ the exterior surface coefficient to a fixed value, then the allow exterior surface coefficient shall be permitted to vary with wind speed.
- the conditioned-zone floor exterior surface (surface facing the raised floor) shall receive no solar radiation.

Informative Note: ~~The assumption of that~~ The assumption of that the air temperature below the raised floor ~~being is~~ is equal to ambient temperature may be approximated either by modeling a building that is hovering 10 feet or more above the ground (a raised floor on stilts for example), or by modeling a very highly ventilated crawl space. The zero solar radiation-to-exterior-floor assumption can be modeled by assigning the highest solar reflectance allowed by the software being tested to the underside of the floor and/or by defining shading planes where walls would be if the raised floor were modeled as a crawl space.

7.2.1.6 Interior Walls. ~~The thermal mass of the interior walls within the conditioned zone shall be modeled, if the program being tested has that capability, have been included for the purpose of modeling the effect of their mass.~~ ***Informative Note:*** They interior walls are not intended to divide the conditioned zone into separately controlled zones.

7.2.1.7 Infiltration. ~~The infiltration rates are specified in Table 7-2 shall be used. The Colorad.TMY and Lasvega.TMY climate sites are at 6145 ft and 2178 ft altitude, respectively, so the density of air is less than that at sea level for both locations. If the program being tested does not use barometric pressure from the weather data, or otherwise does not automatically correct for the change in air density caused by altitude, then adjust the specified infiltration rates shall be adjusted (to yield sea-level mass flow rates equivalent to what would those occurring at the specified altitude,)~~ as

shown in Table 7-2. ~~The listed infiltration rate is shall be independent of wind speed, indoor/outdoor temperature difference, etc or other variables. Only use~~ The attic infiltration rate shall be used if the software being tested allows that input.

Informative Note: Attic infiltration is based on the *Cooling and Heating Load Calculation Manual*^{B-3} for typical ventilation by natural effects.

Informative Note: The density of air is less than that at sea level for both climate locations. The calculation technique used for developing altitude effects on infiltration is included in informative Annex B3.

7.2.1.8 Internal Loads. ~~These are non-HVAC related internally generated loads from equipment, lights, people, animals, etc. Use~~ The hourly internal sensible and latent load schedules for the conditioned zone specified in Table 7-9 shall be used. This schedule disaggregates sensible and latent loads. There ~~shall be~~ are no internal loads in the attic. If the software being tested does not analyze latent loads, then ~~leave them out and use only the sensible portion of the internal loads shall be modeled and the latent loads shall be ignored.~~

Aggregate sensible loads ~~are shall be~~ shall be 70% radiative and 30% convective.

Informative Note: Internal loads are non-HVAC related internally generated loads from equipment, lights, people, animals, etc. Because internal loads are given only for their effect on heating and cooling loads, the equipment fuel type and efficiency associated with generating these loads do not matter.

7.2.1.9 Combined Radiative and Convective Surface Coefficients. If the program being tested does not allow variation of combined surface coefficients, or if it automatically calculates interior and exterior surface convection and radiation, then skip the instructions in this section may be disregarded and proceed to Section 7.2.1.10. Combined surface coefficients are denoted in various section drawings throughout Section 7 as "Interior Film" and "Exterior Film" (e.g., see Figures 7-4 through 7-7). If the program being tested uses combined surface coefficient inputs, then ~~use the~~ information given in Table 7-2 shall be used.

Informative Note: This information is also included with the detailed material descriptions of Tables 7-4 through 7-8, 7-10, and 7-11. Because the heating season average windspeed for Colorad.TMY weather

data is nearly equal to the cooling season average windspeed for Lasvega.TMY data, the listed exterior surface coefficients apply to both climates. See informative Annex B4 and informative Annex B5 for more information on surface coefficients.

Informative Note: Combined surface coefficients are denoted in various section drawings throughout Section 7.2 as "Interior Film" and "Exterior Film" (e.g., see Figures 7-4 through 7-7).

7.2.1.10 Opaque Surface Radiative Properties.

Surface radiative properties are given in Table 7-2 shall be used. These properties shall apply to all opaque exterior and interior building surfaces.

Informative Note: The radiative properties in Table 7-2; they are roughly equivalent to medium color paint or a light color roof.

7.2.1.11 Windows. A great deal of information about the window properties has been provided so that equivalent input for windows is possible for many programs. Use only the information that is relevant to the program being tested. The basic properties of the single-pane window, including shading coefficient, solar heat gain coefficient, and thermal resistance, are provided in Table 7-1 shall be used, as required by the software being tested. Additional information is included in Figure 7-8, Table 7-4, and Tables 7-10 through 7-12 shall be used as required by the software being tested. This information is drawn primarily from the WINDOW 4.1 software^{B-6} for developing detailed glazing properties. For programs that need transmittance or reflectance at other angles of incidence, interpolation between the values of Table 7-12 using the cosine of the incidence angle as the basis of interpolation shall be permitted. Where other unspecified data equivalent inputs are needed, then values that are consistent with those quoted specified shall be applied must be calculated according to the instructions of Section 7.1.5 (Equivalent Modeling Methods).

For the base case, it shall be permitted to model the total glass and frame areas for each wall may be combined into as a single large glass area for that each wall, and similarly to model the total window frame area for each wall as a single large window frame area for each wall. For later cases where shading is used, the specific window geometry must shall be modeled as closely as the software being tested allows. possible.

Informative Note: Extensive information about the window properties has been provided so that

equivalent input for windows is possible for many programs. Only the information that is relevant to the program being tested is intended to be applied. Window information is drawn primarily from the WINDOW 4.1 software^{B-6} for developing detailed glazing properties.

7.2.1.12 Interior Solar Distribution. If the program being tested does not allow for variations of interior solar distribution, then skip this section may be disregarded and proceed to Section 7.2.1.13. Interior solar distribution is the fraction of transmitted solar radiation incident on specific surfaces in a room. If the program being tested does not calculate this effect internally, then use the interior solar fractions from Table 7-3 shall be used. **Informative Note:** Interior solar distribution is the fraction of transmitted solar radiation incident on specific surfaces in a room. The calculation of transmitted solar radiation reflected back out through windows (cavity albedo) is presented in informative Annex B7, Section B7.2.

7.2.1.13 Mechanical System. This mechanical system shall only applies only to the conditioned zone; it shall not does not apply to the unconditioned attic. The intent of the mechanical system is to produce only pure heating load and sensible cooling load outputs. That is, a All equipment shall be is 100% efficient with no duct losses and no capacity limitations. The mechanical system shall be modeled with the following features as noted below and in Sections 7.2.1.14 and 7.2.1.15:

- 100% convective air system
- the thermostat senses only the air temperature
- nonproportional type thermostat (see as specified in Section 7.2.1.14)
- no latent heat extraction.

Informative Note: The intent of the mechanical system is to produce only pure heating load and sensible cooling load outputs.

7.2.1.14 Thermostat Control Strategies.

7.2.1.14.1 The Annual thermostat control settings are shown below shall be used. Heating and cooling seasons shall be for either the entire year or some other reasonable length duration as designated by the program being tested. Two separate simulations are required, one for calculating heating loads and the other for calculating cooling loads.

For Colorad.TMY weather data (heating only)

- HEAT = ON IF TEMP < 68°F; COOL = OFF.

For Lasvega.TMY weather data (cooling only):

- COOL = ON IF TEMP > 78°F; HEAT = OFF.

Informative Note: "TEMP" refers to conditioned zone air temperature.

7.2.1.14.2 The thermostat is nonproportional, in the sense

Informative Note: A non-proportional thermostat operates such that when the conditioned-zone air temperature exceeds the thermostat cooling set-point, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment.

Likewise, when the conditioned-zone air temperature drops below the thermostat heating set-point, the heat addition rate equals the maximum capacity of the heating equipment. A proportional thermostat throttles the heat addition rate (or extraction rate) in proportion to the difference between the zone setpoint temperature and the actual zone temperature. If the program being tested requires the use of a proportional thermostat, a proportional thermostat model can be made to approximate a non-proportional thermostat model by setting a very small throttling range (the minimum allowed by the program being tested).

7.2.1.15 Equipment Characteristics. The following inputs shall be used:

- HEATING CAPACITY = 3.413 million Btu/h (effectively infinite).
- EFFECTIVE EFFICIENCY = 100%.
- COOLING CAPACITY = 3.413 million Btu/h (effectively infinite).
- EFFECTIVE EFFICIENCY = 100%.
- Sensible Cooling only; no latent heat load calculation.
- WASTE HEAT FROM FAN = 0.

The 3.413 million Btu/h requirement comes from the I-P units equivalent of 1 MW. If the software being tested does not allow the specified capacity, then use the largest system that the software being tested will allow shall be used.

Equipment efficiency shall always be modeled as 100%, independent of part loading, indoor dry-bulb temperature and humidity ratio, outdoor dry-bulb

temperature and humidity ratio, and/or other conditions.

Informative Note: The 3.413 million Btu/h requirement comes from the I-P units equivalent of 1 MW.

7.2.2 The Tier 1 Test Cases. The Tier 1 test cases shall be modeled exactly as the designated base case model with revisions as specified in this section. The designated base case model shall be This section describes revisions to the base building required to model the other Tier 1 cases. In some instances the base building for a case is not Case L100A, except for the following cases; for which L100A is not the basis are:

Case Basis for that Case

L155A	L150A
L202A	L200A
L304A	L302A
L324A	L322A

Informative Note: For convenience, relevant portions of the appropriate base building tables and figures have been reprinted, with changes highlighted in bold font. Where applicable, summary figures and tables are listed first, with supplementary detailed tables listed afterward.

7.2.2.1 Case L110A: High Infiltration (1.5 ACH).

Case L110A shall be modeled exactly as Case L100A, except that infiltration for the conditioned zone shall be changed as shown in Table 7-13. The Attic infiltration rate shall remain unchanged.

The Colorad.TMY and Lasvega.TMY climate sites are at 6145 ft and 2178 ft altitude, respectively, so the density of air is less than that at sea level for both locations. If the program being tested does not use barometric pressure from the weather data, or otherwise does not automatically corrects for the change in air density caused by altitude, then adjust the specified infiltration rates shall be adjusted (to yield sea level mass flow rates equivalent to what would those occurring at the specified altitude) as shown in Table 7-13. The listed infiltration rate shall be independent of wind speed, indoor/outdoor temperature difference, etc and other variables.

Informative Note: The density of air is less than that at sea level for both climate locations. The calculation technique used for developing altitude effects on infiltration is included in informative Annex B3.

7.2.2.2 Case L120A: Well-Insulated Walls and Roof. Case L120A ~~is shall be modeled exactly as Case L100A, except~~ that an extra layer of R-38 batt insulation ~~shall be~~ added to the ceiling, and exterior walls ~~shall~~ have 2x6 24" O.C. framing and R-18 batt insulation with R-7.2 polyisocyanurate exterior board insulation. Changes to Case L100A for developing Case L200A shall apply bold-highlighted information in The the following figures and and be consistent with bold highlighted information in the following table, as required by the program being tested. highlight information that is expected to be useful to most users.

- Figure 7-9 Exterior Wall Plan Section - Case L120A
- Figure 7-10 Ceiling Section - Case L120A
- Table 7-14 Building Thermal Summary - Case L120A.

Models requiring Relevant supplementary tables that include more detailed information are shall apply the bold-highlighted information in the following supplementary tables, as required by the program being tested:

- Table 7-15 Component Surface Areas and Solar Fractions - Case L120A
- Table 7-16 Material Descriptions, Exterior Wall – Case L120A
- Table 7-17 Material Descriptions, Ceiling - Case L120A
- Table 7-18 Material Descriptions for Attic as Material Layer - Case L120A. *Informative Note:* ~~(~~ For calculation of equivalent ceiling/attic/roof composite R-value in Table 7-18, see the discussion of the base building attic in the informative note at the end of Section 7.2.1.4).

Informative Note: Information in the tables and figures not highlighted by bold font text is copied from Case L100A.

7.2.2.3 Case L130A: Double-Pane Low-Emissivity Window with Wood Frame. Case L130A ~~shall be~~ modeled exactly as Case L100A, except that all single-pane windows ~~shall be~~ replaced with double-pane low-emissivity (low-e) windows with wood frames and insulated spacers. The basic properties of the window, including shading coefficient, solar heat gain coefficient and thermal resistance, ~~are provided~~ (indicated by bold highlighting in the following table) shall be used, as required by the program being tested:

- Table 7-19 Building Thermal Summary - Case L130A. Window and frame geometry remain as for Case L100A.

Models requiring Relevant supplementary tables that include more detailed information are shall apply the supplementary information in the following tables, as required by the program being tested:

- Table 7-20 Window Summary (Double-Pane, Low-E, Argon Fill, Wood Frame, Insulated Spacer) -Case L130A
- Table 7-21 Glazing Summary, Low-E Glazing System with Argon Gas Fill (Center of Glass Values) - Case L130A
- Table 7-22 Optical Properties as a Function of Incidence Angle for Low-Emissivity Double-Pane Glazing – Case L130A
- Table 7-23 Component Solar Fractions - Case L130A.

Informative Note: Because of the large number of changes to the glazing for this case, Tables 7-20 through 7-22 have **not** been bold highlighted to show where changes occurred. Information in Tables 7-19 and 7-23 not highlighted by bold font text is copied from Case L100A.

Informative Note: ~~Use~~ Only the information that is relevant to the program being tested is intended to be applied. Window properties are drawn from the WINDOW 4.1^{B-6} software for window thermal analysis.

7.2.2.3.1 For programs that need transmittance or reflectance at other angles of incidence, ~~interpolate~~ interpolation between the values of Table 7-22 using the cosine of the incidence angle as the basis of interpolation shall be permitted.

7.2.2.3.2 Where ~~other~~ unspecified data equivalent inputs are needed, ~~then~~ values that are consistent with those ~~quoted~~ specified ~~must be calculated~~ shall be applied according to the instructions of Section 7.1.5 (Equivalent Modeling Methods).

7.2.2.3.3 For programs requiring the input of internal solar distribution, the values with bold highlighting in Table 7-23 shall be used, as required by the software being tested.

Informative Note: There is a slight change in interior surface solar distribution caused by reduced solar lost

(cavity albedo), for those tools that can vary this input, values are included in Table 7-23.

Because of the large number of changes to the glazing for this case, Tables 7-20 through 7-22 have not been highlighted with bold font to show where changes occurred.

7.2.2.4 Case L140A: Zero Window Area. Case L140A is shall be modeled exactly as Case L100A, except that the gross window area (glass and frame) shall be replaced with the Case L100A solid exterior wall materials of Figure 7-4 (see Case L100A) and Table 7-4 (see Case L100A), as specified in Section 7.2.1.3, is the corresponding supplementary table. Changes to the Case L100A model area and thermal parameters for developing Case L140A shall be consistent with the bold-highlighted information in the following tables; summarize the changes:

- Table 7-24 Building Thermal Summary - Case L140A
- Table 7-25 Component Surface Areas - Case L140A.

Informative Note: Information in the tables not highlighted by bold font text is copied from Case L100A.

7.2.2.5 Case L150A: South-Oriented Windows. This case is shall be modeled exactly as Case L100A, except that all windows shall be have been moved to the South wall. These changes are summarized in the following: Changes to Case L100A for developing Case L150A shall apply the following figures and shall be consistent with bold-highlighted information in the following tables, as required by the program being tested:

- Figure 7-11 Exterior Wall and South Window Locations - Case L150A
- Figure 7-12 South Wall Elevation - Case L150A
- Table 7-26 Building Thermal Summary - Case L150A
- Table 7-27 Surface Component Areas and Solar Fractions - Case L150A.

Informative Note: Information in the tables not highlighted by bold font text is copied from Case L100A. The figures contain only new information; changes are not bold highlighted in the figures.

7.2.2.5.1 Interior Solar Distribution. If the program being tested does not allow for variations of interior solar distribution, then skip this section, may be disregarded. Interior solar distribution is the fraction of transmitted solar radiation incident on specific surfaces in a room. If the program being tested does not calculate this effect internally, then use the interior solar fractions from Table 7-27 shall be used. **Informative Note:** Interior solar distribution is the fraction of transmitted solar radiation incident on specific surfaces in a room. The calculation of transmitted solar radiation reflected back out through windows (cavity albedo) is presented in informative Annex B7, Section B7.2.

7.2.2.6 Case L155A: South-Oriented Windows with Overhang. Case L155A is shall be modeled exactly as Case L150A, except that an opaque overhang shall be included at the top of the south exterior wall. The overhang shall extend outward from this wall 2.5 ft, as shown in Figure 7-13. The overhang shall traverse the entire length of the south wall.

Depending on the If the input capabilities of the software being tested, it may not be possible do not allow to model the exact geometry of the windows and overhang to be modeled as shown in Figure 7-13, then. If this is the case, a simplified model of the south wall may be used, such as the conceptual description shown in Figure 7-14 shall be permitted.

Informative Note: In Informative Figure 7-14, shows one possible simplified model. Glass and horizontally oriented framing directly above and below the glass are aggregated into long units, with all elements located properly in the vertical direction to obtain the nearly equivalent shading of Figure 7-13. Proper dimensions for this example are obtained using Figure 7-8 (Case L100A), Figure 7-13 and Table 7-27 (Case L150A). The vertically oriented framing is similarly aggregated in a separate area so that equivalent shading will also result. While the overhang is not shown in Figure 7-14, it must be is included as shown in Figure 7-13.

~~Note that, as explained in Section 7.1, this test requires use of consistent modeling methods for the test cases.~~

Figure 7-14 Example model of south wall for simulating south overhang effect in Case L155A.

Informative Note: Figure 7-14 is informative material.

7.2.2.7 Case L160A: East- and West-Oriented Windows. This case ~~is shall be modeled exactly as Case L100A, except~~ that all windows ~~have been~~ shall be moved to the east and west walls. ~~These changes are summarized in the following:~~ Changes to Case L100A for developing Case L150A shall apply the following figures and shall be consistent with bold-highlighted information in the following tables, as required by the program being tested:

- Figure 7-15. East and West Window Locations, Plan - Case L160A
- Figure 7-16. East/West Wall Elevation - Case L160A
- Table 7-28. Building Thermal Summary - Case L160A
- Table 7-29. Surface Component Areas and Solar Fractions - Case L160A.

Informative Note: Information in the tables not highlighted by bold font text is copied from Case L100A. The figures contain only new information; changes are not bold highlighted in the figures.

7.2.2.8 Case L170A: No Internal Loads. Case L170A ~~is shall be modeled exactly as Case L100, except~~ the internal sensible and latent loads in the conditioned zone ~~shall be~~ set to zero for all hours of the entire year.

7.2.2.9 Case L200A: Energy Inefficient. This case ~~is shall be modeled exactly as Case L100A, except~~ for the following changes:

- Infiltration for the conditioned zone ~~shall be~~ is 1.5 ach, as in Case L110A
- Exterior wall fiberglass insulation ~~shall be~~ is replaced with an air gap
- Floor fiberglass insulation ~~shall be~~ is eliminated
- Ceiling fiberglass insulation ~~shall be~~ is reduced from 5.5 to 3.5 in.

Changes to Case L100A for developing Case L200A shall apply bold highlighted information in

~~The the following figures and tables, as required by the program being tested; highlight information that is expected to be useful to most users.~~

- Figure 7-17 Exterior Wall Plan Section - Case L200A
- Figure 7-18 Raised Floor Exposed to Air, Section - Case L200A
- Figure 7-19 Ceiling Section - Case L200A
- ~~Table 7-13 Conditioned Zone Infiltration for Case L110A (see Case L110A)~~
- Table 7-30 Building Thermal Summary - Case L200A.

Changes shall also apply information from the following table, as required by the program being tested:

- Table 7-13 Conditioned Zone Infiltration for Case L110A (as specified in Section 7.2.2.1).

~~Models requiring~~ Relevant supplementary tables that include more detailed information are shall apply the bold-highlighted information in the following supplementary tables, as required by the program being tested:

- Table 7-31 Material Descriptions, Exterior Wall - Case L200A
- Table 7-32 Material Descriptions, Raised Floor Exposed to Air - Case L200A
- Table 7-33 Material Descriptions, Ceiling - Case L200A
- Table 7-34 Material Descriptions, Ceiling with Attic as Material Layer - Case L200A. Informative Note: ~~(F)~~ For calculation of equivalent ceiling/attic/roof composite R-value, see discussion of the base building attic in Section 7.2.1.4).

Informative Note: Information in the tables and figures not highlighted by bold font text is copied from Case L100A. Table 7-13 contains only new information relevant to infiltration; changes are not bold highlighted.

7.2.2.10 Case L202A: Low Exterior Solar Absorptance Associated with Light Exterior Surface Color. This case ~~shall be~~ is modeled exactly as Case L200A, except that exterior shortwave (visible and UV) absorptance (α_{ext}) ~~shall be~~ is 0.2 for the following opaque exterior surfaces exposed to solar radiation:

- Exterior walls

- Roof
- End gables
- Doors.

Window frames shall remain at $\alpha_{ext} = 0.6$.

7.2.2.11 Slab-on-Grade Series (Cases L302A and L304A). The Slab-on-Grade test cases shall be modeled as specified in this section. Case L100A shall be the base case for Case L302A. Case L302A shall be the base case for Case L304A.

Informative Note: Cases L302A and L304A are designed to compare the results of residential modeling software to example results of informative Annex B20 using the steady-state ASHRAE perimeter method for modeling slab-on-grade heat loss.^{B-7, B-8} This is a simplified method for ground-coupling analysis. For Cases L302A and L304A, the ASHRAE perimeter method assumes heat loss occurs along the entire 168 ft of full slab perimeter. In both cases, an R-2.08 h·ft²·F/Btu carpet with pad is present at the interior surface of the slab. It is understood that an analysis tool could use a more detailed model for slab-on-grade ground coupling, which could have a significant effect on the output. Therefore, results of alternative (somewhat more detailed) ground-coupling analysis are included for these cases as part of the example results of informative Annex B20. This serves to widen the range of example results for the slab-on-grade cases. Case descriptions for the alternative ground-coupling analysis are given in informative Annex B18, where Cases L302B and L304B are the alternative versions of cases L302A and L304A, respectively.

For Cases L302A and L304A, the ASHRAE perimeter method assumes heat loss occurs along the entire 168 ft of full slab perimeter. In both cases, an R-2.08 carpet with pad is present at the interior surface of the slab.

For these slab-on-grade cases, Case L302A is the base case for Case L304A.

7.2.2.11.1 Case L302A: Slab-on-Grade, Uninsulated ASHRAE Slab. This case ~~is~~ shall be modeled exactly as Case L100A, except for the following changes to output requirements and floor construction.

7.2.2.11.1.1 Output Requirements. Cases L302A and L304A require the following output:

a. general reporting requirements of Section 8.1

b. Annual or seasonal heating loads for Colorado TMY data are the only required outputs for cases L302A and L304A as specified in (also see Section 8.2.1).

7.2.2.11.1.2 Floor Construction. The raised-floor-exposed-to-air construction ~~is~~ shall be changed to an uninsulated slab-on-grade construction, ~~as shown in:~~ Changes to Case L100A for developing Case L322A shall apply information in the following figure and shall be consistent with bold-highlighted information in the following table, as required by the program being tested:

- Figure 7-20 Uninsulated Slab-on-Grade Section – Case L302A
- Table 7-35 Building Thermal Summary - Case L302A.

Models requiring more detailed information shall apply the information in the following supplementary table, as required by the program being tested: Note that a carpet is present on the interior surface of the slab. The following supplemental table shows equivalent inputs for modeling the ASHRAE perimeter method with the software used to generate example results of informative Annex B20:

- Table 7-36 Material Descriptions, Slab-on-Grade Floor - Case L302A.

Informative Note: Figure 7-20 contains only new information; changes are not bold highlighted. Information in Table 7-35 not highlighted by bold font text is copied from Case L100A. Because Table 7-36 contains only new information relevant to slab floor construction, it is changes are not bold highlighted, with bold font. Table 7-36 shows equivalent inputs for modeling the ASHRAE perimeter method with the software used to generate example results of informative Annex B20. This includes carpet on the interior surface of the slab.

7.2.2.11.2 Case L304A: Slab-on-Grade, Insulated ASHRAE Slab. This case ~~is~~ shall be modeled exactly as Case L302A, except that the slab ~~is~~ shall be insulated with R-5.4 perimeter insulation, ~~as shown in:~~ Changes to Case L302A for developing Case L304A shall apply bold-highlighted information in the following figure and shall be consistent with bold-highlighted information in the following table, as required by the program being tested:

- Figure 7-21 Slab-on-Grade with Foundation Wall Exterior Insulation, Section - Case L304A

- Table 7-37 Building Thermal Summary - Case L304A

Models requiring more detailed information shall apply the bold-highlighted information in the following supplementary table, as required by the program being tested:

~~The following supplemental table shows equivalent inputs for modeling the ASHRAE perimeter method with the software used to generate example results of informative Annex B20:~~

- Table 7-38. Material Descriptions, Slab-on-Grade Floor - Case L304A.

Informative Note: Table 7-38 shows equivalent inputs for modeling the ASHRAE perimeter method with the software used to generate example results of informative Annex B20. Bold font in the figure and tables for Case L304A highlights changes to Case L302A.

Informative Note: Information in the figures and tables not highlighted by bold font text is copied from Case L302A.

7.2.2.12 Basement Series (Cases L322A and L324A). The Basement test cases shall be modeled as specified in this section. Case L100A shall be the base case for Case L322A. Case L322A shall be the base case for Case L324A.

Informative Note: Cases L322A and L324A are designed to compare the results of residential modeling software to software used to generate example results of informative Annex B20, using the ASHRAE method for modeling basement heat loss from the below-grade basement walls and slab floor.^{B-7, B-8, B-9} It is understood that an analysis tool could use a more detailed model for basement ground coupling, which could have a significant effect on the output. Therefore, results of alternative (somewhat more detailed) ground-coupling analysis are included for these cases as part of the example results of informative Annex B20. This serves to widen the range of example results for the basement cases. Case descriptions for the alternative ground-coupling analysis are given in informative Annex B18, where Cases L322B and L324B are the alternative versions of cases L322A and L324A, respectively.

For these basement cases, Case L322A is the base case for Case L324A.

7.2.2.12.1 Case L322A: Uninsulated ASHRAE Conditioned Basement. ~~Because this case contains numerous changes to the base building (Case L100A), a "recommended input procedure" is also included in this section.~~

Case L322A ~~is~~ shall be modeled **exactly as Case L100A, except** for the following changes.

Informative Note: Because this case contains numerous changes to the base building (Case L100A), Section 7.2.2.12.1.4 defining the input procedure is included in this section.

7.2.2.12.1.1 Output Requirements. Cases L322A and L324A require the following output:
a. general reporting requirements of Section 8.1
b. Annual or seasonal heating loads using Colorad.TMY data are the only required outputs for cases L322A and L324A as specified in (also see Section 8.2.1).

7.2.2.12.1.2 Conditioned Basement Construction. A conditioned basement ~~has been~~ shall be added, with the following envelope and interior floor modifications:

- Add basement walls
- Add concrete basement floor slab
- Replace the previous main floor (formerly above raised floor exposed to air) with an interior main floor/basement ceiling.

Changes to Case L100A for developing Case L322A shall apply information in the following figures and and shall be consistent with bold-highlighted information in the following table, as required by the program being tested; (included after the discussion) contain information that is expected to be useful to most users:

- Figure 7-22 Basement Series Base Building, Section and Plan
- Figure 7-23 Basement Wall and Floor Section – Case L322A
- Figure 7-18 Raised Floor Exposed to Air - Case L200A (with change per recommended input procedure; as specified in Section 7.2.2.12.1.4, Step 4, below)
- Table 7-39 Building Thermal Summary - Case L322A.

Models requiring Relevant supplementary tables that include more detailed information are shall apply the

~~information in the following supplementary tables, as required by the program being tested listed below.~~

~~Because these tables contain only new information relevant to the basement construction, they are not highlighted with bold font.~~

- ~~• Table 7-40 Basement Component Surface Areas – Case L322A~~
- ~~• Table 7-41 Material Descriptions, Basement Wall – Case L322A~~
- ~~• Table 7-42 Material Descriptions, Basement Floor – Case L322A~~
- ~~• Table 7-43 Material Descriptions, Interior Main Floor/Basement Ceiling - Case L322A.~~

~~**Informative Note:** Figures 7-22 and 7-23 and Tables 7-40 through 7-43 contain all new information; changes are not bold highlighted. Information in Table 7-39 not highlighted by bold font is copied from Case L302A.~~

7.2.2.12.1.3 Thermostat control and related modeling notes. Basement air temperature shall be regulated by the same thermostat control as the main floor (see as specified for Case L100A in Section 7.2.1.14), and main floor and basement air shall be assumed to be well-mixed. ~~Therefore, model~~ The entire house (main floor and basement) shall be modeled as a single zone, or modeled as two zones with the main floor and basement as separate zones adjacent to each other with identical thermostat control. In a single-zone model, the main floor/basement ceiling shall be treated like the main floor interior walls. In a two-zone model, the main floor/basement ceiling shall be a partition between the main floor and the basement zones.

7.2.2.12.1.4 Recommended Input Procedure. To develop inputs for Case L322A, begin with Case L100A and proceed as follows:

- ~~1. Add the~~ A basement shall be added with 1539 ft² of floor area and 12312 ft³ of air volume directly below the original conditioned zone as shown in Figure 7-22. The basement wall height ~~is~~ shall be 8' as shown in Figures 7-22 and 7-23. Basement envelope and ceiling component surface areas ~~shall be as~~ are shown in Table 7-39. Models requiring more detailed information shall apply (relevant supplemental data is included in Table 7-40), as required by the program being tested. Thermostat control shall be as described specified in Section 7.2.1.14 above. No additional infiltration through the basement envelope

~~shall be~~ assumed (i.e., the sill is caulked).^{B-9} No additional internal gains shall be present in the basement. Informative Note: If a 2-zone model is applied, internal gains and infiltration are applied to the main floor only.

- ~~2. Construct the~~ The basement walls shall be as shown in Figure 7-23 and Table 7-39. Models requiring more detailed information shall apply the (relevant supplementary information in tables are Table 7-40 and Table 7-41, as required by the program being tested). The walls shall include a rim joist section, as well as above- and below-grade concrete wall sections. The basement wall construction ~~shall be~~ the same for all four basement walls. No windows are shall be included in the basement.

- ~~3. Construct the~~ The basement floor shall be as shown in Figures 7-22 and 7-23 and Table 7-39. Models requiring more detailed information shall apply the (relevant supplemental information in tables are Tables 7-40 and 7-42, as required by the program being tested).

- ~~4. Replace the~~ The base-case main floor (formerly raised floor exposed to air) shall be replaced with the interior main floor/basement ceiling of Table 7-39. Models requiring more detailed information shall apply the (also see supplemental information in Tables 7-40 and 7-43, as required by the program being tested). This floor ~~is~~ shall be based on that of Figure 7-18 (Case L200A), except that the exterior film below the floor shall be replaced by an interior film.

7.2.2.12.2 Case L324A: Interior Insulation Applied to Uninsulated ASHRAE Conditioned Basement Wall. This case ~~is~~ shall be modeled exactly as Case L322A, except that insulation has been shall be added to the interior side of the basement wall and rim joist. The basement floor slab shall remain as is in Case L322A.

Changes to Case L322A for developing Case L324A shall apply bold highlighted information in the following figures and shall be consistent with bold highlighted information in the following table, as required by the program being tested: highlight information that will be useful to most users:

- ~~• Figure 7-24. Insulated Basement Wall and Rim Joist Section - Case L324A~~

- Figure 7-25. Insulated Basement Wall Plan Section - Case L324A
- Table 7-44. Building Thermal Summary - Case L324A.

Models requiring Relevant supplementary tables that include more detailed information are shall apply the bold-highlighted information in the following supplementary tables, as required by the program being tested:

- Table 7-45. Component Surface Areas - Case L324A
- Table 7-46. Material Descriptions, Basement Wall - Case L324A.

Bold font in figures and tables for Case L324A highlight changes relative to Case L322A.

Informative Note: Information in the figures and tables not highlighted by bold font text is copied from Case L322A.

7.2.3 Tier-2 Test Cases. Tier 2 test cases shall be modeled exactly as the designated base case model except as specified in this section. This section describes revisions to the base building required to model the Tier 2 cases. Case L165A is shall be based on Tier 1 Case L160A, and Case P100A shall be based on Tier 1 Case L120A. Case P100A represents shall be the base case for the other P-series cases (P105A, P110A, P140A, and P150A).

Informative Note: Bold font in tables and figures for the Tier 2 cases denotes changes with respect to their appropriate base cases. Where applicable, summary figures and tables are listed first, with supplementary detailed tables listed afterward.

7.2.3.1 Case L165A: East/West Shaded Windows. Case L165A is shall be modeled exactly as Case L160A, except that an opaque overhang and ten opaque fins are shall be added to the east and west walls, as shown in Figure 7-26.

Depending on If the input capabilities of the software being tested, it may not be possible do not allow to model the exact geometry of the windows and shading devices to be modeled as shown in Figure 7-26, then. If this is the case, a nearly equivalent model of the shading devices shall be permitted, may be used such as that described in

Informative Note: Informative Figure 7-27 shows one possible simplified model. , where tThe ten

small fins shown in Figure 7-26 have been replaced with two large fins. It may also be necessary to modify the window geometry. This type of modification process was also presented with Figure 7-14 for Case L155A.

Recall that, as explained in Section 7.1, this test requires use of consistent modeling methods for the test cases.

Figure 7-27 Overhang and fins for east and west windows alternate arrangement – Case L165A

Informative Note: Figure 7-27 is informative material.

7.2.3.2 Case P100A: Passive Solar Base Case (Unshaded). Case P100A is shall be the base case for the passive solar series (P-series) cases. This case is representative of good passive solar heating design. However, for the passive base case, a south wall overhang was not included. To prevent summer overheating, good passive solar design would include an overhang as described in Case P105A.

Case P100A is shall be based on Case L120A, with modifications as described specified below.

Informative Note: Because of the many changes in this case versus Case L120A, it is recommended that inputs for Case P100A be double-checked and results disagreements diagnosed before running the remainder of the P-series cases. An "recommended input procedure" for developing Case P100A from Case L120A is also included in Section 7.2.3.2.8.

Informative Note: This case is representative of good passive-solar heating design. However, for the passive-solar base case, a south wall overhang was not included. To prevent summer overheating, good passive-solar design would include an overhang as described in Case P105A.

The following modifications to Case L120A are required to achieve Case P100A.

7.2.3.2.1 Weather Data and Output Requirements.

The P-series cases require the following output:
a. general reporting requirements of Section 8.1
b. Both the Annual or seasonal heating and sensible cooling load outputs for the P-series cases are generated using only the Colorad.TMY weather data as specified in (also see Section 8.2.2). As noted in Section 7.2.3.2.4 below, tTwo separate simulations

are required: one for calculating heating loads, and the other for calculating cooling loads. *Informative Note:* The need for two simulations is discussed in the informative note just after Section 7.2.3.2.4.

7.2.3.2.2 Construction Details. The building model shall be modeled as follows: Qualitative summary (quantitative details follow below):

- All south window orientation with increased glass area
- Clear double-pane window with wood frame and modified geometry
- R-23 composite floor with brick pavers for thermal mass
- Replacement of ~~Three~~ of the 14 ft lightweight interior walls shall be replaced with three 14 ft double brick walls for thermal mass.

Changes to Case L120A for developing Case P100A shall apply information in ~~the~~ following figures, including bold highlighted information in Figure 7-29, and shall be consistent with bold-highlighted information in the following tables, as required by the program being tested: and figures highlight information that is expected to be useful to most users:

- ~~Figure 7-9 Exterior Wall Section – Case L120A~~
- Figure 7-28 Window, Door, and Mass Wall Locations - Case P100A
- Figure 7-29 Mass Raised Floor Exposed to Air, Section - Case P100A
- Figure 7-30 Interior Mass Wall Section - Case P100A
- Figure 7-31 Window Detail, Vertical Slider 30" Wide by 78" High with 2 3/4" Frame – Case P100A
- Table 7-47 Building Thermal Summary - Case P100A.

Models requiring Relevant supplementary tables that include more detailed information ~~are~~ shall apply the information in the following supplementary tables, including the bold-highlighted information in Tables 7-48 through 7-50, as required by the program being tested:

- ~~Table 7-16 Material Descriptions, Exterior Wall – Case L120A~~
- Table 7-48 Component Surface Areas and Solar Fractions - Case P100A
- Table 7-49 Material Descriptions, Raised Floor Exposed to Air - Case P100A

- Table 7-50 Material Descriptions, Interior Mass Wall - Case P100A
- Table 7-51 Window Summary, Double Pane, Clear, Wood Frame Window - Case P100A
- Table 7-52 Glazing Summary, Clear Double Pane Center of Glass Values - Case P100A
- Table 7-53 Optical Properties as a Function of Incidence Angle for Clear Double-Pane Glazing - Case P100A.

The exterior wall materials of Case L120A as shown in the figure and table below shall be applied, as required by the program being tested:

- Figure 7-9 Exterior Wall Section - Case L120A
- Table 7-16 Material Descriptions, Exterior Wall – Case L120A.

Informative Note: Figure 7-9 and Table 7-16 are referenced for convenience. If the development of the Case P100A input file begins with modifications to Case L120A, changes identified in those tables have already been addressed.

Informative Note: Where appropriate, changes to Case L120A have been highlighted in tables and figures with bold font. Figures 7-28, 7-30, and 7-31, and Tables 7-51 through 7-53 contain only new information; changes are not bold highlighted. Information in Figure 7-29 and Tables 7-47 through 7-50 not highlighted by bold font is copied from Case L120A.

7.2.3.2.3 Radiative Properties of Massive Surfaces. For massive (brick) surfaces, solar absorptance and infrared emittance ~~are~~ shall be 0.6 and 0.9 respectively (the same as for other surfaces).

7.2.3.2.4 Thermostat Control Strategies. ~~Use~~ The annual thermostat control settings ~~noted below~~ shall be used for the P-series cases.

Heating only:

- HEAT = ON IF **TEMP** < 68°F; COOL = OFF.

Cooling only:

- COOL = ON IF **TEMP** > 78°F; HEAT = OFF.

Informative Note: “TEMP” refers to conditioned zone air temperature. Because this is not deadband thermostat control, separate simulations for heating and cooling outputs were ~~required~~ applied to generate example results (just as with similar to the Tier 1

cases, when where Lasvega.TMY was is the cooling climate). Therefore, for Pproper comparison with example results, requires-separate simulations with the tool/software being tested are needed for generating annual (or seasonal) heating and cooling outputs.

7.2.3.2.5 Interior Walls. The thermal mass of the interior walls within the conditioned zone shall be modeled, if the program being tested has that capability. Informative Note: As in the Tier 1 tests, the interior walls (including massive interior walls) have been included for the purpose of modeling their mass effect. They are not intended to divide the conditioned zone into separately controlled zones.

7.2.3.2.6 Raised Floor Exposed to Air. The floor shall be modeled as follows: To simulate a raised floor exposed to air, the test cases require the following assumptions:

- raised floor the air temperature below the raised floor shall be assumed to equal to the outdoor outside air temperature
- the underside of the conditioned-zone floor has shall have an exterior film coefficient of 2.2 Btu/(h·ft²·°F), consistent with a "rough" surface texture and zero windspeed; if the program being tested cannot set the exterior surface coefficient to a fixed value, then allow the exterior surface coefficient shall be permitted to vary with wind speed.
- the conditioned-zone floor exterior surface (surface facing the raised floor) shall receives no solar radiation.

Informative Note: See the informative note just after Section 7.2.1.5 (Case L100A) for further instructions discussion about how to modeling these assumptions.

7.2.3.2.7 Interior Solar Distribution. If the program being tested does not allow for variations of interior solar distribution or calculates this effect internally, then skip this section and proceed to Section 7.2.3.2.8. Otherwise, the interior solar fractions from Table 7-48 shall be used. Informative Note: Interior solar distribution is calculated as shown in informative Annex B19. This represents a more detailed treatment appropriate to passive solar design.

7.2.3.2.8 Recommended Input Procedure. To develop inputs for Case P100A, begin with Case L120A and proceed as follows.

1. ~~Remove a~~ All window assemblies from the north, east, and west walls shall be and replaced them with the Case L120A solid exterior wall material described-specified in Figure 7-9 and Table 7-16 (Case L120A). Resulting component surface areas and solar fractions shall be as are-shown in Table 7-48.

2. ~~Move~~ The door from the south wall shall be moved to the east wall as shown in Figure 7-28. Material properties of doors shall not beare unchanged. Resulting component surface areas and solar fractions shall be as are shown in Table 7-48.

3. ~~Construct the~~ The south wall shall be constructed as shown in Figure 7-28 and Table 7-48. All windows are-shall be clear double-pane with wood frame and are-shall be located on the south wall. The gross window area (including frames) is-shall be 325 ft². The window unit size shall bewas modified as shown, so that more glazing could be applied to the south wall. The resulting changes in-overall (glass plus frame) window properties shall be as are described specified in Figure 7-31 and Table 7-47, and in greater detail in Tables 7-51 through 7-53. The component surface areas shall be as shown in Table 7-48. If component solar fractions have been input in the base case model, then the solar fractions shall be changed as shown in Table 7-48. All insulated wall area shall apply materials and thermal properties as specified for theBecause of the large amount of window area, the only place for batt insulation (see insulated wall section of Figure 7-9 and Table 7-16). The insulated wall area shall be locatedis above the window headers. The remaining portion of the south wall shall uses apply only the materials and thermal properties for the framed wall section from Figure 7-9 and Table 7-16. Resulting component surface areas and solar fractions are shown in Table 7-48.

Informative Note: The modified window unit size allows more glazing to be applied to the south wall. Because of the large amount of window area. The only place for batt insulation is above the window headers.

4. ~~Replace~~ The L120A floor shall be replaced with the raised floor exposed to air described-specified in Figure 7-29 and Table 7-49. (For the purpose of this test, the floor structure is assumed to be sufficient to support the brick pavers without modification.) Resulting eComponent surface areas and solar fractions shall be as are shown in Table 7-48.

Informative Note: For the purpose of this test, the

floor structure is assumed to be sufficient to support the brick pavers without modification.

5. ~~Replace~~ The three 14-ft low-mass interior walls shall be replaced with the double-brick walls as shown in Figure 7-28. The doublebrick interior wall materials shall be as are described-specified in Figure 7-30 and Table 7-50. All other lightweight interior walls shall remain as located in Figure 7-2 (Case L100A). ~~Resulting~~ Component surface areas and solar fractions shall be as are shown in Table 7-48.

7.2.3.3 Case P105A: Passive Solar with Overhang.

Case P105A ~~is~~ shall be modeled exactly as Case P100A, except that a south wall opaque overhang ~~is~~ shall be included that extends outward horizontally 3.47 ft with vertical offset of 2.08 ft from the top of the window (0.83 ft from the top of the wall) as shown in Figure 7-32. The overhang shall traverse the entire length of the south wall. ~~(Overhang width and offset are based on full shading for a summer noon solar altitude angle of 68°, and no shading for a winter noon solar altitude angle of 31°.)~~ Window locations shall remain as shown in Figure 7-28 (Case P100A).

~~Depending on~~ If the input capabilities of the software being tested, it may not be possible do not allow to model the exact geometries of the windows and overhang to be modeled as shown in Figures 7-28 and 7-32, ~~then~~ . If this is the case, a simplified model of the south wall shall be permitted may be used, such as the conceptual description shown in

Informative Note: Informative Figure 7-33 shows one possible simplified model. Proper dimensions for this example ~~would be are~~ obtained using Figure 7-28, Figure 7-31 and Table 7-48 (see Case P100A). While the overhang is not shown in Figure 7-33, it must be included as shown in Figure 7-32.

Informative Note: Overhang width and offset are based on full shading for a summer noon solar altitude angle of 68°, and no shading for a winter noon solar altitude angle of 31°.

Recall that, as explained in Section 7.1, this test requires use of consistent modeling methods for the test cases.

Figure 7-33 Example model of south wall for simulating south overhang effect in Case P105A

Informative Note: Figure 7-33 is informative material.

7.2.3.4 Case P110A: Low-Mass Version of Case P100A. Case P110A ~~is~~ shall be modeled exactly as Case P100A, except for the following changes. The brick pavers ~~have been~~ shall be removed from the floor and replaced with an equivalent-resistance massless floor covering. Also, the three massive interior walls ~~shall be~~ have been replaced with low-mass interior walls such that all interior walls are now configured as in Case L100A (Tier 1 base case).

Changes to Case P100A for developing Case P110A shall apply bold-highlighted information in the following figure and tables, as required by the program being tested:

The following figures and tables highlight these changes:

- ~~• Figure 7-7 Interior Wall Plan Section – Case L100A~~
- Figure 7-34 Raised Floor Exposed to Air, Section – Case P110A
- ~~• Table 7-8 Material Descriptions, Interior Wall – Case L100A~~
- Table 7-54 Building Thermal Summary - Case P110A
- Table 7-55 Component Surface Areas and Solar Fractions - Case P110A
- Table 7-56 Material Descriptions, Raised Floor Exposed to Air - Case P110A.

Case P110A shall apply interior wall materials of Case L100A as shown in the figure and table below, as required by the program being tested:

- Figure 7-7 Interior Wall Plan Section - Case L100A
- Table 7-8 Material Descriptions, Interior Wall – Case L100A.

Informative Note: Information in Figure 7-34 and Tables 7-54 through 7-56 not highlighted by bold font is copied from Case P100A.

7.2.3.5 Case P140A: Zero Window Area Version of Case P100A. Case P140A ~~is~~ shall be modeled exactly as Case P100A, except that the glazing shall be removed from the south wall such that the entire south wall is opaque with the material properties per shown in Figure 7-9 (Case L120A) and specified in Table 7-16 (Case L120A).

Changes to Case P100A for developing Case P140A shall be consistent with bold-highlighted information

in the following tables, as required by the program being tested:~~The following tables summarize the changes:~~

- Table 7-57 Building Thermal Summary - Case P140A
- Table 7-58 Component Surface Areas - Case P140A₂

Informative Note: Information in the tables not highlighted by bold font is copied from Case P100A.

7.2.3.6 Case P150A: Even Window Distribution Version of Case P100A. ~~This Case P150A is shall be modeled exactly as Case P100A, except that all windows are shall be evenly distributed among the walls. Interior walls are shall be as in Case P100A. Changes to Case P100A for developing Case P150A shall apply information from the following figure and shall be consistent with bold-highlighted information in the following tables, as required by the program being tested:~~ These changes are summarized in the following:

- Figure 7-35 Window Locations - Case P150A
- Table 7-59 Building Thermal Summary - Case P150A
- Table 7-60 Component Surface Areas and Solar Fractions - Case P150A.

Informative Note: Information in the tables not highlighted by bold font is copied from Case P100A.

Informative Note: The calculation of interior solar distribution fractions in Table 7-60 assumes that solar energy transmitted through windows, and not absorbed by lightweight furnishings or lost due to cavity albedo, is distributed to all interior surfaces in proportion to their areas. Solar lost (cavity albedo) remains as for Case P100A.

8. CLASS II OUTPUT REQUIREMENTS

4.38.1 Reporting Results

4.38.1.1 Standard Output Reports. The standard output reports included on the accompanying ~~CD~~ electronic media shall be used. Instructions regarding these reports are included in Annex A2. Information required for this report includes:

- a. software name and version number,

b. modeling documentation using “S140outNotes.TXT” on the accompanying ~~CD~~ electronic media for:

- Software identifying information and operating requirements
- Modeling methods used when alternative methods are available in the software (as specified in Section 7.1.4)
- Equivalent modeling methods used when the software does not allow direct input of specified values (as specified in Section 7.1.5)
- Changes to source code for the purpose of running the tests, where such changes are not available in publicly released versions of the software (as specified in Section 7.1.8)
- Omitted test cases and results (as specified in Section 8.1.3)
- Anomalous results (as specified in Section 8.1.4)

c. results for simulated cases using the following files on the accompanying ~~CD~~ electronic media:

- ~~See 5-2out.XLS for the building thermal envelope and fabric load tests of Section 5.2~~
- ~~See 5-3Aout.XLS for the space-cooling equipment performance analytical verification tests of Sections 5.3.1 and 5.3.2~~
- ~~See 5-3Bout.XLS for the space-cooling equipment performance comparative tests of Sections 5.3.3 and 5.3.4~~
- ~~See 5-4out.XLS for the space-heating equipment performance tests of Section 5.4~~
- RESULTS7-2.XLS, sheet tab ‘Sec7-2out’ for the building thermal envelope and fabric load tests of Section 7.2

For the specific Θ output quantities to be included required in the results report are called out specifically for each case, as they appear in refer to the appropriate subsections of Sections 5.2, 5.3, 5.4, and 7.2.

If a program being tested omits a test case, the modeler shall provide an explanation using the modeler report template provided in Annex A2.

4.38.1.2 Simulation Input Files. All supporting data required for generating results with the tested software shall be saved, including:

- Input files
- Processed weather data
- Intermediate files containing calculations used for developing inputs
- A “Readme-software-name-yymmdd.pdf” file that briefly describes the contents of the above files

according to their file type (i.e., their ".xyz" file extension).

8.1.3 Omitted Test Cases. If a program being tested omits a test case, the modeler shall provide an explanation using the modeler report template provided in Annex A2.

4.4.48.1.4 Discussion of Anomalous Results. ~~At the option of the report author, Explanation of anomalous test results may be explained using the modeler report template provided in Annex A2 shall be permitted, but is not required.~~

8.2 Output Requirements for Building Thermal Envelope and Fabric Load Tests of Section 7.2

~~Enter a~~ All results shall be entered into the appropriate standard output report (see Annex A2) as specified below.

8.2.1 Tier-1 Tests. For the Tier-1 Tests, generate output for comparison to the example results as shown in Table 8-1. Seasonal results shall be for heating and cooling seasons for the entire year or some other reasonable length as defined by the tool being tested. For software that designates heating and cooling seasons, enter Julian dates for first and last dates of the heating and cooling seasons designated by the software being tested where indicated in the accompanying file RESULTS7-2.XLS (see sheet "Sec7-2out").

Informative Note: Monthly example results and instructions for use of seasonal results are provided in informative Annex B20.

8.2.2 Tier-2 Tests. For the Tier 2 Tests, generate output for comparison to the example results as shown in Table 8-2. Seasonal results shall be for heating and cooling seasons for the entire year or some other reasonable length as defined by the tool being tested. For software that designates heating and cooling seasons, enter Julian dates for first and last dates of the heating and cooling seasons designated by the software being tested where indicated in the accompanying file RESULTS7-2.XLS (see sheet "Sec7-2out").

Informative Note: ~~Monthly~~ Monthly example results and instructions for use of these results are provided in informative Annex B20.

Informative Note: ~~that i~~ In Table 8-2 for eCases P100A through P150A, the climate data for

generating cooling load outputs is Colorad.TMY. This is because the passive solar design described in Cases P100A and P105A, while appropriate for Colorado Springs, Colorado, is inappropriate for Las Vegas, Nevada.

(This is a normative annex and is part of this standard.)

NORMATIVE ANNEX A1 WEATHER DATA

A1.1 Weather Data for Building Thermal Envelope and Fabric Load Tests of Section 5.2.

The full-year weather data (DRYCOLD.TMY) ~~provided with the accompanying electronic media on the CD provided with this standard method of test~~ shall be used for performing the tests called out in Section 5.2. Site and weather characteristics are summarized in Table A1-1. See Section A1.5 for details about TMY weather data file format, are included in Section A1.5.

A1.2 Weather Data for Space-Cooling Equipment Performance Tests.

A1.2.1 Analytical Verification Test Weather Data.

The weather data listed in Table A1-2 shall be used as ~~called out specified~~ in Sections 5.3.1 and 5.3.2. Ambient dry-bulb and dew-point temperatures are constant in these weather files; constant values of ambient dry-bulb temperature vary among the files. Site and weather characteristics are summarized in Tables A1-3a and A1-3b for the TMY and TMY2 data files, respectively. See Sections A1.5 and A1.6, respectively, for details about the TMY and TMY2 weather data file formats.

Informative Note: These data files represent TMY and TMY2 format weather data files, respectively, with modifications so that the initial fundamental series of mechanical equipment tests may be very tightly controlled. The TMY-format data are three-month-long data files used in the original field trials of the test procedure; the TMY2-format data are year-long data files that may be more convenient for users. For the purposes of HVAC BESTEST the test cases of Sections 5.3.1 and 5.3.2, which uses apply a near-adiabatic building envelope, the TMY and TMY2 data sets are equivalent. (Note that there are small differences in solar radiation, wind speed, etc., that result in a sensible loads difference of 0.2%–0.3% in cases with low internal gains [i.e., CE130, CE140, CE190, and CE195]. This percentage load difference is less [0.01%–0.04%] for the other cases

because they have higher internal gains. These TMY and TMY2 data are not equivalent for use with a non-near-adiabatic building envelope.)

~~Ambient dry-bulb and dew-point temperatures are constant in all the weather files; constant values of ambient dry-bulb temperature vary among the files according to the file name. Site and weather characteristics are summarized in Tables A1-3a and A1-3b for the TMY and TMY2 data files, respectively. Details about the TMY and TMY2 weather data file formats are included in Sections A1.5 and A1.6, respectively.~~

A1.2.2 Comparative Test Weather Data. The full-year weather data file CE300.TM2 provided ~~on~~ with the accompanying ~~CD~~ electronic media shall be used for performing the tests ~~called out specified in~~ Sections 5.3.3 and 5.3.4. Site and weather characteristics of the data file are summarized in Table A1-4. This data file represents TMY2 format weather data; see Section A1.6 for details about TMY2 weather data file format, are included in Section A1.6.

A1.3 Weather Data for Space-Heating Equipment Performance Tests. Weather data listed in Table A1-5 shall be used as specified in Section 5.4. These data are presented in WYEC2 format.¹⁰ See Section A1.7 for a detailed description of the WYEC2 format. Site characteristics are summarized in Table A1-6.

Five full-year weather data files are used in the test suite:

- weather file HE100W.WY2 has a constant outdoor temperature of -30°C;
- weather files HE120W.WY2 and HE130W.WY2 have constant outdoor temperatures of 0°C and +20°C, respectively;
- weather file HE140W.WY2 ~~features~~ has the outdoor temperature varying sinusoidally over each 24-hour period from -20°C to +20°C; and
- weather file HE210W.WY2 represents a more realistic weather set from a heating climate.

Informative Note: Many simulation programs use TMY or WYEC weather data, wherein the hourly time convention is solar time. For the tests of Section 5.4, solar gains are excluded. Therefore, solar time, longitude, latitude, time zone, and ground reflectivity will not impact the simulation results.

A1.4 Weather Data for Section 7 Tests. Full-year TMY weather data listed in Table A1-7 shall be used as ~~called out specified in~~ Section 7.2. Site and weather characteristics are summarized in Tables A1-8 and A1-9. See Section A1.5 for details about TMY weather data file format, are included in Section A1.5.

A1.5 TMY Weather Data Format. For those programs that do not have Typical Meteorological Year (TMY) weather processors, TMY weather data file format is provided in Table A1-10.

Informative Note: This reprint of tables also includes some additional notes based on experience with TMY data. If this summary is insufficient, the complete documentation on TMY weather data¹¹ can be obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina. Their address is Federal Building, Asheville, NC 28801-2733, telephone 828-271-4800. Informative Annex B2 contains additional background information regarding TMY weather data.

Informative Note: The hourly time convention for TMY weather data is solar time, where

$$\text{Solar Time} = \text{Standard Time} + (4 \text{ minutes/degree}) \times (Lst - Lloc) + E$$

and where

Lst = standard meridian longitude (degrees)

$Lloc$ = local site longitude (degrees)

$$E = 229.2[0.000075 + 0.001868 \cos(B) - 0.032077 \sin(B) - 0.014615 \cos(2B) - 0.04089 \sin(2B)]$$

(minutes)

where

$B = 360(n - 81)/365$ (degrees)

n = day of the year, $1 \leq n \leq 365$

E varies roughly ± 15 minutes throughout the year because of cosmology.

Additional background information on the equation of time may be found in the references.¹² Additional background regarding the difference between solar time and standard time is included in informative Annex B11 (Section B11.3).

A1.6 TMY2 Weather Data Format. TMY2 weather data file format is described below.

Informative Note: This information is provided for those programs that do not have Typical Meteorological Year 2 (TMY2) weather processors, TMY2 weather data file format is described below. If this summary is insufficient, the complete documentation on TMY2 weather data¹³ can be obtained at <http://rredc.nrel.gov/solar/pubs/tmy2>.

A1.6.1 File Header. The first record of each file is the file header that describes the station. The file header contains the WBAN number, city, state, time zone, latitude, longitude, and elevation. The field positions and definitions of these header elements are given in Table A1-11, along with sample FORTRAN and C formats for reading the header. A sample of a file header and data for January 1 is shown in Figure A1-1.

A1.6.2 Hourly Records. Following the file header, 8,760 hourly data records provide one year of solar radiation, illuminance, and meteorological data, along with their source and uncertainty flags. Table A1-12 provides field positions, element definitions, and sample FORTRAN and C formats for reading the hourly records.

Each hourly record begins with the year (field positions 2–3) from which the typical month was chosen, followed by the month, day, and hour information in field positions 4-9. *The times are in local standard time.* **Informative Note:** ~~Previous~~ TMYs based on SOLMET/ERSATZ data are in solar time).

Informative Note: For solar radiation and illuminance elements, the data values represent the energy received during the 60 minutes *preceding the hour indicated*. For meteorological elements (with a few exceptions), observations or measurements were made *at the hour indicated*. A few of the meteorological elements had observations, measurements, or estimates made at daily, instead of hourly, intervals. Consequently, the data values for broadband aerosol optical depth, snow depth, and days since last snowfall represent the values available for the day indicated.

A1.7 WYEC2 Weather Data Format. WYEC2 weather data file format is described below.

Informative Note: This information is provided for those programs that do not have Weather Year for Energy Calculations 2 (WYEC2) weather processors, WYEC2 weather data file format is described below.

A1.7.1 Weather files in WYEC2 format consist of 8760 identical fixed-format records (8,784 records for leap years), one for each hour of each day of the year. Each record is 116 characters (plus 2 for CR/LF) in length and is organized according to Table A1-13.

A1.7.2 All WYEC2 values are for Local Standard Time. Irradiance and illuminance fields contain data integrated over the hour. Meteorological fields contain observations made at the end of the hour.

Informative Note: For example, hour 12 contains irradiance/illuminance from hour 11 to 12 and meteorological observations made at hour 12.

(This is a normative annex and is part of this standard.)

NORMATIVE ANNEX A2 STANDARD OUTPUT REPORTS

The standard output reports consisting of the following six forms provided ~~on~~ with the electronic media ~~CD~~ accompanying this standard shall be used:

- Output Results for Cases of Section 5.2 (Sec5-2out.XLS, spreadsheet file)
- Output Results for Cases of Sections 5.3.1 and 5.3.2 (Sec5-3Aout.XLS, spreadsheet file)
- Output Results for Cases of Sections 5.3.3 and 5.3.4 (Sec5-3Bout.XLS, spreadsheet file)
- Output Results for Cases of Section 5.4 (Sec5-4out.XLS, spreadsheet file)
- Output Results for Cases of Section 7.2 (sheet 'Sec7-2out' within RESULTS7-2.XLS spreadsheet file)
- Modeling Notes (S140outNotes.TXT, text file reprinted as Attachment A2.5)

For entering output results into Sec5-2out.XLS, Sec5-3Aout.XLS, Sec5-3Bout.XLS, Sec5-4out.XLS, and sheet 'Sec7-2out' within RESULTS7-2.XLS, the user shall follow the instructions provided at the top of the appropriate electronic spreadsheet file or designated sheet within the spreadsheet file. These instructions are reprinted as Attachments A2.1, A2.2, A2.3, and A2.4, respectively, within this section; instructions for sheet 'Sec7-2out' within RESULTS7-2.XLS are not reprinted here.

For entering modeling notes into S140outNotes.TXT, use the format of the examples given in Attachment A2.6 within this section shall be used. ~~Note:~~ The

report author shall create one modeling notes TXT document for each section of tests, e.g.,

- a. S140outNotes_5-2.TXT for the Class I building thermal envelope and fabric load tests of Section 5.2
- b. S140outNotes_5-3A.TXT for the Class I space cooling equipment performance analytical verification tests of Sections 5.3.1 and 5.3.2
- c. S140outNotes_5-3B.TXT for the Class I space cooling equipment performance comparative tests of Sections 5.3.3 and 5.3.4
- d. S140outNotes_5-4.TXT for the Class I space heating equipment performance tests of Section 5.4
- e. S140outNotes_7-2.TXT for the Class II test procedures of Section 7.2.

Attachment A2.1—Instructions for Entering Results into Sec5-2out.XLS

STANDARD 140 OUTPUT FORM—RESULTS
Sec5-2out.XLS
INSTRUCTIONS:

- 1. Use specified units.
- 2. All radiation data are for sum of direct and diffuse solar radiation.
- 3. Format dates using the appropriate two-digit date followed by a three-digit month code and two-digit hour code (24-hour clock), as shown here:

The Table remains unchanged

For example, a peak occurring on Jan 4 during the 15th hour interval (2–3 p.m.), ~~should~~ shall be input as:

The Table remains unchanged

- 4. Data entry is restricted to Column B or Columns B, C, D. Enter appropriate output in the proper column(s) for the case or hour listed in column A. This worksheet extends down to Row 901. ~~Note that~~ The protection option has been used in this worksheet to help ensure that data are input to the correct cells.

Attachment A2.2—Instructions for Entering Results into Sec5-3Aout.XLS

HVAC BESTEST CASES CE100–CE200 OUTPUT FORM Sec5-3Aout.XLS INSTRUCTIONS:

- 1. Use specified units.

- 2. Data entry is restricted to columns B through T and rows 25 through 38. The protection option has been employed to help ensure that data are input in the correct cells.
- 3. February totals are consumptions and loads just for the month of February. Similarly, February means and maxima are those values just for the month of February.
- 4. Cooling energy consumption, evaporator coil load, zone load, and COP are defined in Section 3.

Attachment A2.3 Instructions for Entering Results into Sec5-3Bout.XLS

Sec5-3Bout.XLS OUTPUT SPREADSHEET FOR HVAC BESTEST, CASES CE300– CE545
INSTRUCTIONS:

- 1. Use specified units.
- 2. Data entry is restricted to the following ranges:

B62..L82:	Annual Sums, Annual Means, and Other
M62..N62:	Annual Means, CE300 Only
B89..L112:	June 28 Hourly Output, Case CE300
B120..L121:	Case CE500 Average Daily Outputs
B129..L130:	Case CE530 Average Daily Outputs
Q62..AB81:	Annual Hourly Integrated Maxima, Consumptions and Loads
AC62..AH62:	Annual Hourly Integrated Maxima, Case CE300—Weather Check
Q89..AN108:	Annual Hourly Integrated Maxima and Minima, COP2 and Zone

- 3. Annual totals are consumption and/or loads just for the entire annual simulation. Similarly, annual means, maxima, and minima are those values that occur for the entire annual simulation. "May-Sep" results are taken using May 1–September 30 data extracted from a full annual simulation.

- 4. Output terminology is defined in the output section of the specification for each case where applicable or in the Glossary (Appendix C).
- 5. Format dates using the appropriate two-digit date followed by a three-letter month code and two-digit hour code (24-hour clock) as shown below.

The Table remains unchanged

For example, a maximum value occurring on August 16 during the 15th hour interval (2–3 P.M.) ~~should~~ shall be input as:

The Table remains unchanged

Attachment A2.4—Instructions for Entering Results into Sec5-4out.XLS

INSTRUCTIONS:

1. Use specified units.
2. Enter data. Data entry is restricted to cells that require results. The protection option has been employed to ensure that data are input into the correct cells.

Attachment A2.5—Standard 140 Output Form—Modeling Notes

MODELING NOTES FOR ASHRAE STANDARD 140-2007

INTRODUCTION

This document ~~contains~~ shall include supplemental information about the ASHRAE Standard 140-2007 tests performed. One S140outNotes document ~~is~~ shall be provided for each set of tests (e.g., one for the building thermal and fabric load tests of Section 5.2, one for the space cooling equipment analytical verification tests of Sections 5.3.1 and 5.3.2, etc.) ~~Six~~ The types of information listed below are shall be provided in this document, each in a separate section:

- a. Software Information
- b. Alternative Modeling Methods
- c. Equivalent Modeling Methods
- d. Non-Specified Inputs
- ~~d~~e. Omitted Test Cases and Results
- e~~f~~. Changes Made to Source Code for the Purpose of Running the Tests, where Such Changes are not Available in Publicly Released Versions of the Software
- f~~g~~. Anomalous Results

~~Text at the start of each section describes the content of the section for the reader and provides instructions for supplying the content. Sample notes are provided in a separate document (S140outNotes_Examples.TXT).~~

Notes in this document ~~are~~ shall be limited to the ~~six~~ topics shown above. Notes must be factual and

objective and ~~may~~ shall only refer to the software being tested. Notes ~~may~~ shall not refer to any other software program.

Informative Note: Text at the start of each section describes the content of the section for the reader and provides instructions for supplying the content. Sample notes are provided in a separate document (S140outNotes_Examples.TXT).

A. SOFTWARE INFORMATION

CONTENT: This section ~~contains~~ shall include reference information for the software - the vendor, name and version of the software plus operating system and computer hardware requirements.

INSTRUCTIONS: ~~Supply~~ Information for items 1 through 7 below shall be provided. Information for Item 8 is optional shall be permitted, but is not required, and can be used to supply additional, relevant information.

1. SOFTWARE VENDOR:
2. SOFTWARE NAME:
3. SOFTWARE VERSION (unique software version identifier):
4. OPERATING SYSTEM REQUIREMENTS:
5. APPROX HARD DISK SPACE REQUIRED FOR INSTALLATION:
6. MINIMUM RAM REQUIRED FOR SOFTWARE OPERATION:
7. MINIMUM DISPLAY MONITOR REQUIREMENTS:
8. OTHER HARDWARE OR SOFTWARE-RELATED REQUIREMENTS:

Informative Note: Item 8 can be used to supply additional, relevant information.

B. REPORT BLOCK FOR ALTERNATIVE MODELING METHODS

CONTENT: ~~This section describes modeling methods used for tests if the software being tested provides alternative modeling methods or algorithms that could be used to for performing the tests.~~ this section shall describe modeling methods used for the tests.

INSTRUCTIONS: ~~If alternative modeling methods are applicable, provide a separate note below for each alternative modeling method or algorithm situation shall be provided. Use~~ The standard format shown

below and ~~supply~~ a separate number and title for each note ~~shall be applied~~. If ~~not~~ alternative modeling methods are not applicable, specify "NONE" in place of the information below.

NOTE 1 - <title>

- 1.1 Describe the Effect Being Simulated:
- 1.2 Optional Settings or Modeling Capabilities (List setting or capability and its physical meaning):
 - 1.2.1 <name>Physical Meaning: <explanation>
 - 1.2.2 <name>
- Physical Meaning: <explanation>
- 1.2.n <name>Physical Meaning: <explanation> etc...
- 1.3 Setting or Capability Used:

C. REPORT BLOCK FOR EQUIVALENT MODELING METHODS

CONTENT: This section shall describes equivalent modeling methods used to perform the tests. When the software ~~cannot~~ does not model an effect exactly as stated in the Standard or does not permit the input values required, equivalent modeling methods can be used shall be permitted to perform the test.

INSTRUCTIONS: If equivalent modeling methods are applied, applicable, provide a separate note below for each instance of equivalent modeling shall be provided. Use ~~†~~ The standard format shown below and ~~supply~~ a separate number and title for each note shall be applied. If equivalent modeling methods are not applicable, specify "NONE" in place of the information below.

NOTE 1 - <title>

- 1.1 Describe the Effect Being Simulated:
- 1.2 Section(s) of the Standard where Relevant Inputs are Specified:
- 1.3 Equivalent Input(s) Used:
- 1.4 Physical, Mathematical or Logical Justification of the Equivalent Input(s) – provide supporting calculations, if relevant:

D. REPORT BLOCK FOR USE OF NON-SPECIFIED INPUTS

CONTENT: This section shall describe non-specified inputs used to perform the tests. Use of non-specified 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.

INSTRUCTIONS: If non-specified inputs are applied, a separate note for each use of non-specified inputs shall be provided. The standard format shown below and a separate number and title for each note shall be applied. If non-specified inputs are not applied, specify "NONE" in place of the information below.

NOTE 1 - <title>

- 1.1 Describe the Effect Being Simulated:
- 1.2 Section(s) of the Standard where Relevant Inputs are Specified:
- 1.3 Non-Specified Input(s) Used:
- 1.4 Physical, Mathematical or Logical Justification for use of the Non-Specified Input(s)
 - provide supporting calculations, if relevant:

~~DE~~. REPORT BLOCK FOR OMITTED TEST CASES AND RESULTS

CONTENT: This section shall describes test cases that were omitted and/or individual results of test cases that were omitted along with the reason for the omission.

INSTRUCTIONS: If test cases were omitted, applicable, provide a separate note below to describe each type of omission shall be provided. Use ~~†~~ The standard format shown below and ~~supply~~ a separate number and title for each note shall be applied. If there are no ~~omitted~~ test cases, specify "NONE" in place of the information below.

NOTE 1 - <title>

- 1.1 List the Case(s) where Results Were Omitted, and which Results Were Omitted for the Case(s):
- 1.2 Explanation for Omitting the Test Case(s) Results:

~~EF~~. REPORT BLOCK FOR CHANGES TO SOURCE CODE FOR THE PURPOSE OF RUNNING THE TESTS, WHERE SUCH CHANGES ARE NOT AVAILABLE IN

PUBLICLY RELEASED VERSIONS OF THE SOFTWARE

CONTENT: This section shall describes changes to software source code made to allow the software to run a test, where such changes are not available in a publicly released version of the software.

~~Informative Note:~~ ~~††~~ This section addresses special situations where a change to source code is necessary to activate a feature or permit inputs needed for a test; but when these features are not available in the publicly released version of the software.

INSTRUCTIONS: If changes to source code for the purpose of running a test are applied, eable, provide separate notes below to describe each source code modification shall be provided. Use† The standard format shown below and supply a separate number and title for each note shall be applied. If changes to source code are not applied, eable, specify "NONE" in place of the information below.

- NOTE 1 - <title>
- 1.1 List the Change(s) to the source code:
 - 1.2 List the Test Case(s) Relevant to the Change(s) in the Source Code:
 - 1.3. Explanation of Why the Change Is Not Included in the Publicly Released Version of the Software:

FG. REPORT BLOCK FOR ANOMALOUS RESULTS

CONTENT: This section ~~provides an opportunity to describe anomalous test results. Describing anomalous results is optional shall be permitted, but is not required. If anomalous test results are described, this section shall be used.~~

INSTRUCTIONS: If ~~applicable anomalous test results are; described, each type of anomalous result shall be described in a separate note. Use†~~ The standard format shown below and ~~supply a separate number and title for each note item shall be applied. If not applicable anomalous results are not discussed, it shall be permitted to specify "NONE" in place of the information below.~~

- NOTE 1 - <title>
- 1.1 Test Case(s) and Specific Results from the Case(s) which are Anomalous:
 - 1.2 Explanation of Reason for the Anomalous Results:

<END OF DOCUMENT>

Attachment A2.6 is all informative material and is not part of the Standard.

**Attachment A2.6 Examples of Modeling Notes
MODELING NOTES FOR ASHRAE
STANDARD 140-2007—EXAMPLES**

Accompanying file "S140outNotes_Examples.TXT" is revised as indicated below

OVERVIEW

This document contains examples of modeling notes entered in the S140outNotes_Sec5-x.TXT file. Examples are provided to guide in filling out the S140outNotes_Sec5-x.TXT file.

Note that in this file sample notes refer to different sections of Standard 140-2007. In an actual S140outNotes_Sec5-x.TXT file the notes would only address one set of tests within Standard 140 (e.g., Section 5.2).

INTRODUCTION

This document ~~contains shall include~~ supplemental information about the ASHRAE Standard 140-2007 tests performed. One S140outNotes document ~~is shall~~ be provided for each set of tests (e.g. one for the building thermal and fabric load tests of Section 5.2, one for the space cooling equipment analytical verification tests of Sections 5.3.1 and 5.3.2, etc.) Six The types of information listed below are shall be provided in this document, each in a separate section:

- a. Software Information
- b. Alternative Modeling Methods
- c. Equivalent Modeling Methods
- d. Non-Specified Inputs
- ~~de.~~ Omitted Test Cases and Results
- ~~ef.~~ Changes Made to Source Code for the Purpose of Running the Tests, where Such Changes are not Available in Publicly Released Versions of the Software
- ~~fg.~~ Anomalous Results

~~Text at the start of each section describes the content of the section for the reader and provides instructions to the vendor for supplying the content. Sample notes are provided in a separate document (S140outNotes_Examples.TXT).~~

Notes in this document ~~are shall be~~ limited to the ~~six~~ topics shown above. Notes must be factual and

objective and ~~may shall~~ only refer to the software being tested. Notes ~~may shall~~ not refer to any other software program.

Informative Note: Text at the start of each section describes the content of the section for the reader and provides instructions for supplying the content. Sample notes are provided in a separate document (S140outNotes_Examples.TXT).

A. SOFTWARE INFORMATION

CONTENT: This section ~~contains shall include~~ reference information for the software—the vendor, name and version of the software plus operating system and computer hardware requirements.

INSTRUCTIONS: Supply information for items 1 through 7 below shall be provided. Information for Item 8 ~~is optional shall be permitted, but is not required, and can be used to supply additional, relevant information.~~

1. SOFTWARE VENDOR: Dummy Software Solutions
2. SOFTWARE NAME: Building Energy Simulation
3. SOFTWARE VERSION (unique software version identifier): 1.00.039
4. OPERATING SYSTEM REQUIREMENTS: Windows 98, Windows NT (Service Pack 4 or later), Windows 2000 (Service Pack 2 or later), or Windows XP (Service Pack 2 or later)
5. APPROX HARD DISK SPACE REQUIRED FOR INSTALLATION:
Maximum = 45 MB
Typical = 15 to 17 MB
6. MINIMUM RAM REQUIRED FOR SOFTWARE OPERATION: 128 MB
7. MINIMUM DISPLAY MONITOR REQUIREMENTS: VGA with 600x800 resolution and 256 colors
8. OTHER HARDWARE OR SOFTWARE-RELATED REQUIREMENTS: (none)

Informative Note: Item 8 can be used to supply additional, relevant information.

B. REPORT BLOCK FOR ALTERNATIVE MODELING METHODS

CONTENT: This section ~~describes modeling methods used for tests if the software being tested~~ provides alternative modeling methods or algorithms that could be used to for performing the tests, this

section shall describe modeling methods used for the tests.

INSTRUCTIONS: If alternative modeling methods are applicable, ~~provide a separate note below for each alternative modeling method or algorithm situation shall be provided.~~ Use ~~the standard format shown below and supply a separate number and title for each note shall be applied.~~ If alternative modeling methods are not applicable, specify “NONE” in place of the information below.

NOTE 1 - Convective Heat Transfer and Radiative Exchange Related to Both Interior and Exterior Surfaces (Section 5-2)

1.1 Describe the Effect Being Simulated: Convective heat transfer and radiative exchange related to both interior and exterior surfaces.

1.2 Optional Settings or Modeling Capabilities:

1.2.1 HEAT BALANCE = 0;
Physical Meaning: Interior surface heat transfer calculated using ASHRAE values for combined convective and radiative coefficient with the radiation component subtracted out; interior radiative exchange is determined using the balanced mean radiant temperature method. Exterior surface heat transfer calculated using combined coefficients for convective and radiative exchange.

1.2.2 HEAT BALANCE = 1;
Physical Meaning: Same as Heat Balance = 0, except interior surface convection is calculated based on zone air and interior surface temperature difference.

1.2.3 HEAT BALANCE = 2
Physical Meaning: Same as Heat Balance = 1, except exterior surface heat transfer is calculated using separate heat transfer coefficients for radiative exchange to sky and ground and for convection to ambient air.

1.3 Setting or Capability Used: HEAT BALANCE = 2

NOTE 2 - Interior Transmitted Solar Radiation Distribution (Section 5-2)

2.1 Describe the Effect Being Simulated: Interior transmitted solar radiation distribution.

2.2 Optional Settings or Modeling Capabilities:

2.2.1 SOLAR DISTRIBUTION = 0

All radiation initially hits the floor. Radiation not initially absorbed by the floor is diffusely reflected and absorbed by all surfaces in proportion to their area-absorptance products.

2.2.2 SOLAR DISTRIBUTION = 1

Beam radiation falling on each surface is calculated by ray tracing. Beam radiation not initially absorbed is diffusely reflected and absorbed by all surfaces in proportion to their area-absorptance products.

2.3 Setting or Capability Used: SOLAR DISTRIBUTION = 1

NOTE 3 - Thermal Behavior of Windows (Section 5-2)

3.1 Describe the Effect Being Simulated: Thermal behavior of windows.

3.2 Optional Settings or Modeling Capabilities:

3.2.1 "Shading Coefficient"

Applies the ASHRAE shading coefficient technique to calculate solar heat gain (e.g., see 1989 *ASHRAE Handbook—Fundamentals*, Chp. 27).

3.2.2 GLASS-TYPE-CODE =< 11

Applies pre-calculated transmittance and absorptance coefficients based on specified glass-type-code; the coefficients are used to calculate solar gain as a function of incidence angle.

3.2.3 GLASS-TYPE-CODE => 1000

Window used from the library W4LIB.DAT, where windows are modeled using thermal and optical properties developed with WINDOW 4.0. [Window 4.0 (March 1992) LBL-32091 UC-350, Berkeley, CA, Lawrence Berkeley Laboratory]

3.2.3.1 Existing window used from W4LIB.DAT

3.2.3.2 Custom window developed using Window 4.0 and added to W4LIB.DAT

3.3 Setting or Capability Used: Custom window developed and added to W4LIB.DAT; see 3.2.3.2 above.

C. REPORT BLOCK FOR EQUIVALENT MODELING METHODS

CONTENT: This section shall describe equivalent modeling methods used to perform the tests. When the software ~~cannot~~ does not model an effect exactly as stated in the Standard or does not permit the input values required, equivalent modeling ~~methods can be used~~ shall be permitted to perform the test.

INSTRUCTIONS: If equivalent modeling methods are applied, ~~able~~ provide a separate note below for each instance of equivalent modeling shall be provided. ~~Use~~ The standard format shown below and ~~supply~~ a separate number and title for each note shall be applied. If equivalent modeling methods are not applicable, specify "NONE" in place of the information below.

NOTE 1 - Thermal Decoupling of Floor From Ground (Section 5-2)

1.1 Describe the Effect Being Simulated: Thermal decoupling of floor from ground.

1.2 Section(s) of the Standard where Relevant Inputs are Specified: 5.2.1.4 and 5.2.1.5.

1.3 Equivalent Input(s) Used: Floor modeled as perfectly decoupled from ground.

1.4 Physical, Mathematical or Logical Justification of the Equivalent Input(s)– provide supporting calculations, if relevant:

Logical Justification: The informative note with Section 5.2.1.5 states that "to reduce uncertainty regarding testing or other aspects of simulating the building envelope, the floor insulation has been made very thick to effectively decouple the floor thermally from the ground."

It is clear from this statement the intent is to eliminate floor-to-ground heat transfer to reduce the uncertainty in results that it will introduce. The prescribed method of doing this is to model a floor with very high R-value (R=25.374 sqm-K/W or U=0.039 W/sqm-K). This assumes that a software program cannot perfectly eliminate floor-to-ground heat transfer and therefore must minimize the error due to floor-to-ground heat transfer via use of a large floor R-Value.

The subject program cannot comply with the prescribed floor R-value; however, the subject program can perfectly decouple the floor from the ground. Because perfect decoupling is interpreted as meeting the intent of section 5.2.1.5, perfect decoupling was used as an equivalent modeling approach.

NOTE 2 - Thermostat Control and Equipment Capacity (Section 5-2)

2.1 Describe the Effect Being Simulated: Thermostat control and equipment capacity

2.2 Section(s) of the Standard where Relevant Inputs are Specified: Sections 5.2.1.13.1 and 5.2.1.13.2

2.3 Equivalent Input(s) Used:

Heating Setpoint = 20°C, Throttling Range = 0.1°K,
Heating Capacity = 3.935 kW
Cooling Setpoint = 27°C, Throttling Range = 0.1°K,
Cooling Capacity = 3.935 kW

2.4 Physical, Mathematical or Logical Justification of the Equivalent Input(s)– provide supporting calculations, if relevant:

Logical Justification: Together sections 5.2.1.13.1 and 5.2.1.13.2 require use of a non-proportional thermostat with which the heat extraction rate is effectively infinite when the zone air temperature exceeds 27°C and the heat addition rate is effectively infinite when the zone air temperature falls below 20°C. The intent of these sections is to establish conditions for which equipment cooling or heating output exactly matches the zone load. This eliminates system effects and system dynamics that could obscure the focus of this test suite, which is zone thermal loads, not system coil loads.

In the subject software program, use of the prescribed inputs constitutes an unstable control system. For example, the moment the zone air temperature exceeds 27°C, the system will provide 1000 kW of cooling to the zone. This quantity of cooling far exceeds the cooling demand, so the zone is overcooled pushing the zone air temperature below 20°C. The moment that happens, the system provides 1000 kW of heating to the zone. This quantity of heating far exceeds the heating demand, so the zone is overheated, pushing the zone air temperature above 27°C. A system with this control will rapidly oscillate between cooling and heating. The system simulation algorithm in the subject program will not be able to

converge on a solution state for any hour because of the unstable nature of this control.

To resolve this problem, a small throttling range was used with the prescribed setpoints, and the cooling and heating capacities were set to values close to the peak cooling and heating demands of the zone. These inputs were chosen empirically by tuning the inputs until thermostat control instability was eliminated and differences between the system cooling coil load and the zone cooling load and between the system heating coil load and the zone heating load were minimized as much as possible. This approach meets the intent of Sections 5.2.1.13.1 and 5.2.1.13.2.

Note: In the subject program the 3.935 kW capacity is not specified directly. Instead it is indirectly defined via supply airflow rate and supply temperature. The supply airflow was 565.6 L/s, the cooling supply air temperature was 20°C and the heating supply air temperature was 27°C. This yields the capacities as follows. The 0.994 factor is the standard 1.207 density x heat capacity x correction factor corrected for site altitude.

Cooling Capacity = $0.994 \times 565.6 \text{ L/s} \times (27^\circ\text{C} - 20^\circ\text{C}) = 3935 \text{ W} = 3.935 \text{ kW}$

Heating Capacity = $0.994 \times 565.6 \text{ L/s} \times (20^\circ\text{C} - 27^\circ\text{C}) = 3935 \text{ W} = 3.935 \text{ kW}$

D. REPORT BLOCK FOR USE OF NON-SPECIFIED INPUTS

CONTENT: This section shall describe non-specified inputs used to perform the tests. Use of non-specified 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.

INSTRUCTIONS: If non-specified inputs are applied, a separate note for each use of non-specified inputs shall be provided. The standard format shown below and a separate number and title for each note

shall be applied. If non-specified inputs are not applied, specify "NONE" in place of the information below.

NOTE 1 – Interior Surface Coefficient Example

1.1 Describe the Effect Being Simulated:

Interior combined surface coefficients

1.2 Section(s) of the Standard where Relevant Inputs are Specified:

5.2.1.10 and 5.3.1.9.

1.3 Non-Specified Input(s) Used:

1.2 Btu/(h·ft²·F)= 6.81 W/(m²·K)

The test specification indicates 8.29 W/(m²·K)

1.4 Physical, Mathematical or Logical Justification for use of the Non-Specified Input(s)

– provide supporting calculations, if relevant:

1.2 Btu/(h·ft²·F) is the recommended default value in the program's user manual based on recent studies cited there. (Dummy Software Solutions, *Building Energy Simulation Program version 1.00.039*, posted at www.dummyurl.com/usersmanual.pdf, see p. 00. Accessed Oct 2010.)

DE. REPORT BLOCK FOR OMITTED TEST CASES AND RESULTS

CONTENT: This section shall describes test cases that were omitted and/or individual results of test cases that were omitted along with the reason for the omission.

INSTRUCTIONS: If test cases were omitted, applicable, provide a separate note below to describe each type of omission shall be provided. Use the standard format shown below and supply a separate number and title for each note shall be applied. If there are no omitted ~~ssions~~ test cases, specify "NONE" in place of the information below.

NOTE 1 - Light Weight Test Cases (Section 5-2)

1.1 List the Case(s) where Results Were Omitted, and which

Results Were Omitted for the Case(s):

600 600FF 230 300 420
610 650FF 240 310 430
620 195 250 320 440
630 200 270 395
640 210 280 400
650 220 290 410

1.2 Explanation for Omitting the Test Case(s)

Results: These test cases require modeling lightweight building construction (approx 12 lb/sqft floor area). This is residential weight construction. The subject software program is intended for modeling commercial buildings and consequently the minimum building construction weight is 30 lb/sqft floor area. Since the required building construction weight for these test cases is well outside the range of intended program operation, these test cases cannot be performed.

NOTE 2 - Case 960- Sunspace, All Results (Section 5-2)

2.1 List the Case(s) where Results Were Omitted, and which Results Were Omitted for the Case(s): Case 960 - Sunspace, all results.

2.2 Explanation for Omitting the Test Case(s)

Results:
The required inputs to model this type of configuration are not available in this software program. Case 960 models a passive solar sun room using a thermal storage wall. In order to model this configuration, the associated algorithm would need to compute:

- a. The hourly proportion of solar radiation absorbed by the individual sunlit surfaces within the sunlit portion of the thermal storage wall.
- b. The effect of introducing infiltration in the thermal storage wall section.
- c. Adjacent space heat transfer between the thermal storage wall and the interior room.

EF. REPORT BLOCK FOR CHANGES TO SOURCE CODE FOR THE PURPOSE OF RUNNING THE TESTS, WHERE SUCH CHANGES ARE NOT AVAILABLE IN PUBLICLY RELEASED VERSIONS OF THE SOFTWARE

CONTENT: This section shall describes changes to software source code made to allow the software to

run a test, where such changes are not available in a publicly released version of the software.

Informative Note: ~~It~~ This section addresses special situations where a change to source code is necessary to activate a feature or permit inputs needed for a test; ~~but~~ when these features are not available in the publicly released version of the software.

INSTRUCTIONS: If changes to source code for the purpose of running a test are applied, ~~able~~, provide separate notes ~~below~~ to describe each source code modification shall be provided. ~~Use~~ The standard format shown below and ~~supply~~ a separate number and title for each note shall be applied. If changes to source code are not applied, ~~able~~, specify "NONE" in place of the information below.

NOTE 1 - Modification of Scheduling Capabilities (Sections 5.3.3, 5.3.4)

1.1 List the Change(s) to the source code: Include capability for hourly varying schedules, where such schedules may be varied for any day of the year, for sensible and latent internal gains, infiltration, outside air and zone thermostat. Currently for the subject software's publicly released version such hourly schedules may only be varied monthly, beginning on the first day of each month and continuing through the entire month.

1.2 List the Test Case(s) Relevant to the Change(s) in the Source Code: More flexible schedules are needed as follows:

- Internal Gains: All cases of Sections 5.3.3 and 5.3.4 (i.e., Cases CE300 through CE545).
- Infiltration and/or Outside Air: Cases CE320, CE330, and CE340 only.
- Thermostat: Case CE350 only.

1.3 Explanation of Why the Change Is Not Included in the Publicly Released Version of the Software: Users of the subject software appear to be satisfied with hourly schedules limited to monthly variation. Changing the source code to accommodate the test cases of Sections 5.3.3 and 5.3.4 for the purpose of testing the calculation engine is justifiable. However, without known demand from users for additional scheduling flexibility, it is difficult to justify additional costs related to enhancing the user interface and revising software documentation.

FG. REPORT BLOCK FOR ANOMALOUS RESULTS

CONTENT: ~~This section provides an opportunity to describe anomalous test results. Describing anomalous results is optional shall be permitted, but is not required. If anomalous test results are described, this section shall be used.~~

INSTRUCTIONS: If applicable, anomalous test results are described, each type of anomalous result shall be described in a separate note. ~~Use~~ The standard format shown below and ~~supply~~ a separate number and title for each note item shall be applied. If ~~not applicable~~, anomalous results are not discussed, it shall be permitted to specify "NONE" in place of the information below.

NOTE 1 - Zone Air Temperature Variations in Test Cases HE210, HE220, HE230 (Section 5.4)

1.1 Test Case(s) and Specific Results from the Case(s) which are Anomalous:

Large differences in minimum/maximum zone air temperatures for test cases HE210, HE220 and HE230 versus reference results.

1.2 Explanation of Reason for the Anomalous Results:

The default settings in the subject simulation program use a 50%/50% mix of explicit and implicit solution schemes for solving for the unknown zone air temperature of the next time step.

The explicit solution of a building simulation case tends to become unstable if the conduction through the walls is relatively large compared to the thermal storage capacity of the zone. For simulated houses with little or no thermal mass, solving the energy balance to obtain the required furnace output may therefore result in oscillating solutions when the default simulation settings are used.

The implicit solution, however, is stable and its zone air temperatures perfectly follow the thermostat settings.

When a 50%/50% mix of explicit and implicit solutions is used, the zone air temperature is sometimes too high and sometimes too low due to the effect of the explicit solution.

If the fully implicit solution scheme is used, the total furnace loads will only differ slightly from furnace loads predicted using the default 50%/50% mix of explicit and implicit solutions. Because HE210, HE220 and HE230 focus on total furnace load rather

than on calculated zone temperatures, it was felt the results using default simulation settings are valid in spite of the anomaly in zone air temperature results.

<END OF DOCUMENT>

“End of Document” only refers to Annex A2, Attachment A2.6; 140-2011 CM revision edits continue below.

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

INFORMATIVE ANNEX B3 INFILTRATION AND FAN ADJUSTMENTS FOR ALTITUDE

Air density correction for altitude was required in the development of the analytical solutions and by modelers generating example results with programs that did not automatically adjust for altitude. This Annex details the altitude correction used in the development of the analytical solutions of Standard 140. These corrections differ slightly from the 2009 ASHRAE Handbook—Fundamentals^{B3-1}. Section B3.3 discusses this in more detail.

B3.1 Adjustments for Section 5.2 Test Cases General Equation

The decline in air density with altitude may be expressed according to the following exponential curve fit:

$$\rho_{\text{air},u} = \rho_{\text{air},0} \times e^{(a)(\text{elev})} \quad (\text{B3-1})$$

B3.2 Adjustments for Section 5.2 Test Cases

where

$\rho_{\text{air},u}$ = air density at specified elevation
 $\rho_{\text{air},0}$ = air density at sea level
 e = inverse Ln
 a = $-1.219755 \times 10^{-4}/\text{m}$
 elev = elevation in meters (m).

Air density at sea level = 1.201385 kg/m³. (this example value is the SI conversion from 0.075 lb/ft³, which is the approximate value for air at 70°F, 14.696 psia; this value was used in IEA BESTEST¹⁷ (Appendix B), and is also cited for “standard air (I-P)” in ASHRAE Terminology of HVAC&R¹).

Air density at 1609 m = 0.987298 kg/m³.

The corrected infiltration rate for 1609 m altitude = (specified rate) × (0.987298/1.201385). (For example, 0.5 ach becomes 0.41 ach, and 1 ach becomes 0.822 ach.)

The corrected vent-fan capacity for 1609 m altitude = (specified capacity using converted I-P conditions under standard conditions at sea-level) × (0.987298/1.201385). (For example, 1703.16 Sm³/h becomes ~~1400~~1399.7 m³/h.) **Note:** Standard conditions (S)—U.S. Standard Atmospheric conditions: with dry air behaving as a perfect gas; at 15°C; and 101.325 kPa (2005 ASHRAE Handbook—Fundamentals, ³ p. 6.1), implies air density = 1.225 kg/m³; Sm³/h—standard cubic meters per hour.

B3.23 Adjustments for Section 7.2 Test Cases

The decline in air density with altitude may be expressed according to the following exponential curve fit:

$$\rho_{\text{air},u} = \rho_{\text{air},0} \times e^{(a)(\text{elev})}$$

For HERS BESTEST^{B-1} parameters of Equation. B3-1 are:

$\rho_{\text{air},u}$ = Air density at specified elevation
 $\rho_{\text{air},0}$ = Air density at sea level = 0.075 lb/ft³ (approximate value)
 e = Inverse Ln
 a = $-3.71781196 \times 10^{-5}/\text{ft}$
 elev = elevation in feet (ft)

This results in:

Air density at 6145 ft = 0.05968 lb/ft³
 Air density at 2178 ft = 0.06917 lb/ft³.

If the software being tested does not allow variation of air density, the specified infiltration rate is adjusted as:

Corrected Infiltration Rate for 6145 ft altitude =
 (Specified Rate) x (0.05968/0.075)
 Corrected Infiltration Rate for 2178 ft altitude =
 (Specified Rate) x (0.06917/0.075)

Table B3-1 summarizes the appropriate variation of infiltration rates from HERS BESTEST specified values for the base case (Case L100A) and cases where infiltration rates or building air volume have varied. These corrections are only to be used with software that does not automatically account for local variations in air density.

Table B3-1 also includes values of equivalent thermal conductance due to infiltration (UA_{inf}) corresponding to altitude-corrected air densities where

$$UA_{inf} = \rho_{air,u} \times V \times c_p$$

and where

V = volumetric air flow rate (ft³/h) converted from values in Table B3-1

c_p = specific heat of air = 0.240 Btu/(lb_m·°F).

Table B3-1. HERS BESTEST Infiltration Rate Adjustment for Altitude

	Air Volume		ACH	CFM	UA _{inf} Btu/h·°F
	(Note 1) ft ³	Altitude ft			
CASE L100A	12312	-	-	-	-
HERS w/ automatic altitude adjustment			0.67	137.5	-
HERS w/ site fixed at sea level					-
Colorado Springs, CO		6145	0.533	109.4	118.2
Las Vegas, NV		2178	0.618	126.8	136.9
CASE L110A	12312	-	-	-	-
HERS w/ automatic altitude adjustment			1.50	307.8	-
HERS w/ site fixed at sea level					-
Colorado Springs, CO		6145	1.194	244.9	264.5
Las Vegas, NV		2178	1.383	283.9	306.6
CASE L322A (Note 2)	24624	-	-	-	-
HERS w/ automatic altitude adjustment			0.335	137.5	-
HERS w/ site fixed at sea level					-
Colorado Springs, CO		6145	0.267	109.4	118.2
ATTIC (ALL CASES)	3463	-	-	-	-
HERS w/ automatic altitude adjustment			2.40	138.5	-
HERS w/ site fixed at sea level					-
Colorado Springs, CO		6145	1.910	110.2	-
Las Vegas, NV		2178	2.213	127.7	-
Note 1: Air volumes listed for specific cases only include those of the conditioned zone(s). Unconditioned attic air volume is listed separately.					
Note 2: Only used if basement model combines main floor and basement zones into a single aggregate zone. Otherwise, Case L322A main floor zone uses the Case L100A infiltration rate and the basement zone infiltration rate is 0 ach.					

B3.3 Comparison with ASHRAE Handbook—Fundamentals

The altitude correction in Sections B3.1 and B3.2 was created by fitting an exponential curve to data in the 1993 ASHRAE Handbook—Fundamentals²¹, chapter 6, Table 1. Starting in 2001 the ASHRAE Handbook—Fundamentals included an equation for calculating altitude corrections in addition to the tabular data. This equation is slightly different from that described in this annex, with a maximum difference of 0.2%.

The decline in atmospheric pressure with altitude is presented in the ASHRAE Handbook—Fundamentals^{B3-1}, page 1.1, equation 3 as:

$$p = 101.325(1 - 2.25577 \times 10^{-5}Z)^{5.2559}$$

where

p = atmospheric pressure at elevation (bar)
Z = elevation in meters (m)

A dimensionless altitude correction factor for pressure or density (these are directly proportional assuming air is an ideal gas) can be expressed as:

$$cf = (1 - 2.25577 \times 10^{-5}Z)^{5.2559}$$

In the Annex B3, Section B3.1 example, infiltration of 1 ach at an elevation of 1609 meters is equivalent to 0.8218 ach using the Annex B3 equation versus 0.8234 ach at sea level using the ASHRAE Handbook—Fundamentals equation.

Existing results tables (including with the accompanying electronic media) are not shown here.

INFORMATIVE ANNEX B8 EXAMPLE RESULTS FOR BUILDING THERMAL ENVELOPE AND FABRIC LOAD TESTS OF SECTION 5.2

The Example results from various detailed building energy simulation programs that applied the tests of Section 5.2 are presented here in tabular and graphic form in the electronic media provided with this standard. These results can be used for a comparison with the software being tested. Alternatively, a user can run a number of different programs through the Standard Method of Test and draw comparisons from those results independently or in conjunction with the results listed here. In either case, when making comparisons the user should employ the diagnostic

logic presented in informative Annex B9, Section B9.4.

For generating example simulation results presented in this annex, along with using consistent modeling methods, simulationists were requested to use the most detailed modeling methods their software allows consistent with the level of detail provided in the test specifications. The building energy simulation computer programs used to generate example results are described in informative Annex B11. These computer programs 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. In Regarding the presented results, to the extent possible input errors or differences have been eliminated. Thus, for a given case the range of differences between results presented in the informative Annex B8 represents algorithmic differences among these computer programs for comparative envelope tests. For any given case, a tested program may fall outside this range without necessarily being incorrect. However, it is worthwhile to investigate the source of significant 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 mis-entered one or more program inputs;
- (b) problem with a particular algorithm in the program;
- (c) 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 example results should not be perceived as better or worse than a program that yields values at the borders of the range.

B8.1 Thermal Envelope and Fabric Load Tests of Section 5.2. Example results are included in the file RESULTS5-2.PDF on the electronic media accompanying this standard. Nomenclature used in the tables and figures are defined in Section B8.2 and

listings of the tables and figures are provided in Section B8.3.

For the convenience of users who wish to plot or tabulate their results along with the example results, an electronic version of the example results has been included with the file RESULTS5-2.XLS on the electronic media provided with this standard accompanying diskette. Section B8.2 Nomenclature and B8.3 formatted table and figure listings apply to this file as well. Further documentation regarding RESULTS5-2.XLS has been included with the file and is printed out in informative Annex B10, Section B10.1 for convenience.

For generating these results, along with using consistent modeling methods, simulationists were requested to use the most detailed modeling methods their software allows. For a summary of how example results were developed see informative Annex B11. For more detailed information about the example results see *IEA BESTEST*⁷.

B8.2 Nomenclature for RESULTS5-2.PDF and RESULTS5-2.XLS

Abbreviations and acronyms used in the result tables and figures are defined below. Results are grouped by case numbers; e.g., "395" is Case 395 (Section 5.2.3.16). Sensitivity results are listed using two case numbers separated by a minus sign; e.g., "610-600" is the difference between Case 610 (Section 5.2.2.1.1) and Case 600 (Section 5.2.1).

<u>Abs.</u>	<u>Absorptance</u>
<u>ABS</u>	<u>Absolute value</u>
<u>ALLCODE</u>	<u>relating to a summary of all listed results</u>
<u>BEL-BRE/UK</u>	<u>Modeler: Belgium, Vrije Universiteit / United Kingdom, Building Research Establishment</u>
<u>BLAST</u>	<u>Simulation model BLAST 3.0 level 193 v. 1 (see Table B11-1)</u>
<u>BRE</u>	<u>Modeler: Building Research Establishment (see Table B11-1)</u>
<u>C</u>	<u>sensible cooling load sensitivity</u>
<u>CLDY</u>	<u>cloudy day results</u>
<u>CLR</u>	<u>clear day results</u>
<u>COOL</u>	<u>annual sensible cooling load sensitivity</u>
<u>Conv</u>	<u>Convection</u>

<u>DELTA</u>	<u>difference sensitivity between listed cases (sensitivity)</u>
<u>DOE21D</u>	<u>Simulation model DOE2.1D 14 (see Table B11-1)</u>
<u>DMU</u>	<u>Modeler: De Montfort University, U.K. (see Table B11-1)</u>
<u>E</u>	<u>East</u>
<u>Ext</u>	<u>Exterior</u>
<u>ESP</u>	<u>Simulation Model ESP-RV8 (see Table B11-1)</u>
<u>ESP-DMU</u>	<u>ESP-RV8 (see Table B11-1)</u>
<u>EW.SHADE</u>	<u>east and west windows with overhangs and fins</u>
<u>EW.WIN</u>	<u>east and west windows</u>
<u>E&W</u>	<u>east and west windows</u>
<u>HIMASS</u>	<u>heavyweight construction</u>
<u>HEAT</u>	<u>annual heating load sensitivity</u>
<u>H</u>	<u>heating load sensitivity</u>
<u>H/C</u>	<u>heating and cooling</u>
<u>Hr</u>	<u>hour</u>
<u>Htg.</u>	<u>Heating</u>
<u>Int</u>	<u>interior</u>
<u>IR</u>	<u>infrared radiation</u>
<u>kW</u>	<u>kilowatt</u>
<u>kWh/m²</u>	<u>kilowatt-hours per square meter</u>
<u>LOMASS</u>	<u>lightweight construction</u>
<u>Max</u>	<u>maximum</u>
<u>MAX/MIN</u>	<u>maximum : minimum</u>
<u>Min</u>	<u>minimum</u>
<u>MWh</u>	<u>megawatt-hour</u>
<u>NREL</u>	<u>Modeler: National Renewable Energy Laboratory</u>
<u>NT.VENT</u>	<u>night ventilation control strategy</u>
<u>Op.</u>	<u>operable</u>
<u>Op.P.Win</u>	<u>opaque window/high conductance wall</u>
<u>Orient</u>	<u>orientation</u>
<u>OP.WINDOW</u>	<u>opaque window/high conductance wall</u>
<u>PCOOL</u>	<u>peak hour sensible cooling load sensitivity</u>
<u>PHEAT</u>	<u>peak hour heating load sensitivity</u>
<u>S</u>	<u>south</u>
<u>S._SHADE</u>	<u>south overhang</u>
<u>S.WIN</u>	<u>south window</u>
<u>S._WINDOW</u>	<u>south window</u>
<u>SERIRES</u>	<u>Simulation model SERIRES 1.2 (see Table B11-1)</u>
<u>SETBACK</u>	<u>setback thermostat control strategy</u>
<u>Sol</u>	<u>solar</u>

SOLRAD	solar radiation	UK-DMU	United Kingdom, De Montfort University
SRESBRE	Simulation model SERIRES 1.2 (see Table B11-1)	VENT	night ventilation control strategy
SRESSUN	SERIRES/SUNCODE 5.7 (see Table B11-1)	w/	with
SRES-BRE	SERIRES 1.2 (see Table B11-1)	W	west
SRES-/SUN	Simulation model SERIRES/SUNCODE 5.7 (see Table B11-1)	WALL	no windows or opaque windows/high conductance walls
S3PAS	Simulation model S3PAS (see Table B11-1)	Win	window
Surf	surface	900SOUTH	Case 900 south window
TASE	Simulation model TASE (see Table B11-1)	910SOUTH	Case 910 south window
TMP	temperature	920WEST	Case 920 west window
Temp	temperature	930WEST	Case 930 west window
TRNSYS	TRNSYS 13.1 (see Table B11-1)	Y	year
TSYS	Simulation model TRNSYS 13.1 (see Table B11-1)	<i>Existing results tables and figures in Annex B8 of Standard 140-2007 are deleted from the printed version of Standard 140; they remain in the accompanying electronic files.</i>	
TSYS-BEL/BRE	TRNSYS 13.1 (see Table B11-1)	B8.3 Listing of Tables and Figures	
USA	USA, National Renewable Energy Laboratory	The following example result tables and figures are included in the RESULTS5-2.PDF and RESULTS5-2.XLS files. The RESULTS5-2.PDF file presents these tables and figures sequentially. The Sheet and Cell Range columns are only applicable to the RESULTS5-2.XLS file.	
US-AT	Modeler: USA, National Renewable Energy Laboratory / Italy, Politecnico Torino		
UK-BRE	United Kingdom, Building Research Establishment		

Example Result Tables

Table	Description	Sheet	Cell Range
Table B8-1	Annual Heating Loads	Tables 1	A7 – P47
Table B8-2	Annual Sensible Cooling Loads		A48 – P89
Table B8-3	Annual Hourly Integrated Peak Heating Loads	Tables 2	A7 – AH47
Table B8-4	Annual Hourly Integrated Peak Sensible Cooling Loads		A48 – AH88
Table B8-5	Free-Float Temperature Output		A89 – AH118
Table B8-6	Low Mass Basic Sensitivity Tests	Tables 3	A7 – P39
Table B8-7	High Mass Basic Sensitivity Tests		A41 – P81
Table B8-8	Low Mass In-Depth (Cases 195 thru 320) Sensitivity Tests	Tables 4	A7 – P81
Table B8-9	Low Mass In-Depth (Cases 395 thru 440) Sensitivity Tests	Tables 5	A7 – P45
Table B8-10	High Mass Basic and In-depth Sensitivity Tests.		A47 – P91
Table B8-11	Annual Transmissivity Coefficient of Windows	Tables 6	A7 – O14
Table B8-12	Annual Shading Coefficient of Window Shading Devices: Overhangs & Fins		A16 – O23
Table B8-13	Case 600 Annual Incident Solar Radiation (kWh/m ²)		A25 – O34
Table B8-14	Case 600 Annual Transmitted Solar Radiation – Unshaded (kWh/m ²)		A36 – O42
Table B8-15	Case 600 Annual Transmitted Solar Radiation – Shaded (kWh/m ²)		A44 – O50

Example Result Figures

Figure	Title	Sheet Tab
B8-1	BESTEST BASIC Annual Incident Solar Radiation	Fig B8-1 Ann Incident Solar
B8-2	BESTEST BASIC Annual Transmitted Solar Radiation Unshaded	Fig B8-2 Ann SolRad Unshaded
B8-3	BESTEST BASIC Annual Transmitted Solar Radiation Shaded	Fig B8-3 Ann SolRad Shaded
B8-4	BESTEST BASIC Annual Transmissivity Coefficient of Windows (Unshaded Transmitted)/(Incident Solar Radiation)	Fig B8-4 Trans Coeff
B8-5	BESTEST BASIC Annual Overhang and Fin Shading Coefficients (1-(Shaded)/(Unshaded)) Transmitted Solar Radiation	Fig B8-5 OH&Fin Shade Coeff
B8-6	BESTEST BASIC Low Mass Annual Heating	Fig B8-6 Lomass Ann Heat
B8-7	BESTEST BASIC Low Mass Annual Sensible Cooling	Fig B8-7 Lomass Ann Cool
B8-8	BESTEST BASIC Low Mass Peak Heating	Fig B8-8 Lomass Peak Heat
B8-9	BESTEST BASIC Low Mass Peak Sensible Cooling	Fig B8-9 Lomass Peak Cool
B8-10	BESTEST BASIC High Mass Annual Heating	Fig B8-10 Himass Ann Heat
B8-11	BESTEST BASIC High Mass Annual Sensible Cooling	Fig B8-11 Himass Ann Cool
B8-12	BESTEST BASIC High Mass Peak Heating	Fig B8-12 Himass Peak Heat
B8-13	BESTEST BASIC High Mass Peak Sensible Cooling	Fig B8-13 Himass Peak Cool
B8-14	BESTEST BASIC Maximum Hourly Annual Temperature Free-Float Cases	Fig B8-14 FF Maximum Temp
B8-15	BESTEST BASIC Minimum Hourly Annual Temperature Free-Float Cases	Fig B8-15 FF Minimum Temp
B8-16	BESTEST BASIC Average Hourly Annual Temperature Free-Float Cases	Fig B8-16 FF Average Temp
B8-17	BESTEST BASIC South Window Shading (Delta) Annual Heating and Sensible Cooling	Fig B8-17 Delta-S Shade-Load
B8-18	BESTEST BASIC South Window Shading (Delta) Peak Heating and Sensible Cooling	Fig B8-18 Delta-S Shade-Peak
B8-19	BESTEST BASIC East & West Window (Delta) Annual Heating and Sensible Cooling	Fig B8-19 Delta-E&W-Load
B8-20	BESTEST BASIC East & West Window (Delta) Peak Heating and Sensible Cooling	Fig B8-20 Delta-E&W-Peak
B8-21	BESTEST BASIC East & West Shaded Window (Delta) Annual Heating and Sensible Cooling	Fig B8-21 Delta-E&WShade-Load
B8-22	BESTEST BASIC East & West Shaded Window (Delta) Peak Heating and Sensible Cooling	Fig B8-22 Delta-E&WShade-Peak
B8-23	BESTEST BASIC Thermostat Setback (Delta) Annual Heating	Fig B8-23 Delta-TSetback-Heat
B8-24	BESTEST BASIC Thermostat Setback (Delta) Peak Heating	Fig B8-24 Delta-TSetback-Peak
B8-25	BESTEST BASIC Vent Cooling (Delta) Annual Sensible Cooling	Fig B8-25 Delta-VentCool-Load
B8-26	BESTEST BASIC Vent Cooling (Delta) Peak Sensible Cooling	Fig B8-26 Delta-VentCool-Peak
B8-27	BESTEST BASIC Sunspace (Delta) Annual Heating and Sensible Cooling	Fig B8-27 Delta-Sunspace-Load
B8-28	BESTEST BASIC Sunspace (Delta) Peak Heating and Sensible Cooling	Fig B8-28 Delta-Sunspace-Peak

Figure	Title	Sheet Tab
B8-29	BESTEST BASIC AND IN-DEPTH Mass Effect (Delta) Annual Heating and Sensible Cooling	Fig B8-29 Delta-Mass Effect-Ann
B8-30	BESTEST BASIC AND IN-DEPTH Mass Effect (Delta) Peak Heating and Sensible Cooling	Fig B8-30 Delta-Mass Effect-Pk
B8-31	BESTEST IN-DEPTH South Window (Delta) Annual Heating and Sensible Cooling	Fig B8-31 Delta-S Win-Ann
B8-32	BESTEST IN-DEPTH South Window (Delta) Peak Heating and Sensible Cooling	Fig B8-32 Delta-S Win-Peak
B8-33	BESTEST IN-DEPTH Low Mass Annual Heating Cases 195 to 250	Fig B8-33 Indepth 1
B8-34	BESTEST IN-DEPTH Low Mass Annual Sensible Cooling Cases 195 to 250	Fig B8-34 Indepth 2
B8-35	BESTEST IN-DEPTH Low Mass Peak Heating Cases 195 to 250	Fig B8-35 Indepth 3
B8-36	BESTEST IN-DEPTH Low Mass Peak Sensible Cooling Cases 195 to 250	Fig B8-36 Indepth 4
B8-37	BESTEST IN-DEPTH Low Mass Annual Heating Cases 270 to 320	Fig B8-37 Indepth 5
B8-38	BESTEST IN-DEPTH Low Mass Annual Sensible Cooling Cases 270 to 320	Fig B8-38 Indepth 6
B8-39	BESTEST IN-DEPTH Low Mass Peak Heating Cases 270 to 320	Fig B8-39 Indepth 7
B8-40	BESTEST IN-DEPTH Low Mass Peak Sensible Cooling Cases 270 to 320	Fig B8-40 Indepth 8
B8-41	BESTEST IN-DEPTH Cases 195 to 220 (Delta) Annual Heating and Sensible Cooling	Fig B8-41 Indepth Delta 1
B8-42	BESTEST IN-DEPTH Cases 195 to 220 (Delta) Peak Heating and Sensible Cooling	Fig B8-42 Indepth Delta 2
B8-43	BESTEST IN-DEPTH Cases 220 to 270 (Delta) Annual Heating and Sensible Cooling	Fig B8-43 Indepth Delta 3
B8-44	BESTEST IN-DEPTH Cases 220 to 270 (Delta) Peak Heating and Sensible Cooling	Fig B8-44 Indepth Delta 4
B8-45	BESTEST IN-DEPTH Cases 270 to 320 (Delta) Annual Heating and Sensible Cooling	Fig B8-45 Indepth Delta 5
B8-46	BESTEST IN-DEPTH Cases 270 to 320 (Delta) Peak Sensible Cooling	Fig B8-46 Indepth Delta 6
B8-47	BESTEST IN-DEPTH Annual Heating Cases 395 to 440, 800, 810	Fig B8-47 Indepth 9
B8-48	BESTEST IN-DEPTH Annual Sensible Cooling Cases 395 to 440, 800, 810	Fig B8-48 Indepth 10
B8-49	BESTEST IN-DEPTH Peak Heating Cases 395 to 440, 800, 810	Fig B8-49 Indepth 11
B8-50	BESTEST IN-DEPTH Peak Sensible Cooling Cases 395 to 440, 800, 810	Fig B8-50 Indepth 12
B8-51	BESTEST IN-DEPTH Cases 395 to 600 (Delta) Annual Heating and Sensible Cooling	Fig B8-51 Indepth Delta 7
B8-52	BESTEST IN-DEPTH Cases 395 to 600 (Delta) Peak Heating and Sensible Cooling	Fig B8-52 Indepth Delta 8
B8-53	BESTEST Case 900FF Annual Hourly Temperature Frequency	Fig B8-53 Hrly-Temp Freq

Figure	Title	Sheet Tab
B8-54	BESTEST Case 600 Cloudy & Clear Day Hourly Incident Solar South Facing Surface	Fig B8-54 Hrly-IncidentSol-S
B8-55	BESTEST Case 600 Cloudy & Clear Day Hourly Incident Solar West Facing Surface	Fig B8-55 Hrly-IncidentSol-W
B8-56	BESTEST HOURLY FREE FLOAT TEMPERATURES Clear Cold Day - Cases 600FF and 900FF	Fig B8-56 Hrly-FF Temp-ColdDay
B8-57	BESTEST HOURLY FREE FLOAT TEMPERATURES Clear Hot Day - Cases 650FF and 950FF	Fig B8-57 Hrly-FF Temp-HotDay
B8-58	BESTEST HOURLY LOADS Clear Cold Day, Case 600 Heating (+), Sensible Cooling (-)	Fig B8-58 Hrly-Loads-Case600
B8-59	BESTEST HOURLY LOADS Clear Cold Day, Case 900 Heating (+), Sensible Cooling (-)	Fig B8-59 Hrly-Loads-Case900

**INFORMATIVE ANNEX B10
Instructions for Working with Results
Spreadsheets Provide with Standard**

For the convenience of users, a printout of documentation for navigating the example results files is included below.

B10.1 Documentation for RESULTS5-2.XLS (given in RESULTS5-2.DOC). This spreadsheet contains the IEA 12B/21C participant results that are presented as informative example results for the Section 5.2 Building Thermal Envelope and Fabric Load Tests as described in Annex B8. Table B10-1 presents an index of all sheets contained in the RESULTS5-2.XLS file.

The “ReadMe” sheet provides a general over-view of the file. Example results tables and figures are listed with location (sheet tab and cell range) in Annex B8,

Section B8.3 and also on the “Table List” and “Figure List” sheets in the XLS file.

New results can be imported to the “YourData” sheet and will automatically appear in all tables and also in the graphic figures. The “YourData” sheet has been designed with the same data structure (data units, format and position) as the Standard Output Report spreadsheet Sec5-2out.XLS file so that new results can be copied directly. Import data so that Cell B61 of Sec5-2out.XLS is in B61 of Sheet “YourData”. Check that the first value (Annual Heating Load for Case 600) is in YourData!B65. The “Adding Results” sheet has instructions for accomplishing this and also has a full tabulation of results locations. New results data will appear in the rightmost column of each table and in all figures.

To print example results or example results with new user generated results, go to the “Title Page” sheet and follow the instructions starting in cell B5.

Table B10-1. Index of Sheets in RESULTS5-2.XLS

Sheet	Description
“Read Me”	General directions to using this workbook.
“Adding Results”	Instructions for adding new results. Also has cell map to individual data items in example results and “YourData” sheets.
“YourData”	For inputting new simulation test results; see sheet “Adding Results” for instructions. Data input to this sheet will pass through into all tables and charts.
“Title Page”	Title Page for printed informative example or new comparison results. Sets headers for tables and charts. See instructions on page.
“Program List”	List of simulation programs and organization producing Annex B8 example results.
“Table List”	Listing of Informative Annex B8 tables with locations.
“Figure List”	Listing of Informative Annex B8 figures with locations.
“Tables 1” through “Tables 6” (6 sheets)	Formatted summary results tables including example simulation results and statistics. See Annex B8, Section B8.3 or the “Table List” sheet in RESULTS5-2.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “YourData”) automatically appears on the right side of each table.
“Fig B8-1 Ann Incident Solar” through “Fig B8-59 Hrly-Loads-Case900” (59 sheets)	59 summary charts (one per sheet). See Annex B8, Section B8.3 or the “Figure List” sheet in RESULTS5-2.XLS for a list of all figures with sheet tab location.
“data for charts”	Unformatted data for use by the 59 charts. New results (entered in sheet “YourData”) automatically appear on the right side of each data table.
“ESP-DMU” through “TASE” (8 sheets)	Results sheets from each simulation program used to produce example results.

B10.2 Documentation for RESULTS5-3A.XLS (given in RESULTS5-3A.DOC). This file contains informative example results generated for the Section 5.3 HVAC Equipment Performance Tests CE100-CE200 as described in Annex B16, Section B16.5.1. Table B10-2 presents an index of all sheets contained in the RESULTS5-3A.XLS file.

The “Read Me” sheet provides a general over view of the file. Example results tables and figures are listed with location (sheet tab and cell range) in Annex B16, Section B16.5.1 and also on the “Table List” and “Figure List” sheets in the XLS file.

New results can be imported to the “YourData” sheet and will automatically appear in the rightmost

column of all tables and also in the graphic figures. The “YourData” sheet has been designed with the same data structure (data units, format and position) as the Standard Output Report spreadsheet Sec5-3Aout.XLS file so that new results can be copied directly. Import data so that Cell B25 of Sec5-3Aout.XLS is in B25 of Sheet “YourData”. Check that the first value (Total Consumption kWh for CE100) is in YourData!B25. The “Adding Results” sheet has instructions for accomplishing this, and also has a full tabulation of results locations.

To print example results or example results with new user generated results go to the “Title Page” sheet and follow the instructions starting in cell B5.

Table B10-2. Index of Sheets in RESULTS5-3A.XLS

Sheet	Description
“Read Me”	General directions to using workbook.
“Adding Results”	Instructions for adding new results. Also has cell map to individual data items in example results and “YourData” sheets.
“YourData”	For inputting new simulation test results; see sheet “Adding Results” for instructions. Data input to this sheet will pass through into all tables and charts.
“Title Page”	Title Page for printed informative example or new comparison results. Sets headers for tables and charts. See instructions on page.
“Program List”	List of simulation programs and organization producing Annex B16, Section B16.5.1 example results
“Table List”	Listing of Informative Annex B16, Section B16.5.1 tables with locations.
“Figure List”	Listing of Informative Annex B16, Section B16.5.1 figures with locations.
“Q-Prt1” through “Q-Prt7” (7 sheets)	Formatted summary results tables including quasi-analytical solution results, example simulation results, and statistics. See Annex B16, Section B16.5.1 or the “Table List” sheet in RESULTS5-3A.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “YourData”) automatically appear on the right side of each table.
“Fig B16.5.1-1 COP” through “Fig B16.5.1-26 QCL-QZL” (26 sheets)	26 summary charts (one per sheet). See Annex B16, Section B16.5.1 or the “Figure List” sheet in RESULTS5-3A.XLS for a list of all figures with sheet tab location.
“A”	Unformatted data compilation, all programs
“Q”	Formatted summary results tables including quasi-analytical solution results, example simulation results, and statistics. Data here feeds into data sheets for use in charts. Same tables are presented one per sheet on sheets Q-Ptr1 to Q-Ptr7. New results (entered in sheet “YourData”) automatically appear on the right side of each table. See below for Sheet Q table locations.
“Data-Electr” through “Data- TempHum” (5 sheets)	Formatted data sheets for use by the 26 data charts. New results (entered in sheet “YourData”) automatically appear on the right side of each data table.
“DOE21E-NREL” through “E+V1” (7 sheets)	Results sheets from each simulation program used to produce example results.
“Analytical-TUD” through “Analytical-HTAL2” (3 sheets)	Individual quasi-analytical solution results.

B10.3 Documentation for RESULTS5-3B.XLS (given in RESULTS5-3B.DOC). This file contains informative example results generated for the Section 5.3 HVAC Equipment Performance Tests CE300-CE545 as described in Annex B16, Section B16.5.2. Table B10-3 presents an index of all sheets contained in the RESULTS5-3B.XLS file.

The “Read Me” sheet provides a general over-view of the file. Example results tables and figures are listed with location (sheet tab and cell range) in Annex B16, Section B16.5.2 and also on the “Table List” and “Figure List” sheets in the XLS file.

New results can be imported to the “YourData” sheet and will automatically appear in the rightmost column of all tables and also in the graphic figures. The “YourData” sheet has been designed with the same data structure (data units, format and position) as the Standard Output Report spreadsheet Sec5-3Bout.XLS file so that new results can be copied directly. Import data so that Cell B62 of Sec5-3Bout.XLS is in B62 of Sheet “YourData”. Check that the first value (Total Consumption kWh for CE300) is in YourData!B62. The “Adding Results” sheet has instructions for accomplishing this, and also has a full tabulation of results locations.

To print example results or example results with new user generated results go to the “Title Page” sheet and follow the instructions starting in cell B5.

Table B10-3. Index of Sheets in RESULTS5-3B.XLS

Sheet	Description
“Read Me”	General directions to using this workbook.
“Adding Results”	Instructions for adding new results. Also has cell map to individual data items in example results and “YourData” sheets.
“YourData”	For inputting new simulation test results; see sheet “Adding Results” for instructions. Data input to this sheet will pass through into all tables and charts.
“Title Page”	Title Page for printed informative example or new comparison results. Sets headers for tables and charts. See instructions on page.
“Program List”	List of simulation programs and organization producing Annex B16, Section B16.5.2 example results
“Table List”	Listing of Informative Annex B16, Section B16.5.2 tables with locations.
“Figure List”	Listing of Informative Annex B16, Section B16.5.2 figures with locations.
“Table-Q”	Formatted summary results tables including example simulation annual mean results and statistics. See Annex B16, Section B16.5.2 or the “Table List” sheet in RESULTS5-3B.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “Your data”) automatically appear on the right side of each table.
“Table-R”	Formatted summary results tables including example simulation annual hourly maximum and minimum results and statistics. See Annex B16, Section B16.5.2 or the “Table List” sheet in RESULTS5-3B.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “Your data”) automatically appear on the right side of each table.
“Table-S”	Formatted summary results tables including example simulation June 28 hourly results. See Annex B16, Section B16.5.2 or the “Table List” sheet in RESULTS5-3B.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “Your data”) automatically appear in the bottommost table.
“Table-T”	Formatted summary results tables including example simulation sensitivities to annual mean, maximum and minimum results and statistics. See Annex B16, Section B16.5.2 or the “Table List” sheet in RESULTS5-3B.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “Your data”) automatically appear on the right side of each table.
“Fig B16.5.2-1 Qtot” through “Fig B16.5.2-52 HrOHR” (52 sheets)	Summary charts (one per sheet). See Annex B16, Section B16.5.2 or the “Figure List” sheet in RESULTS5-3B.XLS for a list of all figures with sheet tab location.
“A”	Unformatted raw data compilation for all programs. Used by other results tables.
“Qdata” through “Tdata” (4 sheets)	These sheets are similar to “Table-Q” thru “Table-T” but formatted for use as source data for charts .
“TRNSYS-TUD” through “HOT3000” (6 sheets)	Results sheets from each simulation program used to produce example results.

B10.4 Documentation for RESULTS5-4.XLS (given in RESULTS5-4.DOC). This file contains informative example results generated for the Section 5.4 HVAC Equipment Performance Tests HE100-HE230 as described in Annex B16, Section B16.6. Table B10-4 presents an index of all sheets contained in the RESULTS5-4.XLS file.

The “Read Me” sheet provides a general over-view of the file. Example results tables and figures are listed with location (sheet tab and cell range) in Annex B16, Section B16.6 and also on the “Table List” and “Figure List” sheets in the XLS file.

New results can be imported to the “YourData” sheet and will automatically appear in the rightmost

column of all tables and also in the graphic figures. The “YourData” sheet has been designed with the same data structure (data units, format and position) as the Standard Output Report spreadsheet Sec5-4out.XLS file so that new results can be copied directly. Import data so that Cell B20 of Sec5-4out.XLS is in B62 of Sheet “YourData”. Check that the first value (TOTAL FURNACE LOAD GJ for case HE100) is in YourData!B20. The “Adding Results” sheet has instructions for accomplishing this, and also a full tabulation of results locations.

To print example results or example results with new user generated results go to the “Title Page” sheet and follow the instructions starting in cell B6.

Table B10-4. Index of Sheets in RESULTS5-4.XLS

Sheet	Description
“Read Me”	General directions to using the workbook.
“Adding Results”	Instructions for adding new results. Also has cell map to individual data items in example results and “YourData” sheets.
“YourData”	For inputting new simulation test results; see sheet “Adding Results” for instructions. Data input to this sheet will pass through into all tables and charts.
“Title Page”	Title Page for printed informative example or new comparison results. Sets headers for tables and charts. See instructions on page.
“Program List”	List of simulation programs and organization producing Annex B16, Section B16.6 example results.
“Table&Figure List”	Listing of Informative Annex B16, Section B16.6 tables and figures with locations.
“Tables”	Formatted summary results tables including analytical/quasi-analytical solution results, example simulation results and statistics. See Annex B16, Section B16.6 or the “Table List” sheet in RESULTS5-4.XLS for a list of all tables with sheet tab and cell range location. New results (entered in sheet “Your data”) automatically appear on the right side of each table.
“Fig B6.6-1 LOAD” through “Fig B16.6-7 MIN T” (7 sheets)	7 summary charts (one per sheet). See Annex B16, Section B16.6 or the “Figure List” sheet in RESULTS5-4.XLS for a list of all figures with sheet tab location.
“A”	Unformatted raw data compilation, all programs used by tables.
“Q-Chart Data”	Unformatted data compilation, all programs. Used by charts.
“DOE21E” through “EnergyPlusV10” (3 sheets)	Results sheets from each simulation program used to produce example results.

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

ANNEX B13 COP DEGRADATION FACTOR (CDF) AS A FUNCTION OF PART-LOAD RATIO (PLR)

[Section B13.3 is appended to Annex B13, to include information on research regarding part load performance. This is all new material; underline/strikethrough editing is not applied.]

B13.3 Effect of Part Load Operation on Moisture Removal

The current set of reference results applies a simplifying assumption in the test specification (see Sections 5.3.1.10.1 and 5.3.3.10.1) that, “All ... moisture that condenses on the evaporator coil ... leaves the system through a condensate drain.” This simplifying assumption is common to the simulation tools used to develop the example results of Annex B16. Published work^{B13-1} indicates that this simplification deviates from reality at a part-load condition, and especially for single-stage systems where the indoor air distribution fan operates continuously, as in cases CE300-CE440. This is because of latent performance degradation caused by evaporation of condensate from the evaporator coil during the compressor off-cycle, which effectively causes a trade-off of reduced latent capacity for increased sensible capacity (or sensible zone-load reduction) because of the evaporative cooling that results. The latent performance degradation effect is reduced when the air distribution fan cycles on/off with the compressor, as in the CE100 and CE500 series cases. The researchers also note that most mainstream hourly whole-building energy simulation programs do not consider part-load latent performance degradation and therefore tend to overestimate moisture removal. Their article cites a study that showed 5%–10% underprediction of relative humidity levels in a typical small office application for a single-stage system with continuous air distribution fan operation in a humid climate. Related overprediction in energy use may be 5%–10%. The researchers have been working to

incorporate a part-load latent degradation model into EnergyPlus. One issue with the use of the model is that parameters necessary to accurately estimate latent performance degradation exist only for a limited number of cooling coils and equipment configurations. To address this, these researchers have been working to develop guidelines for selecting model parameters for a greater variety of cooling coils and equipment configurations.

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

ANNEX B16 ANALYTICAL AND QUASI-ANALYTICAL SOLUTION RESULTS AND EXAMPLE SIMULATION RESULTS FOR HVAC EQUIPMENT PERFORMANCE TESTS OF SECTIONS 5.3 AND 5.4

B16.1 Introduction

~~The Example~~ results from quasi-analytical solutions and various detailed building energy simulation programs applied to the tests of Section 5.3 and 5.4 are presented here-in tabular and graphic form in the electronic media provided with this standard. Example results for Section 5.3 tests are included with files RESULTS5-3A.PDF and RESULTS5-3B.PDF, and Section 5.4 test results are included in file RESULTS5-4.PDF. A listing of the tables and figures in these files can be found in Sections B16.5 and B16.6. These results can be used for a comparison with the software being tested. Alternatively, a user can run a number of different programs through the Standard Method of Test or generate their own quasi-analytical solution results and draw comparisons from those results independently or in conjunction with the results listed here. In either case, when making comparisons the user should employ the diagnostic logic presented in informative Annex B9.

For convenience to users who wish to plot or tabulate their results along with the ~~example results, an electronic version of the~~ analytical and quasi-

analytical solution results, and example simulation results, ~~has been included with the spreadsheet files RESULTS5-3A.XLS, RESULTS5-3B.XLS and RESULTS5-4.XLS~~ are included in the accompanying electronic media, in the accompanying files. Spreadsheet navigation instructions are included in RESULTS5-3A.DOC, RESULTS5-3B.DOC and RESULTS5-4.DOC, and have been printed out in informative Annex B10, Sections B10.2, B10.3 and B10.4, respectively, for convenience.

B16.2 Importance of Analytical and Quasi-Analytical Solution Results

A characteristic difference between the Annex B8 results for the building thermal envelope and fabric load tests versus the Annex B16 results for the HVAC equipment performance tests is that the Annex B16 results of Sections B16.5.1 and B16.6 include quasi-analytical solutions. In general, it is difficult to develop worthwhile test cases that can be solved analytically or quasi-analytically, but such solutions are extremely useful when possible. Analytical or quasi-analytical solutions represent a “mathematical truth standard”; that is, given the underlying physical assumptions in the case definitions, there is a mathematically correct solution for each case. In this context, the underlying physical assumptions regarding the mechanical equipment as defined in cases CE100-CE200 and HE100-HE170 are representative of typical manufacturer data normally used by building design practitioners. Many “whole-building” simulation programs are designed to work with this type of data.

It is important to understand the difference between a “mathematical truth standard” and an “absolute truth standard.” In the former, we only test the solution process for a model, not the appropriateness of the solution; that is, we accept the given underlying physical assumptions while recognizing that these assumptions represent a simplification of physical reality. An approximate truth standard from an experiment tests both the solution process and appropriateness of the model within experimental uncertainty. The ultimate or “absolute” validation truth standard would be comparison of simulation results with a *perfectly performed* empirical experiment, with all simulation inputs *perfectly defined*. In reality, an experiment is performed and the experimental object is specified within some acceptable range of uncertainty. Such experiments are possible, but expensive. We recommend

developing a set of empirical validation experiments in the future.

The quasi-analytical and analytical solution results presented in selected parts of Annex B16 represent a mathematical truth standard. This allows identification of bugs in the software that would not otherwise be apparent from comparing software only to other software and therefore improves the diagnostic capabilities of the test procedure. Further discussion of how quasi-analytical and analytical solutions were developed is included in Annex B17.

B16.3 Example Simulation Results

The building energy simulation computer programs used to generate example results are described in informative Annex B17.

B16.3.1 Results for Analytical Verification Tests.

B16.3.1.1 Because the quasi-analytical and analytical solution results constitute a reliable set of theoretical results (a mathematical truth standard), the primary purpose of including simulation results for the CE100-CE200 and HE100-HE170 cases in Sections B16.5.1 and B16.6 is to allow simulationists to compare their relative agreement (or disagreement) versus the quasi-analytical and analytical solution results to that for other simulation results. Perfect agreement among simulations and analytical or quasi-analytical solutions is not necessarily expected. The results give an indication of what sort of agreement is possible between simulation results and the analytical or quasi-analytical solution results.

B16.3.1.2 Because the physical assumptions of a simulation may be different from those for the analytical or quasi-analytical solutions, a tested program may disagree with such solutions without necessarily being incorrect. However, it is worthwhile to investigate the sources of the differences.

B16.3.2 Results for Comparative Tests. The computer programs used to generate example results for Section B16.5.2 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. Regarding the presented results, input errors or differences have been eliminated to the extent possible. Thus, for a given case the range of differences between results presented in informative Section B16.5.2 represents algorithmic differences among these computer programs for comparative space cooling equipment tests. For any given case, a tested program may fall outside the range of given example results without necessarily being incorrect. Also for any given case, a program that yields values in the middle of the range of the example results should not be perceived as better or worse than a program that yields values at the borders of the range.

B16.3.3 General Comments Regarding Simulation Results.

B16.3.3.1 It is worthwhile to investigate the source of differences for a given set of simulation results in both the analytical verification and comparative tests because 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 mis-entered one or more program inputs;
- b. a problem with a particular algorithm in the program;
- c. one or more program algorithms used outside their intended range.

B16.3.3.2 For generating example simulation results presented in this annex, along with using consistent modeling methods, simulationists were requested to use the most detailed modeling methods their software allows. The example simulation results were

the product of numerous iterations to incorporate clarifications to the test specification, simulation input file corrections, and simulation software improvements. Where improvements to simulation programs or simulation inputs were made as a result of running the tests, such improvements must have mathematical and physical bases and must be applied consistently across tests. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed. For a summary of how quasi-analytical solution and simulation results were developed see informative Annex B17. For more detailed information about these results see *HVAC BESTEST Volume 1*⁷, *HVAC BESTEST Volume 2*⁸ and *HVAC BESTEST For Fuel-Fired Furnaces*³⁸.

B16.3.3.3 For consistent numbering of test cases within the standard, case numbers used for the mechanical equipment tests in Sections 5.3 and 5.4 have been changed from the numbering used in the original research reports where the test specifications were developed. For example, in Section 5.3.1, "Case CE100" was named "Case E100" in the original research.

B16.4 Nomenclature

Abbreviations and acronyms used in the result tables and figures are defined below. Results are grouped by case numbers, e.g., "CE100" is Case CE100 (Section 5.3.1). Sensitivity results are listed using two case numbers separated by a minus sign, e.g., "CE110-100" is the difference between Case CE110 (Section 5.3.2.1.1) and Case CE100. Some cases are denoted with a case number followed by "as" and a number denoting another case. This indicates the case is similar to the "as" case except for the noted changes.

abs	<u>absolute value</u>
Analytical	quasi-analytical solution
Apr	April
ARI	Air-Conditioning & Refrigeration Institute
Aug	August
CA-SIS	<u>simulation model: CA-SIS VI (see Table B17-1)</u>
CETC	<u>modeler: CANMET Energy Technology Centre, Natural Resources Canada, Canada</u>
CIEMAT	<u>modeler: Centro de Investigaciones Energeticas, Medioambientales y</u>

	Technologicas
Circ	<u>circulation</u>
CLM2000	<u>simulation model</u> : CLIM2000 2.1.6 (see Table B17-1)
CODYRUN	<u>simulation model</u> : CODYRUN/LGIMAT (see Table B17-2)
Comp.	compressor
Compr.	compressor
COP	coefficient of performance
COP2	alternative coefficient of performance, see Section 3.1
Ctrl.	control
Dec	December
Del	difference <u>sensitivity</u> between listed cases (<u>sensitivity</u>)
Delta	<u>difference</u> sensitivity between listed cases (<u>sensitivity</u>)
DOE21E	<u>simulation model</u> : DOE-2.1E ESTSC version 088, or DOE-2.1E JHirsch version 133 (see Table B17-1) (for Section B16.5.1)
DOE21E-E	<u>simulation model</u> : DOE-2.1E, ESTSC version 120 (see Table B17-2) (for Section B16.5.2)
DOE-2.1E	<u>simulation model</u> : DOE-2.1E ESTSC version 088 (<u>see Table B17-1</u>) (for Section B16.5.1), or DOE-2.1E JHirsch version 133 (<u>see Tables B17-1 and B17-3</u>) (for Sections B16.5.1 and B16.6)
DOE-2.1E-E	<u>simulation model</u> : DOE-2.1E, ESTSC version 120 (see Table B17-2) (for Section B16.5.2)
DOE-2.2	<u>simulation model</u> : DOE-2.2 version NT42j (see Table B17-2)
dry	dry coil
Ec.	economizer
EDB	<u>dry-bulb temperature of cooling coil entering air</u>
EDF	Electricité de France
eff	<u>efficient</u>
E+	<u>simulation model</u> : EnergyPlus 1.0.0.023 (see Table B17-1) (for Section B16.5.1)
EnergyPlus	<u>simulation model</u> : EnergyPlus 1.0.0.023 (see Table B17-1) (for Section B16.5.1), <u>EnergyPlus 1.1.0.020</u> (see Table B17-2) (for Section B16.5.2), or EnergyPlus 1.0.2.008 (<u>see Table B17-3</u>) (for Section B16.6)
Enth	Enthalpy
ESP-r/HOT3000	<u>simulation model</u> : <u>ESP-r/HOT3000</u> (see Table B17-2) (for Section B16.5.2) <u>ESP-r/HOT3000 version 1.7</u> (see Table B17-3) (for Section B16.6)
EWB	<u>wet-bulb temperature of cooling coil entering air</u>
Feb	February
GARD	<u>modeler</u> : GARD Analytics
h	<u>hour</u>
hHi	high
HOT3000	<u>simulation model</u> : <u>see ESP-r/HOT3000/ESP-r</u> (see Table B17-2)
HTAL1	quasi-analytical solution with ideal controller by Hochschule Technik & Architektur Luzern
HTAL2	quasi-analytical solution with realistic controller model by Hochschule Technik & Architektur Luzern

Hum.	humidity
IDB	indoor dry-bulb temperature
Inf or Infl	infiltration
Jan	January
Jul	July
Jun	June
kWh	kilowatt hours
kWh,e	kilowatt hours, electrical
kWh,th	kilowatt hours, thermal
lat	latent internal gains
Lim.	limit
lo	low
m	mid-range
Mar	March
Max	maximum
Min	minimum
Nov	November
NRCan	<u>modeler</u> : Natural Resources Canada, <u>also see</u> <i>CETC</i>
NREL	<u>modeler</u> : National Renewable Energy Laboratory
OA	<u>outdoor</u> (outside) air
Oct	October
OD	outdoor
ODB	outdoor dry-bulb temperature
OHR	outdoor humidity ratio
Org	<u>organization</u>
PL	part-load ratio
PLR	part-load ratio
Prg	<u>simulation program</u>
Qcoil,lat	latent coil load
Qcoil,s	sensible coil load
Qcoil,t	total sensible + latent coil load
Qcomp	compressor electric energy
Q ID fan	indoor fan electric energy
Q OD fan	outdoor fan electric energy
Qtot	total electric energy of compressor + both fans
sens	sensible internal gains
Sep	September
SH	sensible heat ratio
SHR	sensible heat ratio
T	temperature
Temp.	temperature
TRNSYS	<u>simulation model</u> : TRNSYS-TUD (see Table B17-2)
TRN-id₁	<u>simulation model</u> : TRNSYS-TUD with ideal controller (see Table B17-1)
TRNSYS-ideal	
TRN-re₂	<u>simulation model</u> : TRNSYS-TUD with realistic controller (see Table B17-1)

TRNSYS-real

Tstat	thermostat
TUD	<u>modeler</u> : Technische Universitat Dresden
UR	<u>modeler</u> : University of Reunion Island
v.	versus
Wh	watt hours
Wh,e	watt hours, electrical
Wh,th	watt hours, thermal
w/	with
x	multiplied by
@	at
50/50	50% outside <u>outdoor</u> air, 50% infiltration air

B16.5 Tables and Graphs of Example Results for Space-Cooling Equipment, Cases CE100-CE545

B16.5.1 Analytical Verification Test Results, Cases CE100-CE200

The following example results tables and figures are included in the files RESULTS5-3A.PDF and RESULTS5-3A.XLS. Tables and figures appear sequentially in the PDF results file. In the tables listing below, “Sheet Tab” and “Cell Range” and are provided for users working with the RESULTS5-3A.XLS file. Tables and figures include both example simulation and quasi-analytical solution results.

Tables

<i>Table</i>	<i>Description</i>	<i>Sheet Tab</i>	<i>Cell Range</i>
Table B16.5.1-1	Space Cooling Electricity Consumption	Q-Prt1	A7 – Q76
Table B16.5.1-2	COP: Mean, and (Max-Min)/Mean	Q-Prt2	A7 – Q42
Table B16.5.1-3	Coil Loads: Total, Sensible, and Latent	Q-Prt3	A7 – Q59
Table B16.5.1-4	Sensible Coil Load minus Zone Load (Fan Heat)		A60 – Q78
Table B16.5.1-5	Zone Loads: Total, Sensible, and Latent	Q-Prt4	A7 – Q59
Table B16.5.1-6	Latent Coil Load minus Zone Load (Should be 0)		A60 – Q78
Table B16.5.1-7	Sensitivities for Space Cooling Electricity Consumption	Q-Prt5	A7 – Q96
Table B16.5.1-8	Sensitivities for COP and Coil Loads	Q-Prt6	A7 – Q96
Table B16.5.1-9	Indoor Drybulb Temperature: Mean and (Max-Min)/Mean	Q-Prt7	A7 – Q41
Table B16.5.1-10	Humidity Ratio: Mean and (Max-Min)/Mean		A43 – Q78

Figures

Figure	Title	Sheet Tab
B16.5.1-1	HVAC BESTEST: Mean COP	Fig B16.5.1-1 COP
B16.5.1-2	HVAC BESTEST: (Maximum - Minimum)/Mean COP	Fig B16.5.1-2 COPvar
B16.5.1-3	HVAC BESTEST: Mean COP Sensitivities	Fig B16.5.1-3 delCOP
B16.5.1-4	HVAC BESTEST: Total Space Cooling Electricity Consumption	Fig B16.5.1-4 Qtot
B16.5.1-5	HVAC BESTEST: Total Space Cooling Electricity Sensitivities	Fig B16.5.1-5 dQtot
B16.5.1-6	HVAC BESTEST: Compressor Electricity Consumption	Fig B16.5.1-6 Qcomp
B16.5.1-7	HVAC BESTEST: Total Compressor Electricity Sensitivities	Fig B16.5.1-7 dQcomp
B16.5.1-8	HVAC BESTEST: Total Indoor (Supply) Fan Electricity Consumption	Fig B16.5.1-8 Qidfan
B16.5.1-9	HVAC BESTEST: Indoor (Supply) Fan Electricity Sensitivities	Fig B16.5.1-9 dQidfan
B16.5.1-10	HVAC BESTEST: Outdoor (Condenser) Fan Electricity Consumption	Fig B16.5.1-10 Qodfan
B16.5.1-11	HVAC BESTEST: Outdoor (Condenser) Fan Electricity Sensitivities	Fig B16.5.1-11 dQodfan
B16.5.1-12	HVAC BESTEST: Total Coil Load	Fig B16.5.1-12 QCtot
B16.5.1-13	HVAC BESTEST: Total Coil Load Sensitivities	Fig B16.5.1-13 dQCtot
B16.5.1-14	HVAC BESTEST: Sensible Coil Load	Fig B16.5.1-14 QCsens
B16.5.1-15	HVAC BESTEST: Sensible Coil Load Sensitivities	Fig B16.5.1-15 dQCsens
B16.5.1-16	HVAC BESTEST: Latent Coil Load	Fig B16.5.1-16 QClat
B16.5.1-17	HVAC BESTEST: Latent Coil Load Sensitivities	Fig B16.5.1-17 dQClat
B16.5.1-18	HVAC BESTEST: Mean Indoor Drybulb Temperature	Fig B16.5.1-18 IDB
B16.5.1-19	HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Drybulb Temperature	Fig B16.5.1-19 IDBvar
B16.5.1-20	HVAC BESTEST: Mean Indoor Humidity Ratio	Fig B16.5.1-20 Humrat
B16.5.1-21	HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Humidity Ratio	Fig B16.5.1-21Humratvar
B16.5.1-22	HVAC BESTEST: Total Zone Load	Fig B16.5.1-22 QZtot
B16.5.1-23	HVAC BESTEST: Sensible Zone Load	Fig B16.5.1-23 QZsens
B16.5.1-24	HVAC BESTEST: Latent Zone Load	Fig B16.5.1-24 QZlat
B16.5.1-25	HVAC BESTEST: Sensible Coil Load - Zone Load (Fan Heat)	Fig B16.5.1-25 QZfan
B16.5.1-26	HVAC BESTEST: Latent Coil Load - Latent Zone Load (Should = 0)	Fig B16.5.1-26 QCL-QZL

B16.5.2 Comparative Test Results, Cases CE300-CE545

The following example simulation results tables and figures are included in the files RESULTS5-3B.PDF and RESULTS5-3B.XLS. Tables and figures appear sequentially in the PDF file. In the tables listing below the “Sheet Tab” and “Cell Range” columns are provided for users working with the RESULTS5-3B.XLS file.

Tables

<i>Table</i>	<i>Description</i>	<i>Sheet Tab</i>	<i>Cell Range</i>
B16.5.2-1	Annual Space Cooling Electricity Consumption (Total, Compressor)	Table-Q	A7 – O56
B16.5.2-2	Annual Space Cooling Electricity Consumption (Supply Fan, Condenser Fan)		A57 – O106
B16.5.2-3	Weather Data Checks, CE300 Only		A109 – O119
B16.5.2-4	Annual Space Cooling Coil Loads (Total, Sensible)		A120 – O169
B16.5.2-5	Annual Space Cooling Coil Loads (Latent)		A170 – O195
B16.5.2-6	Various Annual Means (COP2, IDB)		A196 – O245
B16.5.2-7	Various Annual Means (Humidity Ratio, Relative Humidity)		A246 – O295
B16.5.2-8	F(ODB) Sensitivities, CE500 and CE530, April 30 and June 25 (Energy, Coil Loads)		A296 – O349
B16.5.2-9	F(ODB) Sensitivities, CE500 and CE530, April 30 and June 25 (COP2, Zone Conditions)		A350 – O382
B16.5.2-10	Hourly Integrated Maxima (Total Cooling System Energy Consumption and Total Coil Load)		Table-R
B16.5.2-11	Hourly Integrated Maxima (Sensible Coil Load and Latent Coil Load)	A55 – AB102	
B16.5.2-12	Hourly Integrated Maxima and Minima (COP2)	A103 – AB150	
B16.5.2-13	Hourly Integrated Maxima and Minima (IDB)	A151 – AB198	
B16.5.2-14	Hourly Integrated Maxima and Minima (Zone Humidity Ratio)	A199 – AB246	
B16.5.2-15	Hourly Integrated Maxima and Minima (Relative Humidity)	A247 – AB295	
B16.5.2-16	June 28 Hourly Output - Case CE300	Table-S	A7 – M215
	TRNSYS-TUD		A7 – M35
	DOE-2.2		A39 – M65
	DOE-2.1E-E		A69 – M95
	ENERGYPLUS		A99 – M126
	CODYRUN		A129 – M155
	HOT3000		A159 – M185
	Tested Program		A189 – M215
B16.5.2-17	Delta Annual Space Cooling Electricity Consumptions (Total, Compressor)	Table-T	A7 – O50
B16.5.2-18	Delta Annual Space Cooling Electricity Consumptions (Fans)		A52 – O95
B16.5.2-19	Delta Annual Cooling Coil Loads		A100 – O143
B16.5.2-20	Delta Various Annual Means (COP2, IDB)		A146 – O189
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B16.6 Tables and Graphs of Example Result for Space-Heating Equipment Cases HE100-HE230.

The following example results tables and figures are included in the files RESULTS5-4.PDF and RESULTS5-4.XLS. Tables and figures appear sequentially in the PDF file. In the tables listing below the “Sheet Tab” and “Cell Range” columns are provided for users working with the RESULTS5-4.XLS file. Tables and figures include example simulation, analytical solution, and quasi-analytical solution results.

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B16.6-6	Maximum Zone Temperature (°C)	B16.1-6 MAX T
B16.6-7	Minimum Zone Temperature (°C)	B16.1-7 MIN T

Revise Table B 17-1 as follows.

DOE-2.1E-088	LANL/LBNL/ESTSC, ^{a,b,c} USA	CIEMAT, ^d Spain	DOE21E/CIEMAT <u>DOE2.1-E/CIEMAT</u>
DOE-2.1E-133	LANL/LBNL/JJH, ^{a,b,c} USA	NREL/JNA, ^f USA	DOE21E/NREL <u>DOE2.1-E/NREL</u>
ENERGYPLUS 1.0.0.023	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-OBT, ^{a,g,h,i,j,k}	GARD Analytics, USA	Energy+ EnergyPlus/ GARD

Revise Table B 17-2 as follows.

TRNSYS 14.2-TUD with real controller model	University of Wisconsin, USA; Technische Universität Dresden, Ger.	Technische Universität Dresden, Germany	TRNSYS- TUD /TUD
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Revise Table B 17-3 as follows.

Table B17-3 Participating Organizations and Computer Programs, Analytical Verification and Comparative Test Cases HE100–HE230

Model	Authoring Organization	Implemented By	Abbreviation
ESP-r/HOT3000 Tier 1 tests - version 1.1 Tier 2 tests - version 1.7	CETC/ESRU, ^{a,b} Canada/United Kingdom	CETC, ^a Canada	ESP-r/HOT3000/CETC
EnergyPlus 1.0.2.008	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-OBT, ^{c,d,e,f,g,h}	GARD Analytics, USA	EnergyPlus/GARD
DOE-2.1E version c133	LANL/LBNL/JJH, ^{i,c,j} USA	CETC, ^a Canada	DOE-2.1E/CETC
Analytical/Quasi-Analytical Solutions	CETC ^a	CETC ^a	Analytical/Quasi-Analytical

^aCETC CANMET Energy Technology Centre, Natural Resources Canada, Canada

^bESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

^cLBNL: Lawrence Berkeley National Laboratory, United States

^dUIUC: University of Illinois Urbana/Champaign, United States

^eCERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, United States

^fOSU: Oklahoma State University, United States

^gFSEC: University of Central Florida, Florida Solar Energy Center, United States

^hDOE-OBT: U.S. Department of Energy, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, United States

ⁱLANL: Los Alamos National Laboratory, United States

^jJJH: James J. Hirsch & Associates, United States

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

ANNEX B2318

VALIDATION METHODOLOGIES AND OTHER RESEARCH RELEVANT TO STANDARD 140

~~B2318.1 Overall Validation Methodology~~ Model Validation and Testing

Standard 140 was developed to identify and diagnose differences in predictions that may be caused by algorithmic differences, modeling limitations, faulty coding, or input errors. Standard 140 allows all elements of a complete validation approach to be added as they become available. This structure corresponds to the following validation methodology, with subdivisions creating a matrix of six areas for

testing:

- (a) Comparative Tests - Building Thermal Fabric
- (b) Comparative Tests - Mechanical Equipment and On-Site Energy Generation Equipment
- (c) Analytical Verification - Building Thermal Fabric
- (d) Analytical Verification - Mechanical Equipment and On-Site Energy Generation Equipment
- (e) Empirical Validation - Building Thermal Fabric
- (f) Empirical Validation - Mechanical Equipment and On-Site Energy Generation Equipment.

This is an abbreviated way of representing the overall parameter space in which building energy simulation programs operate. Each cell in the matrix represents a very large region in the space. The current set of tests focus on categories 1, 2, and 4. The Standard 140, Section 5 tests are based on procedures developed by the National Renewable Energy Laboratory (NREL) and field-tested by the International Energy Agency (IEA) over three IEA

research tasks.^{17,7,8,38} The Section 7 tests are based on procedures developed by NREL and field tested by the Home Energy Rating Systems (HERS) Council Technical Committee.⁴⁶ Additional tests have been developed under ASHRAE research projects,^{45,47} and under joint IEA Solar Heating and Cooling Programme/Energy Conservation in Buildings and Community Systems Task 34/Annex 43,^{B23-0aatk} which are intended to fill in other categories of the validation matrix.

B23.1.1 Methodological Basis. There are three ways to evaluate a whole-building energy simulation program's accuracy:^{B23-0aatk, B23-0aatk, B23-0btik, 43}

~~An overall validation methodology consists of three parts:~~

- ~~a. Empirical Validation - which compares calculated results from a program, subroutine, algorithm, module, or software object to monitored data from a real building, test cell, or laboratory experiment.~~
- ~~a. Comparative Testing - in which a program is compared to itself or to other programs~~
- ~~b. Analytical Verification - in which compares the output from a program, subroutine, algorithm, module, or software object is compared to results from a known analytical solution or to results from a set of closely agreeing quasi-analytical solutions or verified numerical models or a generally accepted numerical method for isolated heat transfer under very simple, highly constrained boundary conditions~~
- ~~c. Comparative Testing - which compares a program to itself or to other programs~~
- ~~e. Empirical Validation - in which calculated results from a program, subroutine, algorithm, or software object are compared to monitored data from a real building, test cell, or laboratory experiment.~~

Table B1823-1 compares these techniques.^{B23-0aatk}

^{B23-0aatk, B23-0btik, 7, 43, 44} In this table the term "model" is the

representation of reality for a given physical behavior. For example, heat transfer may be simulated with one-, two-, or three-dimensional conduction models. The term "solution process" encompasses the mathematics and computer coding to solve a given model. The solution process for a model can be perfect, while the model remains inappropriate for a given physical situation, such as using a one-dimensional conduction model where two-dimensional conduction dominates. The term "truth standard" represents the standard of accuracy for predicting real behavior. An analytical solution is a "mathematical truth standard" but only tests the solution process for a model, not the appropriateness of the model. An approximate truth standard from an experiment tests both the solution process and appropriateness of the model within experimental uncertainty. The ultimate (or "absolute") validation truth standard would be comparison of simulation results with a perfectly performed empirical experiment, with all simulation inputs perfectly defined.

~~The methodologies may be further subdivided within each category as building envelope tests and mechanical equipment tests, creating a matrix of six areas for testing including:~~

- ~~(a) Comparative Tests - Building Thermal Fabric~~
- ~~(b) Comparative Tests - Mechanical Equipment and On-Site Energy Generation Equipment~~
- ~~(c) Analytical Verification - Building Thermal Fabric~~
- ~~(d) Analytical Verification - Mechanical Equipment and On-Site Energy Generation Equipment~~
- ~~(e) Empirical Validation - Building Thermal Fabric~~
- ~~(f) Empirical Validation - Mechanical Equipment and On-Site Energy Generation Equipment.~~

TABLE B1823-1

Advantages and Disadvantages of Various Validation Techniques^{B23-0aatk}

Technique	Advantages	Disadvantages
<i>Empirical Validation</i> Test of model and solution process	<ul style="list-style-type: none"> • Approximate truth standard within experimental accuracy • Any level of complexity 	<ul style="list-style-type: none"> • Experimental uncertainties: <ul style="list-style-type: none"> - Instrument calibration, spatial/temporal discretization - Imperfect knowledge/specification of the experimental object (building) being simulated • High quality, detailed measurements are expensive and time consuming • Only a limited number of test conditions are practical
<i>Analytical Verification</i> Test of solution process	<ul style="list-style-type: none"> • No input uncertainty • Exact mathematical <u>or secondary mathematical</u> truth standard for the given model • Inexpensive 	<ul style="list-style-type: none"> • No test of model validity • Limited to highly constrained cases for which analytical <u>or quasi-analytical</u> solutions can be <u>developed</u>
<i>Comparative Testing</i> Relative test of model and solution process	<ul style="list-style-type: none"> • No input uncertainty • Any level of complexity • Many diagnostic comparisons possible • Inexpensive and quick 	<ul style="list-style-type: none"> • No absolute truth standard (only statistically based acceptance ranges are possible)

B23.1.1.1 Empirical Validation

Establishing an absolute truth standard for evaluating a program's ability to analyze physical behavior requires empirical validation, but this is only possible within the range of measurement uncertainty, including that related to instruments, spatial and temporal discretization, and the overall experimental design. Test cells and buildings are large, relatively complex experimental objects. The exact design details, material properties, and construction in the field cannot be perfectly known, so there is some uncertainty about the simulation model inputs that accurately represent the experimental object. Meticulous care is required to describe the experimental apparatus as clearly as possible to modelers to minimize this uncertainty. This includes experimental determination of as many material properties and other simulation model *inputs* as possible, including overall building parameters such as overall steady-state heat transmission coefficient, infiltration rate, and thermal capacitance. Measurement of these overall parameters allows for a closure check on the individual parameters that sum

up to the overall parameters – for example, building envelope material properties or individual steady-state envelope component conductances that sum up to the overall steady-state heat transmission coefficient. Also required are detailed meteorological measurements. For example, many experiments measure global horizontal solar radiation, but very few experiments measure the splits between direct, diffuse, and ground reflected radiation, all of which are inputs to many whole-building energy simulation programs.

The National Renewable Energy Laboratory (NREL) divides empirical validation into different levels, because many past validation studies produced inconclusive results. The levels of validation depend on the degree of control over possible sources of error in a simulation. These error sources consist of seven types, divided into two groups:

B23.1.1.1.1 External Error Types

- Differences between actual building microclimate versus weather input used by the program

- Differences between actual schedules, control strategies, effects of occupant behavior, and other effects from the real building versus those assumed by the program user
- User error deriving building input files
- Differences between actual physical properties of the building (including HVAC systems) versus those input by the user

B23.1.1.1.2 Internal Error Types

- Differences between actual thermal transfer mechanisms in the real building and its HVAC systems versus the simplified model of those processes in the simulation (all models, no matter how detailed, are simplifications of reality)
- Errors or inaccuracies in the mathematical solution of the models
- Coding errors

The simplest level of empirical validation compares a building's actual long-term energy use to that calculated by a computer program, with no attempt to eliminate sources of discrepancy. Because this is similar to how a simulation tool is used in practice, it is favored by many in the building industry. However, it is difficult to interpret the results because

all possible error sources are acting simultaneously. Even if there is good agreement between measured and calculated performance, possible offsetting errors prevent a definitive conclusion about the model's accuracy. More informative levels of validation involve controlling or eliminating various combinations of error types and increasing the information density of output-to-data comparisons (e.g., comparing temperature and energy results at time scales ranging from subhourly to annual). At the most detailed level, all known sources of error are controlled to identify and quantify unknown error sources and to reveal causal relationships associated with error sources.

This principle also applies to intermodel comparative testing and analytical verification. The more realistic the test case, the more difficult it is to establish causality and diagnose problems; the simpler and more controlled the test case, the easier it is to pinpoint sources of error or inaccuracy. Methodically building up to realistic cases is useful for testing interactions between algorithms modeling linked mechanisms.

Table B23-2 Types of Extrapolation^{B23-0atk}

<u>Obtainable Data Points</u>	<u>Extrapolation</u>
<u>A few climates</u>	<u>Many climates</u>
<u>Short-term total energy use</u>	<u>Long-term total energy use, or vice versa</u>
<u>Short-term (hourly) temperatures and/or fluxes</u>	<u>Long-term total energy use, or vice versa</u>
<u>A few equipment performance points</u>	<u>Many equipment performance points</u>
<u>A few buildings representing a few sets of variable and parameter combinations</u>	<u>Many buildings representing many sets of variable and parameter combinations, or vice versa</u>
<u>Small-scale: simple test cells, buildings, and mechanical systems; laboratory experiments</u>	<u>Large-scale complex buildings with complex HVAC systems, or vice versa</u>

B23.1.1.2 Analytical Verification

“Analytical verification” is 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. Here the term “analytical solution” is the mathematical solution of a model that has an exact result for a given set of parameters and simplifying assumptions. The term “quasi-analytical solution” is the mathematical solution of a model for a given set of parameters and simplifying assumptions, which may include minor interpretation differences; such a result 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. The term “verified numerical model” is a numerical model with solution accuracy verified by close agreement with an analytical solution and/or other quasi-analytical or numerical solutions, according to a process that demonstrates convergence in the space and time domains. Such numerical models may be verified by applying an initial comparison with an analytical solution(s), followed by comparisons with other numerical models for incrementally more realistic cases where analytical solutions are not available.

B23.1.1.2.1 Mathematical Truth Standards

An analytical solution provides an exact “mathematical truth standard”, limited to highly constrained cases for which exact analytical solutions can be derived. A “secondary mathematical truth standard” can be established based on the range of disagreement of a set of closely agreeing verified numerical models or other quasi-analytical solutions. Once verified against all available classical analytical solutions, and compared with each other for a number of other diagnostic test cases that do not have exact analytical solutions, the secondary mathematical truth standard can be used to test other models as implemented within whole building simulation programs. Although an analytical solution provides the best possible mathematical truth standard, a secondary mathematical truth standard greatly enhances diagnostic capability for identifying software bugs and modeling errors as compared to the purely comparative method. This is because the range of disagreement among the results that comprise the secondary truth standard is typically much narrower than the range of disagreement

among whole-building simulations that may be applying less rigorous modeling methods. The secondary mathematical truth standard also allows somewhat more realistic (less constrained) boundary conditions to be used in the test cases, extending the analytical verification method beyond the constraints inherent for classical analytical solutions.

B23.1.1.2.2 Methodology for Establishing Secondary Mathematical Truth Standards

The following methodology for verifying numerical models to develop a secondary mathematical truth standard facilitates extension of analytical verification techniques. The methodology applies to both development of test cases and implementation of the numerical models. The logic for developing test cases may be summarized as follows:

- Identify or develop exact analytical solution(s) that may be used as a mathematical truth standard for testing detailed numerical models using parameters and simplifying assumptions of the analytical solution.
- Apply a numerical solution process that demonstrates convergence in the space and time domains for both the analytical-solution test case(s) and additional test cases where numerical models are applied.
- Once validated against the analytical solution(s), use the numerical models to develop test cases that progress toward more realistic (less idealized) conditions, which do not have exact analytical solutions.
- Check the numerical models by rigorously comparing their results to each other while developing the more realistic cases.
- Good agreement for the numerical models versus the analytical solution – and versus each other for subsequent test cases – verifies them as a secondary mathematical truth standard based on the range of disagreement among them.
- Use the verified numerical-model results as reference results for testing other models of the given behavior, which have been incorporated into whole building simulation computer programs.

Additional rules for developing and implementing analytical verification test cases – some of which generally apply for all test techniques – are:

- Make test cases as simple as possible, to minimize input errors
- Make test cases as robust as possible, to maximize signal to noise ratio for a tested feature
- Vary test cases incrementally – varying just a single parameter when possible – so that disagreements among results can be quickly diagnosed
- For numerical models, check sensitivity to spatial and temporal discretization, length of simulation, convergence tolerance, etc. and demonstrate that modeling is at a level of detail where including further detail yields negligible sensitivity in the results; document such work in detailed modeler reports
- Use independently developed and implemented models, and revise the test specification as needed to accommodate various modeling approaches (including for less detailed models); this reduces bias by ensuring that the test specification clearly addresses different modeling approaches.
- For resolving disagreements among results that comprise a secondary truth standard, it is helpful to utilize an additional independent expert-party not directly involved in developing the models or results being compared
- Corrections to models must have a clear mathematical or physical basis and must be consistently applied across all test cases. Arbitrary alteration of a model solely for the purpose of better matching a given data set is not allowed.

Furthermore, use of greater than two models is better for diagnosing disagreements. This is because if only two models are used it may be difficult to identify which model is causing the disagreement. For more than two models, if one model disagrees with the others, it is likely that an error lies with that model.

B23.1.1.3 Combining Empirical, Analytical and Comparative Techniques

A comparison between measured and calculated performance represents a small region in an immense N-dimensional parameter space. Investigators are constrained to exploring relatively few regions in this space, yet would like to be assured that the results are

not coincidental (e.g., not a result of offsetting errors) and do represent the validity of the simulation elsewhere in the parameter space. Analytical and comparative techniques minimize the uncertainty of extrapolations around the limited number of sampled empirical domains. Table B23-2 classifies these extrapolations. Use of the term “vice versa” in Table B23-2 is intended to mean that the extrapolation can go both ways (e.g., from short-term to long-term data and from long-term to short-term data). This does not mean that such extrapolations are correct, but only that researchers and practitioners have either explicitly or implicitly made such inferences in the past.

Figure B23-1 shows one process to combine analytical, empirical, and comparative techniques. These three techniques may also be used together in other ways; for example, intermodel comparisons may be done before an empirical validation exercise, to better define the experiment and to help estimate experimental uncertainty by propagating all known error sources through one or more whole-building energy simulation programs.^{B23-8tk, B23-9tk}

For the path shown in Figure B23-1, the first step is running the code against analytical verification test cases to check its mathematical solution. Discrepancies must be corrected before proceeding further.

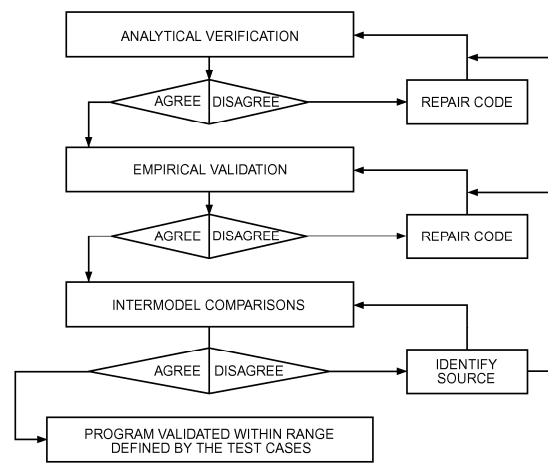


Figure B23-1 Validation Method^{B23-0atk}

Second, the code is run against high-quality empirical validation data, and errors are corrected. Diagnosing error sources can be quite difficult and is an area of research in itself. Comparative techniques can be used to create diagnostic procedures.^{7, 8, 17, 38, 43, 44, 45, 46, 47,}

^{48, B23-10tk, B23-11tk} and better define the empirical experiments.

The third step is to check agreement of several different programs with different thermal solution and modeling approaches (that have passed through steps 1 and 2) in a variety of representative cases. This uses the comparative technique as an extrapolation tool. Deviations in the program predictions indicate areas for further investigation.

When programs successfully complete these three stages, they are considered validated for cases where acceptable agreement was achieved (i.e., for the range of building, climate, and mechanical system types represented by the test cases). Once several detailed simulation programs have satisfactorily completed the procedure, other programs and simplified design tools can be tested against them. A validated code does not necessarily represent truth. It does represent a set of algorithms that have been shown, through a repeatable procedure, to perform according to the current state of the art.

The NREL methodology for validating building energy simulation programs has been generally accepted by the International Energy Agency, ^{B23-12tk} ASHRAE Standard 140 and Addendum p to ASHRAE Standard 90.1, and elsewhere, with refinements suggested by other researchers. ^{B23-12tk, B23-13tk, B23-14tk, B23-15tk, B23-16tk, B23-17tk, B23-18tk, B23-19tk}

Additionally, the Commission of European Communities has conducted considerable work under the PASSYS program. ^{B23-20tk, B23-21tk}

B23.1.2 Summary Of Previous Testing And Validation Work

Other work summarizes approximately 100 articles and research papers on analytical, empirical, and comparative testing, from 1980 through mid-2001. ^{7, B23-0btk}

B23.2 Other Relevant Research

There are a number of other simulation test suites in various stages of completion that could eventually be included in Standard 140. These include, among others:

(a) ASHRAE RP-1052, "Development of an Analytical Verification Test Suite for Whole Building energy Simulation Programs –

- ⁴⁵ Building Fabric"
- (e) "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)" ⁴⁶
- (a) "IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction" ^{B23-1tk}
- (b) "IEA BESTEST Multi-Zone Non-Airflow In-Depth Diagnostic Cases" ^{B23-2tk}
- (c) ASHRAE RP-865, "Development of Accuracy Tests for Mechanical System Simulation" ⁴⁷
- (d) "Building Energy Simulation Test for Existing Homes (BESTEST-EX), Phase 1 Test Procedure: Building Thermal Fabric Cases." ^{B23-3tk}
- (e) "RESNET Mechanical Equipment Tests" ^{B23-4tk}
- (f) ASHRAE RP-1052, "Development of an Analytical Verification Test Suite for Whole Building energy Simulation Programs – Building Fabric" ⁴⁵
- (a)(g) "RADTEST Radiant Heating and Cooling Test Cases" ⁴⁸
- (b)(h) "Proposed IEA BESTEST Ground-Coupled Cases"
- (e)(i) ETNA BESTEST Empirical Validation Test Specification ⁴⁹
- (d)(j) "Daylighting – HVAC Interaction Tests for the Empirical Validation of Building Energy Analysis Tools" ⁵⁰
- (e)(k) "Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools" ⁵¹
- (f) "IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction" ²
- (g) "IEA BESTEST Multi-Zone Non-Airflow In-Depth Cases" ²
- (h)(l) "BESTEST Airflow Cases"
- (i)(m) "Empirical Validations of Shading/Daylighting/Load Interactions in Building Energy Simulation Tools" ⁵²
- (j)(n) "Chilled Water and Hot Water Mechanical Equipment and Control Comparative and Empirical Validation Tests" ^{B23-5tk}
- (k)(o) "Double-Skin Façade Comparative and Empirical Validation Tests" ^{B23-6tk}

(Note: Because items e, i, j, k, m, and n-h and l are works in progress, no references can yet be cited for them.)

B23.2.1 IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction^{B23-1atk, B23-1btk}

were developed by National Renewable Energy Laboratory (NREL) in conjunction with IEA SHC Task 34/ECBCS Annex 43. The test cases include a steady-state three-dimensional analytically solved case and two other idealized steady-state and periodically varying comparative test cases for checking proper implementation of detailed three-dimensional numerical ground heat transfer models run independently of whole-building energy simulations. Where the detailed numerical models have good agreement with the analytical solution and good agreement with each other for other test cases, they may be classified as “verified numerical models” that establish a secondary mathematical truth standard based on their range of disagreement. The test suite also includes a set of less idealized cases to compare ground heat transfer models integrated with whole-building simulations to the verified numerical models (secondary mathematical truth standard). Parametric variations in these cases include periodic ground surface temperature variation (versus steady-state), floor slab aspect ratio, slab size, deep ground temperature depth, interior and exterior convective coefficients (realistic versus high values to test the effect of surface temperature uniformity), and ground conductivity. As of this writing, adaptation of the test cases for Standard 140 is in progress.

B23.2.2 IEA BESTEST Multi-Zone Non-Airflow In-Depth Diagnostic Cases^{B23-2tk}

were developed by NREL in conjunction with IEA SHC Task 34/ECBCS Annex 43. The test cases include an analytical verification case that tests a model's ability to correctly keep account of interzonal conduction heat transfer, three comparative cases for testing the ability of programs to account for multi-zone shading by a single shading object and self-shading of the building by zones that shade other zones, and a comparative case to test the ability to model internal windows between zones. Shading and internal window test cases employ idealized glazing and building zones designed as calorimeters for testing shading and solar gains effects. As of this writing, adaptation of the test cases for Standard 140 is in progress.

B23.2.3 ASHRAE RP-865⁴⁷ These tests are analytical verification tests that focus on the ability to model thermal physics related to the air-side of mechanical equipment. The tests were developed by

Pennsylvania State University and Texas A&M University as an ASHRAE research project. Cases allow the comparison of quasi-analytical solutions to program results for the purpose of testing the ability of programs to model air-side mechanical equipment and systems. These tests are subdivided by system type, for example, constant-volume dual duct or variable-volume single duct with reheat. As of this writing, NREL and ASHRAE Standing Standard Project Committee (SSPC) 140 are revising the test cases and beginning simulation trials for Standard 140 adaptation.

B23.2.4 BESTEST-EX^{B23-3tk} is based on the current HERS BESTEST^{dknn} cases of Section 7.2. However, BESTEST-EX is specifically designed to test programs that model energy efficiency improvements to existing residential construction. As such, the BESTEST-EX cases include modifications to HERS BESTEST inputs to be more appropriate for poorly insulated older buildings (e.g., updated default convective surface coefficients), and includes the capability to test more detailed weather-driven infiltration models. BESTEST-EX also includes a new methodology for testing the ability to apply calibration of models to existing home utility billing data, to estimate retrofit energy savings. The procedure tests the ability to model the following retrofit cases: infiltration air sealing, attic insulation, wall insulation, programmable thermostat, low-emissivity windows, low exterior solar-absorbance roof (cool roof), and external solar shading. BESTEST-EX was developed by NREL in collaboration with a housing-retrofit industry working group.

B23.2.5 RESNET Mechanical Equipment Tests^{B23-4tk}

These test cases are designed for testing more simplified building energy analysis tools commonly used for residential modeling. The procedures test the ability to model space heating equipment, space cooling equipment, duct distribution system efficiency, and domestic hot water system performance. The space heating and cooling equipment tests verify the ability to model furnaces, air conditioners, and air-source heat pumps. The duct distribution system efficiency tests utilize results from ASHRAE Standard 152.^{B23-7tk} The test cases are published by the Residential Energy Services Network (RESNET).

B182.2.61 ASHRAE RP-1052⁴⁵ These tests are analytical verification tests that focus on the ability to model thermal physics related to the building fabric.

The tests were developed by Oklahoma State University as an ASHRAE research project. Cases allow the comparison of analytical solutions to program results for the purpose of testing the ability of programs to model steady-state convection and conduction, exterior and interior infrared radiation, exterior solar radiation, transient conduction, infiltration, convective and radiant internal gains, ground coupling, solar transmission through windows, internal (transmitted) solar radiation distribution, and external shading.

B18.2.2 HERS BESTEST⁴⁶ is similar to the current test cases included in Section 5.2 of Standard 140 in that it is a comparative test that focuses on the building envelope. However, HERS BESTEST was designed for testing more simplified building energy analysis tools commonly used for residential modeling and specifically for home energy rating systems (HERS). As such, it uses more realistic test cases but goes into less detail in testing specific building physics algorithms than Standard 140. HERS BESTEST was developed by NREL in cooperation with the Technical Committee of the HERS Council (now Residential Energy Services Network [RESNET]).

B18.2.3 ASHRAE RP-865⁴⁷ These tests are analytical verification tests that focus on the ability to model thermal physics related to the air-side of mechanical equipment. The tests were developed by Pennsylvania State University and Texas A&M University as an ASHRAE research project. Cases allow the comparison of quasi-analytical solutions to program results for the purpose of testing the ability of programs to model air-side mechanical equipment and systems. These tests are subdivided by system type, for example, constant volume dual duct or variable volume single duct with reheat.

B18.2.74 RADTEST⁴⁸ is a comparative test developed by Hochschule für Technik + Architektur Luzern in conjunction with the IEA Solar Heating and Cooling Task 22. Cases allow the comparison of program results to each other for the purpose of testing the ability of programs to model radiant heating or cooling hydronic loop systems embedded in the building shell (e.g., floor, ceiling, etc.).

B18.2.85 Proposed IEA BESTEST Ground-Coupled Cases is a pilot set of realistic comparative test cases developed by the National Renewable Energy Laboratory (NREL) in conjunction with the IEA Solar Heating and Cooling (SHC) Programme Task 22. These cases focus on the ability to model

ground-coupled heat transfer and could directly append the building fabric cases of Section 5.2. Cases allow the comparison of program results to each other for the purpose of testing the ability of programs to model interaction of the building with the atmosphere through the ground, effects of solar radiation on ground-coupled surfaces, effects of calculated film coefficients versus constant film coefficients, slab-on-grade geometries with and without insulation, basement geometries with and without insulation, interaction of the building with the deep ground conditions including heat sinks such as water tables, and walkout basement construction. As a result of substantial undiagnosable disagreements among detailed model results for these test cases, NREL developed the in-depth ground heat transfer cases described in Section B18.2.96 above. NREL plans to continue work on the pilot cases and other more realistic ground-coupled heat transfer cases after completion of the in-depth cases.

B18.2.96 ETNA BESTEST⁴⁹ is an empirical validation test developed by Electricité de France in conjunction with J. Neymark & Associates and the National Renewable Energy Laboratory. Cases allow the comparison of empirical data to program results, allowing for validation of models within the uncertainty of the experiments. Test cases focus on the ability to model thermal loads associated with the building fabric in artificial and natural climatic configurations. Parametric variations in a natural climate configuration include dynamic thermal diffusion (with windows insulated and covered), solar gains (windows uncovered), thermostat setback, variation of interior surface convective coefficient (by varying mixing fan flow rate), variation of heater type, variation of thermal mass (insulation over the floor slab), and interactions of these. Parametric variations in an artificial climate configuration include tests for the ability to model outside-outdoor air ventilation/infiltration, internal gains, and typical wall mounted “convective” and “radiant” heaters versus a heater designed for ideal pure convective output with uniform mixing of zone air (commonly assumed by simulations). Data were gathered in the artificial climate configuration to empirically characterize steady-state overall building heat loss coefficient; steady-state thermal conductance of individual walls, floor, ceiling, and windows; and internal thermal capacitance. Measurements were also made with the objectives of estimating interior convective surface coefficients and empirically characterizing incidence-angle-dependent window

optical transmittance.

B1823.2.107 Daylighting – HVAC Interaction Tests for the Empirical Validation of Building

Energy Analysis Tools⁵⁰ were developed by Iowa State University and Iowa Energy Resource Station in conjunction with IEA SHC Task 22. Cases allow the comparison of empirical data to program results, allowing for validation of models within the uncertainty of the experiments. The tests focus on the ability to model daylighting/HVAC interaction. Identical rooms connected to separate mechanical systems are used with the difference that one room has dimmable ballasts; interior illuminance, solar irradiance, and heating loads were measured in both rooms.

B1823.2.118 Economizer Control Tests for the Empirical Validation of Building Energy Analysis

Tools⁵¹ were developed by Iowa State University and Iowa Energy Resource Station in conjunction with IEA SHC Task 22. Cases allow the comparison of empirical data to program results, allowing for validation of models within the uncertainty of the experiments. The test cases focus on the ability to model economizer control and outdoor air in VAV Systems. Parametric variations of economizer control tests include outside air versus return air temperature comparison, with parametric variations for 0% and 20% minimum ~~outside-outdoor air~~, and outside air versus return air enthalpy comparison with 0% minimum ~~outside-outdoor air~~.

B18.2.9 IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-On-Grade Construction

~~are being developed by National Renewable Energy Laboratory in conjunction with IEA SHC Task 34/ECBCS Annex 43. The test cases include a steady-state three-dimensional analytically solved case and two other idealized steady-state and periodically varying comparative test cases for checking proper implementation of detailed three-dimensional numerical ground heat transfer models run independently of whole-building energy simulations. If the detailed numerical models have good agreement with the analytical solution and good agreement with each other for other test cases, they can be established as a secondary mathematical truth standard within their range of disagreement. The test suite also includes a set of less idealized cases to compare ground heat transfer models integrated with whole-building simulations to the detailed numerical~~

~~models (secondary mathematical truth standard). Parametric variations in these cases include periodic ground surface temperature variation (versus steady-state), floor slab aspect ratio, slab size, deep ground temperature depth, interior and exterior convective coefficients (realistic versus high values to test the effect of surface temperature uniformity), and ground conductivity.~~

B18.2.10 IEA BESTEST Multi-Zone Non-Airflow In-Depth Cases

~~are being developed by National Renewable Energy Laboratory in conjunction with IEA SHC Task 34/ECBCS Annex 43. The test cases include an analytical verification case that tests a model's ability to correctly keep account of interzonal conduction heat transfer, three comparative cases for testing the ability of programs to account for multi-zone shading by a single shading object and self-shading of the building by zones that shade other zones, and a comparative case to test the ability to model internal windows between zones. Shading and internal window test cases employ idealized glazing and building zones designed as calorimeters for testing shading and solar gains effects.~~

B1823.2.121 BESTEST Airflow Cases

~~are being developed by a group led by Institutes of National Colleges of Technology, Japan, in conjunction with IEA SHC Task 34/ECBCS Annex 43. The airflow cases emphasize natural ventilation, buoyancy, wind driven, temperature-difference, and mechanical-fan driven flows. A further case will include a large internal vertical opening that provides bi-directional flow by buoyancy. Cases have been developed in one-zone and three-zone configurations, and many of the test cases include analytical solutions. As of this writing, the final project report has not yet been completed.~~

B1823.2.132 Empirical Validations of Shading/Daylighting/Load Interactions in Building Energy Simulation Tools

⁵² were developed by the Swiss Federal Laboratories for Materials Testing and Research (EMPA), Iowa State University, and Iowa Energy Resource Station (ERS), in conjunction with IEA SHC Task 34/ECBCS Annex 43. The suite includes eight empirical validation experiments conducted at EMPA that test the ability to model: 1) overall test cell conductance, 2) overall test cell internal capacitance, 3) glazing only, 4) glazing with external textile shading screen, 5) glazing with internal textile shading screen, 6) glazing with external Venetian blinds, 7) glazing with internal miniblinds, and 8) a

complete window, i.e., glazing with a frame. Additional work done at ERS created an empirical validation data set for daylighting controls, using dimmable ballasts, fabric shades, miniblinds, exterior shading fins, and equipment for scheduled internal gains.

B1823.2.143 Chilled Water and Hot Water Mechanical Equipment and Control Comparative and Empirical Validation Tests ~~are being were~~ developed by Dresden University of Technology in conjunction with IEA SHC Task 34/ECBCS Annex 43. This work tests the ability to model chilled- and hot-water mechanical systems used for space conditioning. The tests focus on single component models including chiller, boiler, cooling coil (dry/wet regime with condensing water flow rate measurement), heat exchanger (terminal reheat), and hydronic network (pipes, pump, valve). Empirical data for both the hot-water and the chilled-water systems were obtained from several experiments conducted at the Iowa Energy Resource Station (ERS) for a chilled water system, a heating water system, and hydronic heat exchanger coils.

B1823.2.154 Double-Skin Façade Comparative and Empirical Validation Tests ~~are being were~~ developed by Aalborg University in conjunction with IEA SHC Task 34/ECBCS Annex 43. ~~The objective for this project is to assess~~ the ability of building energy analysis tools to predict heat transfer, ventilation flow rates, cavity air and surface temperatures, and solar protection effect and interaction with building services systems in buildings with a double-skin façade. Comparative and empirical validation test cases include variations with all façade openings closed, all façade openings open to the outside, and bottom façade opening open to outside while the top opening is open to inside. Within the test cases are a number of variations to check the influence of various parameters, including driving force of airflow (buoyancy, wind, mechanical fan, combined forces), internal (thermal) and external (thermal, solar, wind) boundary conditions, and opening area (fully opened, opening area controlled by temperature and/or airflow rate).

B1823.3 Recommended Additional Research The additional tests listed in B1823.2 do not cover the following areas:

- (a) *Comparative Tests – Mechanical and On-Site Energy Generation Equipment:* Additional tests beyond those in the HVAC BESTEST unitary cooling and

heating equipment cases (Sections 5.3 and 5.4), RADTEST (Section B1823.2.74), and hydronic space conditioning equipment tests (Section B1823.2.143)

- (b) *Analytical Verification – Mechanical and On-Site Energy Generation Equipment:* Additional tests beyond those in RP-865 (Section B1823.2.3) and HVAC BESTEST unitary cooling and heating equipment cases (Sections 5.3 and 5.4)
- (c) *Empirical Validation*
- Building Thermal Fabric: A set of carefully controlled empirical experiments with sequential logic similar to that in the Standard 140 comparative test cases of Section 5.2
 - Mechanical and On-Site Energy Generation Equipment: Additional tests beyond the economizer control tests (Section B1823.2.118) and hydronic equipment tests (Section B1823.2.143).

More work to develop such Methods of Test is recommended.

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

ANNEX B24 INFORMATIVE REFERENCES

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