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ASHRAE STANDARD

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

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[Informative Note: Additions to the current standard are shown in this addendum by underlining and deletions by ~~strikethrough~~, unless otherwise indicated in the informative notes.]

[Informative Note: Revise title of Annex B16 in the table of contents as indicated.]

Annex B16 Analytical and Quasi-Analytical Solution Results and Example Simulation Results for HVAC Equipment Performance Tests

[Informative Note: Revise the current foreword as indicated.]

(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 ~~(SMOT)~~ 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*
- *analytical verification tests that focus on mechanical equipment performance.*

These tests are part of an overall validation methodology described in Annex B18.

This procedure 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 examines 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. 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~~HVAC~~ 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 these steady-state cases, the following parameters are varied: sensible internal gains, latent internal gains, zone thermostat setpoint (entering dry-bulb temperature), and outdoor dry-bulb temperature. Parametric variations isolate the effects of the parameters singly and in various combinations and isolate the influence of part-loading of equipment, varying sensible heat ratio, "dry" coil (no latent load) versus "wet" coil (with dehumidification) operation, and operation at typical Air-Conditioning and Refrigeration Institute (ARI) rating conditions. 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. 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.

[Informative Note: Remaining part of foreword is unchanged.]

3. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

3.1 Terms Defined for This Standard

[Informative Note: Revise the following definition by specifying that PLR is for cooling.]

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: Add the following definitions to Section 3.1.]

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

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

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

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

[Informative Note: Revise the acronyms as shown.]

3.2 Abbreviations and Acronyms Used in This Standard

Abs	absorptance
ACH	air changes per hour
ADP	apparatus dew point
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BF	bypass factor
Cd	degradation coefficient
CDF	coefficient of performance degradation factor
CFM	cubic feet per minute
CIBSE	Chartered Institution of Building Services Engineers
COP	coefficient of performance
Coef	coefficient
Cp	specific heat ~~(J/kg·K)~~, J/(kg·K)
DBT	dry-bulb temperature, °C
E, W, N, S	east, west, north, south
EDB	entering dry-bulb temperature
EER	energy efficiency ratio
EWB	entering wet-bulb temperature
Ext	exterior
FF	free-floating thermostat control strategy (no heating or cooling)
High mass	heavy mass
HIR	heat input ratio
HVAC	heating, ventilating, and air conditioning
I.D.	inside diameter
IDB	indoor dry-bulb temperature
Int	interior
k	thermal conductivity ~~(W/m·K)~~, W/(m·K)
Low mass	light mass
N/A	not applicable
NOAA	National Oceanic and Atmospheric Administration
NSRDB	National Solar Radiation Database
O.D.	outside diameter
ODB	outdoor dry-bulb temperature
PLF	part-load factor
PLR	part-load ratio for cooling
PLR_f	part-load ratio for furnace
R	unit thermal resistance ~~(m^2·K/W)~~, m^2·K/W
Refl	reflectance
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient

SHR	sensible heat ratio
SI	Système Internationale
STP	standard temperature and pressure
Surf	surface
t	thickness, m
T	zone air temperature
TMY	Typical Meteorological Year
TMY2	Typical Meteorological Year 2
Trans	solar transmittance
TUD	Technische Universität Dresden
U	unit thermal conductance or overall heat transfer coefficient ~~(W/m^2·K)~~, W/(m^2·K)
UA	thermal conductance, W/K
WBAN	Weather Bureau Army Navy
wg	water gauge
WYEC2	Weather Year for Energy Calculations 2

4. METHODS OF TESTING

[Informative Note: Make the following revisions in Sections 4.1–4.4.]

4.1 Applicability of Test Method

The method of test is provided for analyzing and diagnosing building energy simulation software using software-to-software, ~~and~~ software-to-quasi-analytical-solution, and software-to-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 programs to the example simulation results provided in the informational Annex B8, to the example analytical and quasi-analytical solutions and simulation results in the informative Annex B16, 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 informational Annex B9.

4.2 Organization of Test Cases. The specifications for determining input values are provided case by case in Section 5. Weather information required for use with the test cases is provided in Annex A1. 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 Annex B9 on diagnostic logic. In some instances (e.g., Case 620, Section 5.2.2.1.2), a case developed from modifications to Case 600 (Section 5.2.1) will also serve as the base case for other cases. The cases are grouped as:

a. Building Thermal Envelope and Fabric Load Base Case (see 4.2.1)
b. Building Thermal Envelope and Fabric Load Basic Tests (see 4.2.2)
   - Low mass (see 4.2.2.1)
   - High mass (see 4.2.2.2)
   - Free float (see 4.2.2.3)
c. Building Thermal Envelope and Fabric Load In-Depth Tests (see 4.2.3)
d. Space-Cooling ~~HVAC~~ Equipment Performance Base Case (see 4.2.4)
e. Space-Cooling ~~HVAC~~ Equipment Performance Parameter Variation Tests (see 4.2.5)
f. Space-Heating Equipment Performance Analytical Verification Base Case (see 4.2.6)
g. Space-Heating Equipment Performance Analytical Verification Tests (see 4.2.7)
h. Space-Heating Equipment Performance Comparative Tests (see 4.2.8)

4.2.1 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.

4.2.2 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.

4.2.2.1 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.

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

4.2.2.3 Free-float basic tests (Cases 600FF, 650FF, 900FF, and 950FF) have no heating or cooling systems. 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.

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

4.2.3.1 In-depth Cases 195 through 320 analyze the ability of software to model building envelope loads for a non-deadband 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.

4.2.3.2 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.

4.2.4 Space-Cooling~~HVAC~~ Equipment Performance Base Case. The configuration of the base-case (Case E100) 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.

4.2.5 Space-Cooling~~HVAC~~ Equipment Performance Parameter Variation Tests. In these steady-state cases (cases E110 through E200), 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.

4.2.6 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.

4.2.7 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.

4.2.8 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 Reporting Results. 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. documentation of modeling methods used when alternative methods are available in the software using "S140outNotes.TXT" on the accompanying CD, and
c. results for simulated cases using the following files on the accompanying CD:

- Sec5-2out.XLS for the building thermal envelope and fabric load tests of Section 5.2
- Sec5-3out.XLS for the space-cooling~~HVAC~~ equipment performance tests of Section 5.3~~.~~
- Sec5-4out.XLS for the space-heating equipment performance tests of Section 5.4.

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

4.4 Comparing Output to Other Results. Annex B8 gives example simulation results for the building thermal envelope and fabric load tests. Annex B16 gives quasi-analytical solution results and example simulation results for the HVAC equipment performance tests. The user may choose to compare output with the example results provided in Annex B8 and Annex B16 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). Information about how the example results were produced is included in informational Annex B11 and Annex B17. For the convenience to users who wish to plot or tabulate their results along with the example results, electronic ver-

sions of the example results have been included with the files RESULTS5-2.XLS (for Annex B8)~~ and~~, RESULTS5-3.XLS (for Annex B16), and RESULTS5-4.XLS (also for Annex B16) on the accompanying CD. Documentation regarding RESULTS5-2.XLS~~ and~~, RESULTS5-3.XLS, and RESULTS5-4.XLS have been included with the files and is printed out in Annex B10.

4.4.1 Criteria for Determining Agreement Between Results. There are no formal criteria for when results agree or disagree. Determination of when results agree or disagree is left to the user. In making this determination, the user should consider

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. if 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 ~~HVAC~~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.

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 Annex B9.

5. TEST PROCEDURES

[Informative Note: Make revisions to Section 5.1 as noted.]

5.1 Modeling Approach

This modeling approach shall apply to all the test cases presented in Sections 5.2~~, and~~ 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 savings time or holidays for scheduling. TMY weather data are in hourly bins corresponding to solar time as described in Annex A1. 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 (6×8 m $\times$ 2.7 m = 129.6 m^3). Make the thicknesses 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. Such inputs are in the 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 option was used in the Standard Output Report (see Annex A2).

5.1.5 Simulation Initialization and Preconditioning. If your software allows, begin the simulation initialization process with zone air conditions that equal the outdoor air conditions. If your program allows for preconditioning (iterative simulation of an initial time period until temperatures or fluxes, or both, stabilize at initial values), use that capability.

5.1.6 Simulation Duration

5.1.6.1 Results for the tests of Section 5.2 are to be taken from a full annual simulation.

5.1.6.2 For the tests of Section 5.3, run the simulation for at least the first two months for which the weather data are provided. Give output for the second month of the simulation (February) in accordance with Section 6.3. The first month of the simulation period (January) serves as an initialization period.

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

[Informative Note: Revise the titles of Sections 5.3 and 5.3.2 as shown.]

5.3 Input Specification for Space-Cooling~~HVAC~~ Equipment Performance Tests

5.3.2 Space-Cooling~~HVAC~~ Equipment Performance Parameter Variation Tests

[Informative Note: Add entirely new Section 5.4, including new figures and tables.]

5.4 Input Specification for Space-Heating Equipment Performance Tests. 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 modeled as detailed in this section and its subsections.

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 result disagreements be diagnosed before going on to the other cases. When diagnosing the results, it is important to compare result 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 HE100W.WY2, provided on the CD accompanying this standard as described in Annex A1, Section A1.3.

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

5.4.1.2 Output Requirements. Case HE100 requires all of the output described in Section 6.4.

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

5.4.1.3 Building Geometry. The base case building is a 48 m^2 floor area, single-story, low mass building with rectangular prism geometry and internal measurements as shown in Figure 13. The zone air volume is 129.6 m^3.

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

5.4.1.4.1 Material properties for the exterior wall, floor, and roof are listed in Table 29. The roof will 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 your software does not allow the specified insulation levels, use the thickest insulation your program will permit and reduce the floor and wall areas to achieve the same UA values as defined in Table 29. The zone air volume must remain 129.6 m^3.

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

5.4.1.4.3 Air density at 115 m altitude is 1.185 kg/m^3.

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

Soil thermal conductivity (k)	= 1.3 W/(m·K)
Soil density	= 1500 kg/m^3
Soil specific heat	= 800 J/(kg·K)
Deep ground temperature	= 10°C

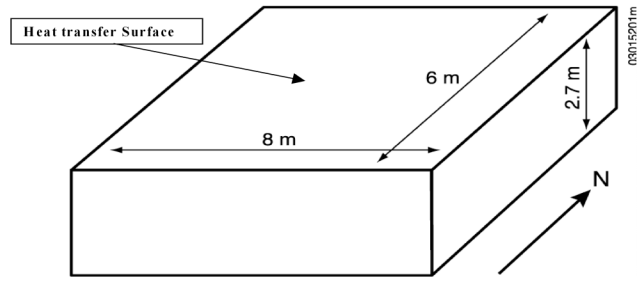

Figure 13 Base case building with heat transfer surface.

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

Infiltration rate = 0.0 ACH (air changes per hour) for entire simulation period.

5.4.1.6 Internal Heat Gains. 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 your program does not allow for the definition of convection coefficients, follow the approach described in Section 5.4.1.9.

Surface convection coefficients will 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 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 your software does not allow a definition of zero for h_c, then set these coefficients to as small a value as possible.

5.4.1.7.1 The floor will have the same exterior film coefficient as the other walls, as if the entire zone were suspended above the ground.

TABLE 29 Material Specifications for Base Case

Element	Area, m^2	k, W/(m·K)	t, m	U^a, W/(m^2·K)	R^b, m^2·K/W
Wall	75.6	0.01	1.00	0.01	100
Floor	48.0	0.01	1.00	0.01	100
Roof (*heat transfer surface*)	48.0	0.0714	0.01	7.14	0.14

[a] This is the U-factor defined between internal and external surfaces of an envelope component and as such does not include the resistance offered by surface convection and longwave radiation.

[b] This is the R-value defined between internal and external surfaces of an envelope component and as such does not include the resistance offered by surface convection and longwave radiation.

5.4.1.7.2 If your program models radiation and convection together, then set the combined heat transfer coefficient for the roof heat transfer surface to 20 W/(m^2·K). For all other surfaces, set this value to zero. If your software program requires a non-zero value for the combined heat transfer coefficient, then set it to as small a value as is allowed.

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 be used for all internal and external surfaces:

- longwave emissivity, $\lambda \rightarrow 0$ at all internal and external surfaces
- solar absorptivity, $\alpha \rightarrow 0$ at all internal and external surfaces.

If your software does not allow a definition of zero for λ or for α, then set them to as small a value as possible.

5.4.1.9 Heat Exchange by Infiltration. For programs that do not allow for the definition of convection coefficients, the heating loads are driven by infiltration of outdoor air through the zone. The configuration of the base case building is a single near-adiabatic rectangular zone where energy is transferred to 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 14.

5.4.1.9.2 Building Envelope Thermal Properties. Material properties for the exterior wall, floor, and roof are as listed in Table 30.

5.4.1.9.3 Infiltration

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

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.

5.4.1.10 Mechanical System. The mechanical system represents a simple sealed combustion, fuel-fired furnace heating system.

5.4.1.10.1 General Information. The general test conditions for the mechanical system are as follows:

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

5.4.1.10.2 Thermostat Control Strategy. Control settings are as follows:

Heat = on if temperature < 20°C; otherwise Heat = off
Cool = off

The controls for this system are ideal in that equipment is assumed to maintain the setpoint exactly when it is operated and 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°C or OFF at setpoint +y°C. If your software requires input for these settings, then use the minimum allowable values.

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.

The thermostat is nonproportional in the sense that when the zone air temperature drops below the thermostat heating setpoint, the heat generation rate is assumed to equal the

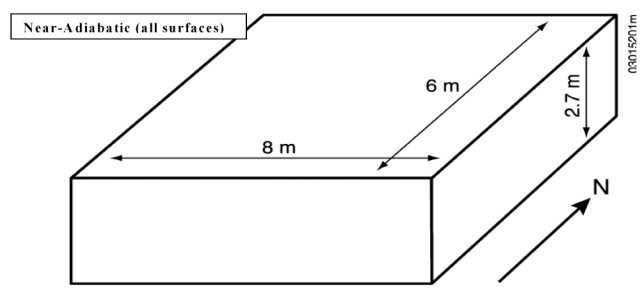

Figure 14 Base case building with all surfaces near adiabatic.

TABLE 30 Material Specifications for Base Case

Element	Area, m^2	k, W/(m·K)	t, m	U^a, W/(m^2·K)	R^b, m^2·K/W
Wall	75.6	0.01	1.00	0.01	100
Floor	48.0	0.01	1.00	0.01	100
Roof	48.0	0.01	1.00	0.01	100

[a] This is the U-factor defined between internal and external surfaces of an envelope component and as such does not include the resistance offered by surface convection and longwave radiation.

[b] This is the R-value defined between internal and external surfaces of an envelope component and as such does not include the resistance offered by surface convection and longwave radiation.

maximum capacity of the heating equipment corresponding to environmental conditions at the time of operation. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by your program). A PLF = $f(\mathrm{PLR}_f)$ 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 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. Residential furnaces 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

$$\mathrm{PLR}_f = \frac{\text{Load Placed on Furnace}}{\text{Furnace Capacity}},$$

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:

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

For simulation programs, the part-load performance can be defined in terms of a part-load curve, as a plot of PLF vs. PLR_f. The part-load curve chosen for this suite of test cases is illustrated in Figure 15. The equation for this curve is

$$\mathrm{PLF} = \frac{\mathrm{PLR}_f}{\mathrm{HIR}(\mathrm{PLR}_f)},$$

where

$$\mathrm{HIR}(\mathrm{PLR}_f) = a + b \times \mathrm{PLR}_f + c \times \mathrm{PLR}_f^2 + d \times \mathrm{PLR}_f^3 .$$

Henderson[A-3] defines the HIR coefficients for a condensing gas furnace as:

$a = 0.0080472574$

$b = 0.87564457$

$c = 0.29249943$

$d = -0.17624156$

$\mathrm{HIR}(\mathrm{PLR}_f)$ 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.

For the base case (Case HE100), the furnace runs continuously at full-load capacity. Therefore, part-load operation is not examined. If your software requires input for the part-load operation, use the above equation.

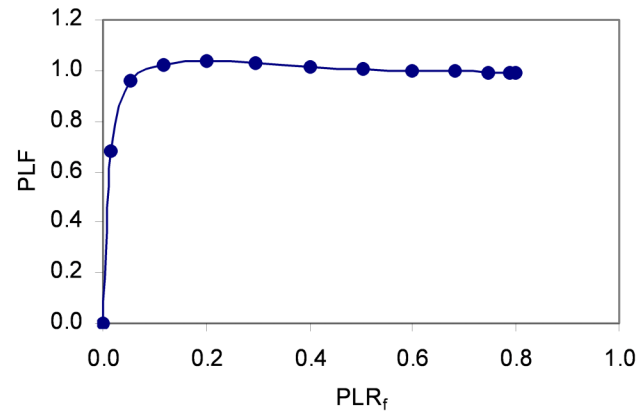

Figure 15 Part-load factor curve.

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 HHV of natural gas is 38 MJ/m^3. The HHV is 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.

5.4.1.10.6 Fans. There is 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 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 is exactly the same as Case HE100 except:

Furnace full-load efficiency = 80%

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 is exactly the same as Case HE110, except that the applicable weather file is HE120W.WY2. These data are provided in the files accompanying this standard and are described in Annex A1, Section A1.3.

Part-load performance data are as described before (see Section 5.4.1.10.4).

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 is exactly the same as Case HE110 except that the applicable weather file is HE130W.WY2

These data are provided in the files accompanying this standard and are described in Annex A1, Section A1.3.

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 exactly the same as Case HE110 except that the applicable weather file is HE140W.WY2

These data are provided in the files accompanying this standard and are described in Annex A1, Section A1.3.

These weather data are represented by Figure 16, 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

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

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

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 is exactly the same as Case HE140, except that a circulating fan runs continuously.

Circulating fan power draw = 200 W, runs continuously
Circulating fan flow rate = 0.355 m^3/s

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.

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 the same as Case HE150, except that the circulating fan cycles with burner operation (i.e., burner on → fan on; burner off → fan off).

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.

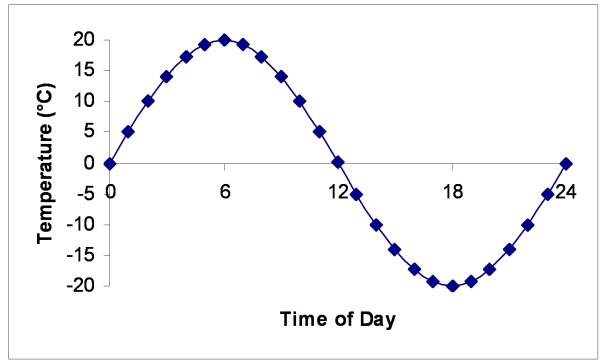

Figure 16 Temperature varying sinusoidally from +20°C to –20°C over a 24-hour period.

Case HE170 is exactly the same as Case HE150, except that the draft fan electrical consumption is incorporated. The circulating fan operates exactly as before (continuously).

Draft fan power draw = 50 W, cycles with burner operation (i.e., burner on→ fan on; burner off →fan off).

Draft fan heat is exhausted in the flue; none of the draft fan heat is introduced into the zone.

5.4.3 Space-Heating Equipment Performance Comparative Tests. 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 is exactly the same as Case HE170, except that the weather data and circulating fan control strategy are changed as noted below.

5.4.3.1.1 Weather Data. For this test case, use Weather File HE210W.WY2 of weather data provided on the CD accompanying this standard as described in Annex A1, Section A1.3.

5.4.3.1.2 Fans. The fans are as follows:

Circulating fan power draw = 200 W, cycles with burner operation (i.e., burner on→fan on, burner off →fan off)

Draft fan operation is the same as in case HE170.

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 the same as Case HE210, except that the zone setpoint temperature follows the relationship illustrated in Figure 17.

For 6h00 ≤ time of day ≤ 23h00, then

Heat = on if temperature < 20°C; otherwise Heat = off

Cool = off

For 23h00 < time of day < 6h00, then

Heat = on if temperature < 15°C; otherwise Heat = off

Cool = off

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 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 remain as in case HE220.

6. OUTPUT REQUIREMENTS

6.1 Annual Outputs for Building Thermal Envelope and Fabric Load Tests of Section 5.2

[Informative Note: Revise the following table number as shown.]

TABLE 31~~29~~ Daily Hourly Output Requirements for Building Thermal Envelope and Fabric Load Tests of Section 5.2

[Informative Note: Revise the following title of Section 6.3 as shown.]

6.3 Output Requirements for Space-Cooling~~HVAC~~ Equipment Performance Tests of Section 5.3

[Informative Note: Add entirely new Section 6.4.]

6.4 Output Requirements for Space-Heating Equipment Performance Tests of Section 5.4. All these values shall be entered into the appropriate standard output report (see Annex A2).

The outputs listed immediately below shall include cumulative consumptions or average loads (as appropriate) for the entire three-month simulation period. Sections 6.4.1–6.4.3 detail 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). *Total Furnace Load* refers to the load at the furnace coil.

6.4.1.2 Cumulative (Total) Energy Delivered to the Furnace (GJ). *Total Furnace Input* refers to the combustion energy of the fuel consumed by the furnace.

6.4.1.3 Average Rate of Fuel Consumption (m^3/s). The *Fuel Consumption* corresponds to the ratio of the *Total Furnace Input* (GJ, see section 6.4.1.2) to the fuel HHV (38 MJ/m^3, see section 5.4.1.10.5) to the time of the simulation (3 months = 7.776×10^6 s) as shown in the following equation:

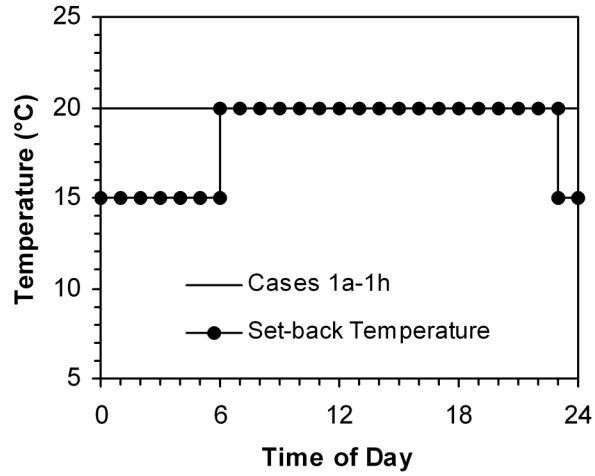

Figure 17 Setback temperatures over a 24-hour period.

$$\text{Fuel Consumption} = \frac{\text{Furnace Input}}{\text{HHV} \times 7.776 \times 10^6} \times 1000$$

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).

(This is a normative annex and is part of this standard.)

ANNEX A1
WEATHER DATA

[Informative Note: Revise the title of Section A1.2 as follows. Also revise section references in the last sentence of this section.]

A1.2 Weather Data for Space-Cooling~~HVAC~~ Equipment Performance Tests. The weather data listed in Table A1-2 shall be used as called out in Section 5.3. 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, which uses 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., E130, E140, E190, and E195].

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.~~3~~ 4 and A1.~~4~~5, respectively.

[Informative Note: Revise the title of Tables A1-2, A1-3a, and A1-3b as follows.]

TABLE A1-2 Weather Data for Space-Cooling~~HVAC~~ Equipment Performance Tests

TABLE A1-3a Site and Weather Summary for Space-Cooling~~HVAC~~ Equipment Performance Tests—TMY Data

TABLE A1-3b Site and Weather Summary for Space-Cooling~~HVAC~~ Equipment Performance Tests—TMY2 Data

[Informative Note: Add new Section A1-3 including new tables.]

A1.3 Weather Data for Space-Heating Equipment Performance Tests. Weather data listed in Table A1-4 shall be used as specified in Section 5.4. These data are presented in WYEC2 format.[A-8] See Section A1.6 for a detailed description of the WYEC2 format. Site characteristics are summarized in Table A1-5.

Five three-month-long (January 1 – March 31) 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 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.

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.

[Informative Note: Revise titles of sections below from A1.3…A1.4 to A1.4…A1.5 as shown. Also revise references in Sections A1.4 and A1.5 as shown.]

A1.~~3~~ 4 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-~~4~~6. 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 data[9] 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.

TABLE A1-4 Weather Data for Space-Heating Equipment Performance Tests

Data Files	Applicable Cases	Applicable Cases' Sections
HE130W.WY2	HE130	5.4.2.3
HE140W.WY2	HE140, HE150, HE160, HE170	5.4.2.4, 5.4.2.5, 5.4.2.6, 5.4.2.7
HE210W.WY2	HE210, HE220, HE230	5.4.3.1, 5.4.3.2, 5.4.3.3

TABLE A1-5 Site Summary for Space-Heating Equipment Performance Tests—WYEC2 Data

Weather type	Artificial conditions
Weather format	WYEC2
Latitude	45.32° North
Longitude (local site)	75.67° West
Altitude	115 m (380 ft)
Time zone (standard meridian longitude)	5 (75° West)
Ground reflectivity	0.2
Site	Flat, unobstructed, located exactly at weather station

Informative Annex B2 contains additional background information regarding TMY weather data.

The hourly time convention for TMY weather data is solar time, where

$$\text{Solar Time} = \text{Standard Time} + (4 \text{ minutes/degree}) \times (Lst - Lloc) + E\,,$$

where

Lst = standard meridian longitude (degrees),

$Lloc$ = local site longitude (degrees), and

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) and

n = day of the year, $1 \le n \le 365$.

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.[10]

Additional background regarding the difference between solar time and standard time is included in informative Annex B11 (Section B11.3).

A1.4~~-~~5 TMY2 Weather Data Format. 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 data[11] can be obtained at http://rredc.nrel.gov/solar/pubs/tmy2.

A1.4~~5~~.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-~~5~~7, 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.

A1.4~~5~~.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-~~6~~ 8 provides field positions, element definitions, and sample FORTRAN and C formats for reading the hourly records.

[Informative Note: Revise the numbering of the following tables as shown.]

TABLE A1-4~~-~~6 Typical Meteorological Year Data Format

TABLE A1-~~5~~ 7 Header Elements in the TMY2 Format (For First Record of Each File)

TABLE A1-~~6~~ 8 Data Elements in the TMY2 Format (For All Except the First Record)

[Informative Note: Add Section A1.6.]

A1.6 WYEC2 Weather Data Format. For those programs that do not have Weather Year for Energy Calculations 2 (WYEC2) weather processors, WYEC2 weather data file format is described below.

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 A1-9.

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. 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.)

ANNEX A2
STANDARD OUTPUT REPORTS

[Informative Note: Add item c and references to corresponding attachments (A2.3 and A2.7) as shown, modify previous references to account for new sections as shown, and change second reference to Sec5-2out.XLS to Sec5-3out.XLS in second paragraph.]

The standard output report consists of ~~three~~ four forms provided on the CD accompanying this standard:

a. Output Results for Section 5.2 Cases (Sec5-2out.XLS, spreadsheet file)
b. Output Results for Section 5.3 Cases (Sec5-3out.XLS, spreadsheet file)
c. Output Results for Section 5.4 Cases (Sec5-4out.XLS, spreadsheet file)
d. Modeling Notes (S140outNotes.TXT, text file reprinted as Attachment A2.3)

For entering output results into Sec5-2out.XLS, ~~and~~ Sec5-3out.XLS, and Sec5-4out.XLS, follow the instructions provided at the top of the appropriate electronic spreadsheet file. These instructions are reprinted as Attachments A2.1, ~~and~~ A2.2, and A2.3, respectively, within this section.

For entering modeling notes into S140outNotes.TXT, use the format of the following examples given as Attachments A2.4~~5~~, ~~and~~ A2.~~5~~6, and A2.7 within this section.

[Informative Note: Add Attachment A2.3 as shown.]

Attachment A2.3 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.

TABLE A1-9 Data Elements in the WYEC2 Format

Field Number	Data Positions	Flag Position(s)	Data Element
001	001-005	–	WBAN station identification number
002	006-006	–	File source code
003	007-014	–	Year, Month, Day, Hour (2 characters each)
101	015-018	–	Extraterrestrial irradiance, kJ/m^2
102	019-022	023-024	Global horizontal irradiance, kJ/m^2
103	025-028	029-030	Direct normal irradiance, kJ/m^2
104	031-034	035-036	Diffuse horizontal irradiance, kJ/m^2
105	037-040	041	Global horizontal illuminance, 100 lux
106	042-045	046	Direct normal illuminance, 100 lux
107	047-050	051	Diffuse horizontal illuminance, 100 lux
108	052-055	056	Zenith luminance, 100 Cd/m^2
110	057-058	059	Minutes of sunshine, 0–60 minutes
201	060-063	064	Ceiling height, 10 m
202	065-068	069	Sky condition
203	070-073	074	Visibility, 100 m
204	075-082	083	Present weather
205	084-088	089	Station pressure, 10 Pa
206	090-093	094	Dry-bulb temperature, 0.1°C
207	095-098	099	Dew-point temperature, 0.1°C
208	100-102	103	Wind direction, 0–359 degrees
209	104-107	108	Wind speed, 0.1 m/s
210	109-110	111	Total sky cover, 0–10 in tenths
211	112-113	114	Opaque sky cover, 0–10 in tenths
212	115-115	116	Snow cover

[Informative Note: Change Attachments A2.3, A2.4, and A2.5 to A2.4, A2.5, and A2.6 as shown.]

Attachment A2.~~3~~ 4 Standard 140 Output Form—Modeling Notes

Attachment A2.4~~5~~ Example of Modeling Notes for BLAST 3.0[5]

Attachment A2.~~5~~6. Example of Modeling Notes for DOE-2.1E[12]

[Informative Note: Add Attachment A2.7 as shown.]

Attachment A2.7 Example of Modeling Notes for ESP-r/HOT3000[~~A-2~~]

STANDARD 140 OUTPUT FORM–MODELING NOTES

INSTRUCTIONS: See Annex A2.

SOFTWARE: *ESP-r/HOT3000*

VERSION: *bpsh3k versions 1.1 and 1.7*

DOCUMENT BELOW THE MODELING METHODS USED IF ALTERNATIVE MODELING METHODS OR ALGORITHMS ARE AVAILABLE IN THE SOFTWARE BEING TESTED.

(See Annex A2 for examples.)

Simulated Effect:

Zone Temperature Controller

Optional Settings or Modeling Capabilities:

- Basic controller for heating/cooling
- Free-float controller
- Basic pre-heat or pre-cool controller
- Fixed heat injection and extraction
- PID control action for heating/cooling
- Flux connection between zone and plant
- Multi-stage control with hysteresis
- Variable supply temperature with constraints
- Heat pipe from outside to inside
- Separate flux ON and OFF setpoints
- Match sensed/recorded value (ideal)
- Match sensed/recorded value (ON/OFF)
- Time-proportioning (ON/OFF) control
- Floating ‘“three position” control
- Optimum start control
- Optimum stop control
- Fuzzy logic PI-PD control

- Null controller
- Multi-sensor heating/cooling
- Evaporative source (surface)
- Slave capacity controller

Setting or Capability Used:

ESP-r/H3K basic (ideal) controller used with heating capacity of 20 kW while the furnace capacity is set to 10 kW.

Physical Meaning of Option Used:

In ESP-r, the controller has a defined capacity. When the load of the space is less than the capacity, the setpoint is maintained and the actual load is reported. If the load is greater than the capacity of the controller, ESP-r sets the load equal to the controller's capacity. In this case, the actual load is not met and the setpoint is not satisfied.

A value greater than 10 kW is used for the ideal controller heating capacity to allow the load of the zone to exceed 10 kW if this is what the solution dictates. This way, the load on the furnace is not limited to a maximum of 10 kW and it is possible to predict the proper number of under-heating hours for the zone.

This is an issue only with test HE230.

(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 B1
TABULAR SUMMARY OF TEST CASES

[Informative Note: Revise the introduction to Annex B1 as shown to modify reference to Section 5.3 tests and to refer to table B1-3 and Section 5.4.]

Tables B1-1a and B1-1b include a tabular summary of the building thermal envelope and fabric load test cases described in Section 5.2, in SI units only. Tables B1-2a and B1-2b include a tabular summary of the Space-Cooling~~HVAC~~ Equipment Performance test cases described in Section 5.3, in SI and I-P units, respectively. Table B1-3 summarizes the Space-Heating Equipment test cases described in Section 5.4, in SI units only.

[Informative Note: Add the following abbreviations to the nomenclature used in Tables B1-3.]

Nomenclature

DBT	dry-bulb temperature
Temp	temperature
PLR_f	part-load ratio for furnace

[Informative Note: Revise titles of Tables B1-2a and B1-2b as shown.]

TABLE B1-2a Space-Cooling Equipment~~HVAC~~ BESTEST Case Descriptions (SI Units)

TABLE B1-2b Space-Cooling Equipment~~HVAC~~ BESTEST Case Descriptions (I-P Units)

[Informative Note: Add Table B1-3 as shown.]

TABLE B1-3 Space-Heating Equipment BESTEST Cases Descriptions

Case #	Zone		Weather File	Equipment				
				Furnace			Circulating Fan (W)	Draft Fan (W)
	Outdoor DBT (°C)	Indoor Setpoint Temp. (°C)		Capacity (kW)	Steady-State Efficiency	PLR_f		
Analytical Verification Tests								
HE100	–30	20	HE100W	10	100%	1	0	0
HE110	–30	20	HE100W	10	80%	1	0	0
HE120	0	20	HE120W	10	80%	0.4	0	0
HE130	20	20	HE130W	10	80%	0.0	0	0
HE140	–20 to 20	20	HE140W	10	80%	0.0–0.8	0	0
HE150	–20 to 20	20	HE140W	10	80%	0.0–0.8	200-cont	0
HE160	–20 to 20	20	HE140W	10	80%	0.0–0.8	200-cyclic	0
HE170	–20 to 20	20	HE140W	10	80%	0.0–0.8	200-cont	50-cyclic
Comparative Tests								
HE210	varying	20	HE210W	10	80%	0–1.0	200-cyclic	50-cyclic
HE220	varying	15 to 20	HE210W	10	80%	0–1.0	200-cyclic	50-cyclic
HE230	varying	15 to 20	HE210W	5	80%	0–1.0	200-cyclic	50-cyclic

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ANNEX B10
INSTRUCTIONS FOR WORKING WITH RESULTS SPREADSHEETS PROVIDED WITH THE STANDARD

[Informative Note: Add new Section B10.3.]

B10.3 Documentation for RESULTS5-4.XLS (given in RESULTS5-4.DOC). Import data so that Cell A1 of Sec5-4out.XLS is in A1 of Sheet "YD" (your data). Check that the first value (TOTAL FURNACE LOAD GJ for A1) is in YD!B20. See Sheet A (rows 10–20) for tabulation of results locations. Your data will then appear in columns E, I, and M of Sheet A, in the rightmost column of each table on Sheet Q (used for making the charts). Chart update of "your data" is not automated.

Contents of Sheets:

Sheet	Description
'A'	Raw data compilation.
'YD'	For inputting new results (your data); see above for instructions.
'B', 'C', 'D'	Results from each simulation program.
'Q'	Formatted summary results tables including analytical/quasi-analytical solutions, simulations, and statistics. "Your data" automatically appears on the right side of each table. See below for Sheet Q table locations.
'LOAD' thru 'MIN T' (7 sheets)	Seven summary charts (one per sheet). Import of "your data" into these charts is not automated. However, the data do appear automatically on the right side of the tables used for making the charts (in Sheet Q). See below.

Contents of Sheet Q:

Description	Cell Range
TOTAL FURNACE LOAD	A5 – J19
TOTAL FURNACE INPUT	A21 – J35
FUEL CONSUMPTION	A37 – J51
FAN ENERGY (BOTH FANS)	A37 – I62
MEAN ZONE TEMPERATURE	A64 – H70
MAXIMUM ZONE TEMPERATURE	A72 – H78
MINIMUM ZONE TEMPERATURE	A80 – H86

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[Informative Note: Revise title of Annex B16 as shown.]

ANNEX B16
ANALYTICAL AND QUASI-ANALYTICAL SOLUTION RESULTS AND EXAMPLE SIMULATION RESULTS FOR HVAC EQUIPMENT PERFORMANCE TESTS

[Informative Note: Add reference to Section 5.4 tests.]

B16.1 Introduction. The results from quasi-analytical solutions and various detailed building energy simulation programs applied to the tests of Sections 5.3 and 5.4 are presented here in tabular and graphic form. 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 RESULTS5-3.XLS and RESULTS5-4.XLS in the accompanying files. Spreadsheet navigation instructions are included in RESULTS5-3.DOC and RESULTS5-4.DOC and have been printed out in informative Annex B10, Sections B10.2 and B10.3 for convenience.

[Informative Note: Add references to analytical results and Section 5.4 tests as shown.]

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 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 E100–E200 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 accept the given underlying physical assumptions while recognizing that these assumptions represent a simplification of physical reality. The ultimate or "absolute" validation standard would be comparison of simulation results with a *perfectly performed* empirical experiment, the inputs for which are *perfectly specified* to the simulationists. 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 minor disagreements among the two sets of quasi-analytical solution results presented in Annex B16 are small enough to allow 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 solutions were developed is included in Annex B17.

B16.3 Example Simulation Results. Because the quasi-analytical solution results constitute a reliable set of theoretical results (a mathematical truth standard), the primary purpose of including simulation results for the E100–E200 and HE100–HE170 cases in Annex B16 is to allow simulationists to compare their relative agreement (or disagreement) versus the quasi-analytical solution results to that for other simulation results. Perfect agreement among simulations and quasi-analytical solutions is not necessarily expected. The results give an indication of what sort of agreement is possible between simulation results and the quasi-analytical solution results.

Because the physical assumptions of a simulation may be different from those for the quasi-analytical solutions, a tested program may disagree with the quasi-analytical solutions without necessarily being incorrect. However, it is worthwhile to investigate the source of 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 misentered one or more program inputs;
b. problem with a particular algorithm in the program; or
c. one or more program algorithms used outside their intended range.

For generating simulation results, 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 deck corrections, and simulation software improvements. 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*[8] *Volume 1*[8] and *HVAC BESTEST For Fuel-Fired Furnaces.*[A-6]

B16.4 Nomenclature

[Informative Note: Add the following abbreviations to the nomenclature used in Table B1-3 as shown and revise existing abbreviations for EnergyPlus and DOE2.1E to avoid version conflicts.]

Results are grouped by case numbers, e.g., "E100" is Case E100 (Section 5.3.1). Sensitivity results are listed using two case numbers separated by a minus sign, e.g., "E110–100" is the difference between Case E110 (Section 5.3.2.1.1) and Case E100.

Analytical	quasi-analytical solution
ARI	Air-Conditioning & Refrigeration Institute
CA-SIS	CA-SIS VI (see Table B17-1)
CIEMAT	Centro de Investigaciones Energeticas, Medioambientales y Technologicas
CLM2000	CLIM2000 2.1.6 (see Table B17-1)
COP	coefficient of performance
Delta	sensitivity between listed cases
DOE21E	DOE-2.1E-088 or DOE-2.1E-133 (see Table B17-1) (for Section B16.5)
DOE-2.1E	DOE-2.1E-133 (for Section B16.6)
dry	dry coil
EDF	Electricité de France
Energy+	EnergyPlus 1.0.0.023 (see Table B17-1) (for Section B16.5)
EnergyPlus	EnergyPlus 1.0.2.008 (for Section B16.6)
Hi	high
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
IDB	indoor dry-bulb temperature
kWh	kilowatt hours

kWh,e	kilowatt hours, electrical
lat	latent internal gains
lo	low
m	mid-range
Max	maximum
Min	minimum
GARD	GARD Analytics
NREL	National Renewable Energy Laboratory
ODB	outdoor dry-bulb temperature
PL	part-load ratio
PLR	part-load ratio
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
SH	sensible heat ratio
SHR	sensible heat ratio
TRN-id	TRNSYS-TUD with ideal controller (see Table B17-1)
TRN-re	TRNSYS-TUD with realistic controller (see Table B17-1)
TUD	Technische Universitat Dresden
v.	versus
x	multiplied by
@	at

[Informative Note: Create Section B16.5 and put Space-Cooling Equipment results (tables and graphs already in Annex B16 of the 2004 edition) in it. Create Section B16.6 and put Fuel Fired Furnace results (the ones added below) in it.]

B16.5 Tables and Graphs of Results for Space-Cooling Equipment Cases E100–E200

B16.6 Tables and Graphs of Results for Space-Heating Equipment Cases HE100–HE170 and HE210–HE230. The following tables provide a comparison of the results calculated from the methods outlined in section B17.2 with the results obtained from the test cases using three different software simulation tools: ESP-r/HOT3000,[A-2] EnergyPlus,[A-1] and DOE2.1E.[A-7]

Comparison of Energy Delivered by Fuel-Fired Furnace (Load) and Rate of Fuel Consumption.

Total Furnace Load (GJ)

				Analytical/Quasi-Analytical	
Cases	**ESP-r /HOT3000**	**EnergyPlus**	**DOE 2.1E**	**Heat Transfer Surf Method**	**Infiltration Method**
HE100	77.94	77.75	77.73	77.74	77.77
HE110	77.94	77.75	77.73	77.74	77.77
HE120	31.25	31.1	31.12	31.1	31.11
HE130	0	0	0.15804	0	0
HE140	31.26	31.1	31.07	31.1	31.11
HE150	29.88	29.59	29.55	29.65	29.66
HE160	31.26	30.46	30.48	31.1	31.11
HE170	29.88	29.59	29.55	29.65	29.66
HE210	41.36	42.04	42.08	N/A	N/A
HE220	39.41	39.87	39.87	N/A	N/A
HE230	34.32	34.59	34.49	N/A	N/A

Total Furnace Input (GJ)

				Analytical/Quasi-Analytical	
Cases	**ESP-r /HOT3000**	**EnergyPlus**	**DOE 2.1E**	**Heat Transfer Surf Method**	**Infiltration Method**
HE100	77.74	77.71	78.30	77.71	77.71
HE110	96.92	97.22	97.81	97.22	97.22
HE120	38.41	38.27	38.41	38.27	38.30
HE130	0.00	0.00	0.14	0.00	0.00
HE140	39.00	39.00	38.71	39.00	39.00
HE150	37.23	36.94	36.64	37.02	37.02
HE160	38.12	38.12	37.82	38.09	38.12
HE170	37.23	36.94	36.64	37.02	37.02
HE210	50.53	52.01	52.30	N/A	N/A
HE220	47.87	49.35	49.35	N/A	N/A
HE230	41.37	42.55	43.14	N/A	N/A

Total Furnace Input (m^3/s)

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Analytical/Quasi-Analytical Heat Transfer Surf Method	Analytical/Quasi-Analytical Infiltration Method
HE100	0.000263	0.000263	0.000265	0.000263	0.000263
HE110	0.000328	0.000329	0.000331	0.000329	0.000329
HE120	0.00013	0.0001295	0.00013	0.0001295	0.0001296
HE130	0	0	0.00000049	0	0
HE140	0.000132	0.000132	0.000131	0.000132	0.000132
HE150	0.000126	0.000125	0.000124	0.0001253	0.0001253
HE160	0.000129	0.000129	0.000128	0.0001289	0.000129
HE170	0.000126	0.000125	0.000124	0.0001253	0.0001253
HE210	0.000171	0.000176	0.000177	N/A	N/A
HE220	0.000162	0.000167	0.000167	N/A	N/A
HE230	0.00014	0.000144	0.000146	N/A	N/A

The results of the comparison of the circulating and draft fan energy consumption (kWh) are shown in the following table. Again, the results for fan energy are in slight disagreement for the comparative cases.

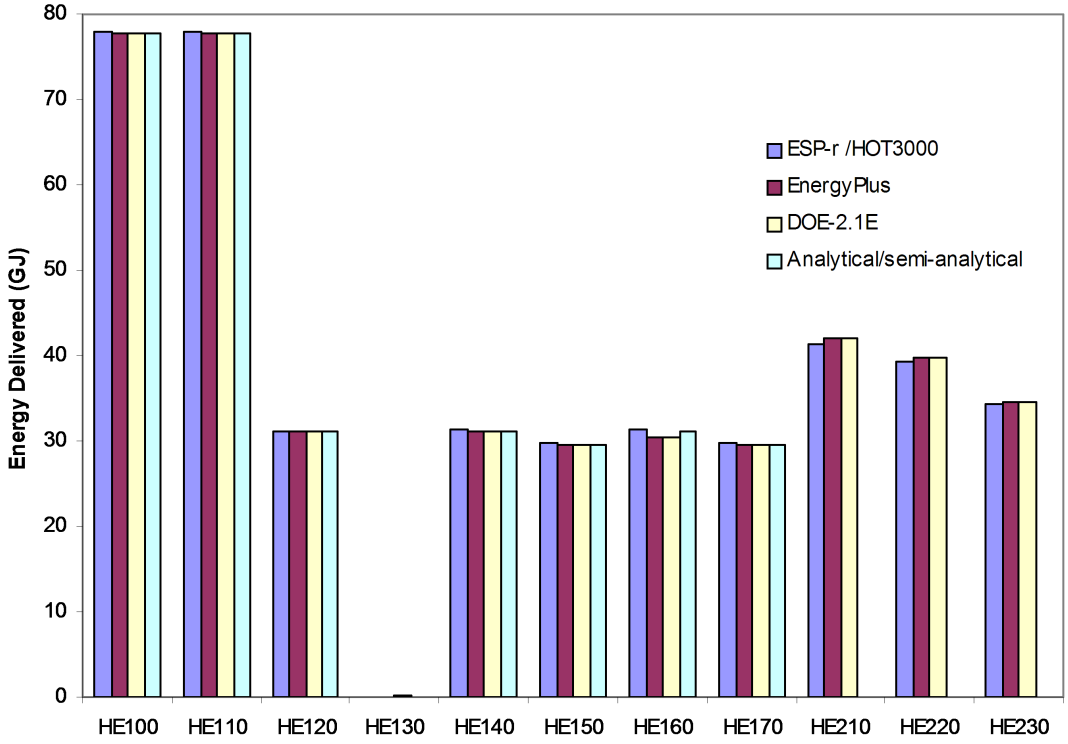
Comparison of Fan Energy Consumption (kWh)

Case	Analytical/ Quasi-Analytical	ESP-r/HOT3000	EnergyPlus	DOE-2.1E
HE150	432	432	433.3	432.1
HE160	172.76	170.2	172.2	172.3
HE170	473.18	473.4	473.1	473.3
HE210	N/A	281.6	291.4	299.2
HE220	N/A	268.3	276.1	282.2
HE230	N/A	458.3	431.4	480

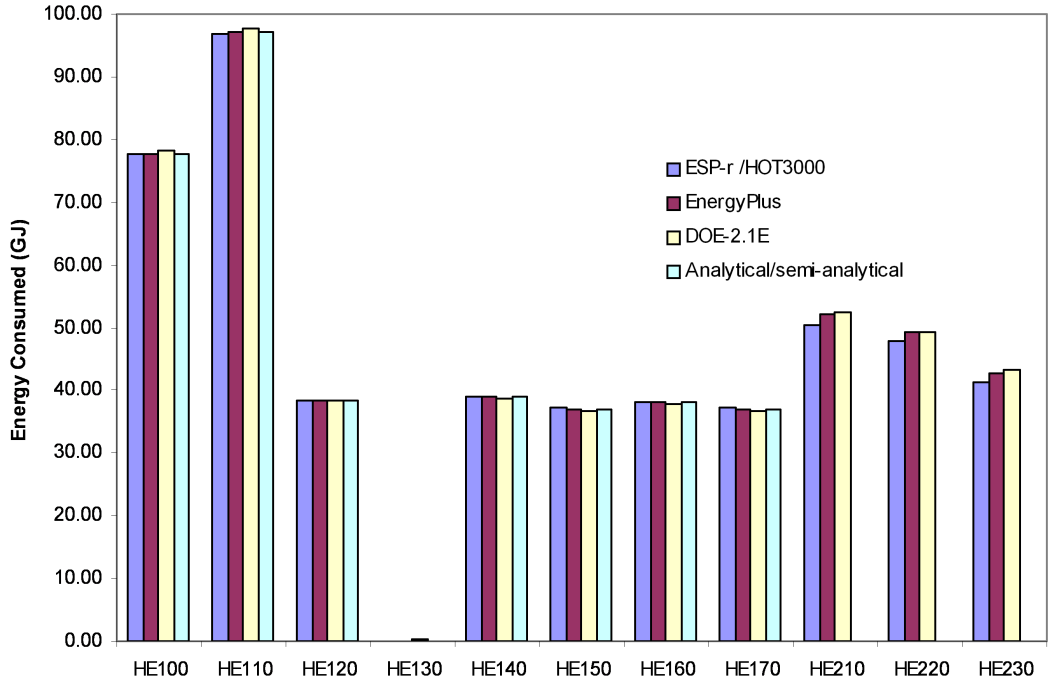
In addition, the mean, maximum, and minimum zone temperatures were of interest for the comparative test cases, especially Case HE230 where the furnace is undersized. This table shows a comparison of these values for the three test simulation tools.

Comparison of the Mean, Maximum, and Minimum Temperatures for the Comparative Test Cases

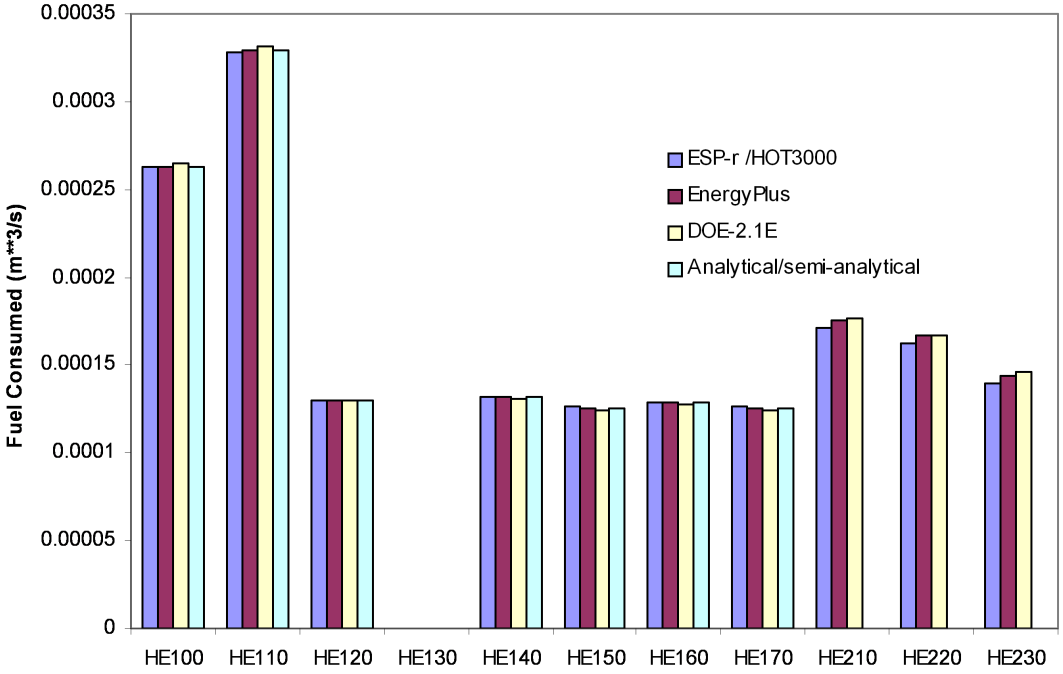
Case	Mean Temperature (°C)			Maximum Temperature (°C)			Minimum Temperature (°C)		
	ESP-r/ HOT3000	EnergyPlus	DOE- 2.1E	ESP-r/ HOT3000	EnergyPlus	DOE- 2.1E	ESP-r/ HOT3000	EnergyPlus	DOE- 2.1E
HE210	20.01	20	19.96	21.45	20	20.05	20	20	19.83
HE220	18.75	18.53	18.5	22.7	20	20.05	15	15	14.88
HE230	15.48	15.17	15.46	20.14	20	20.05	1.45	4.48	5.33



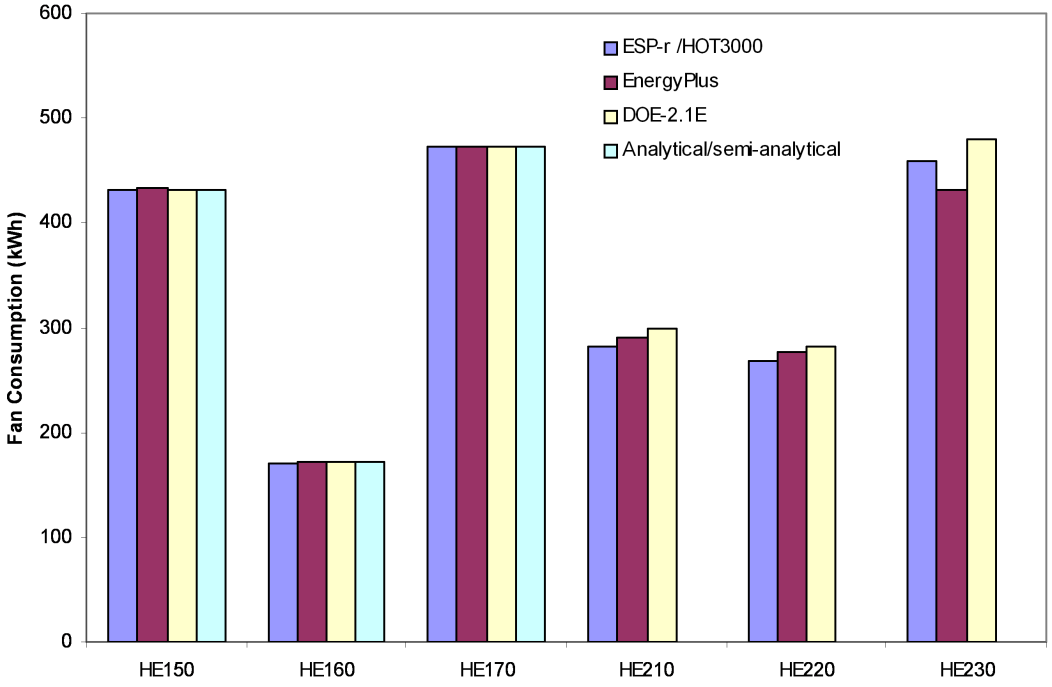
Comparison of the energy delivered for fuel-fired furnace test cases (in GJ).



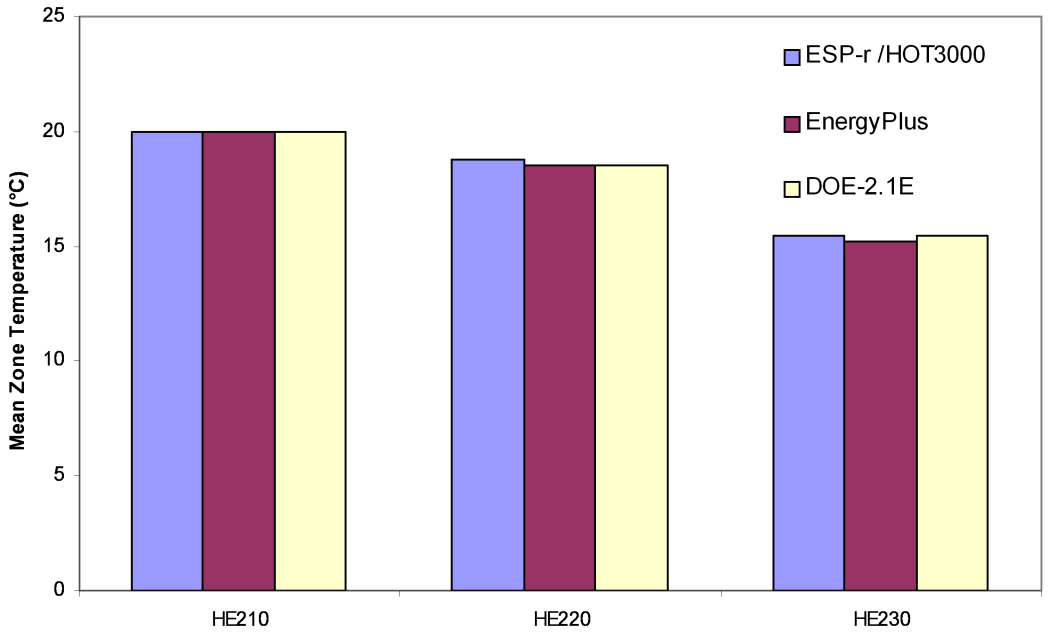
Comparison of the energy consumed for fuel-fired furnace test cases (in GJ).



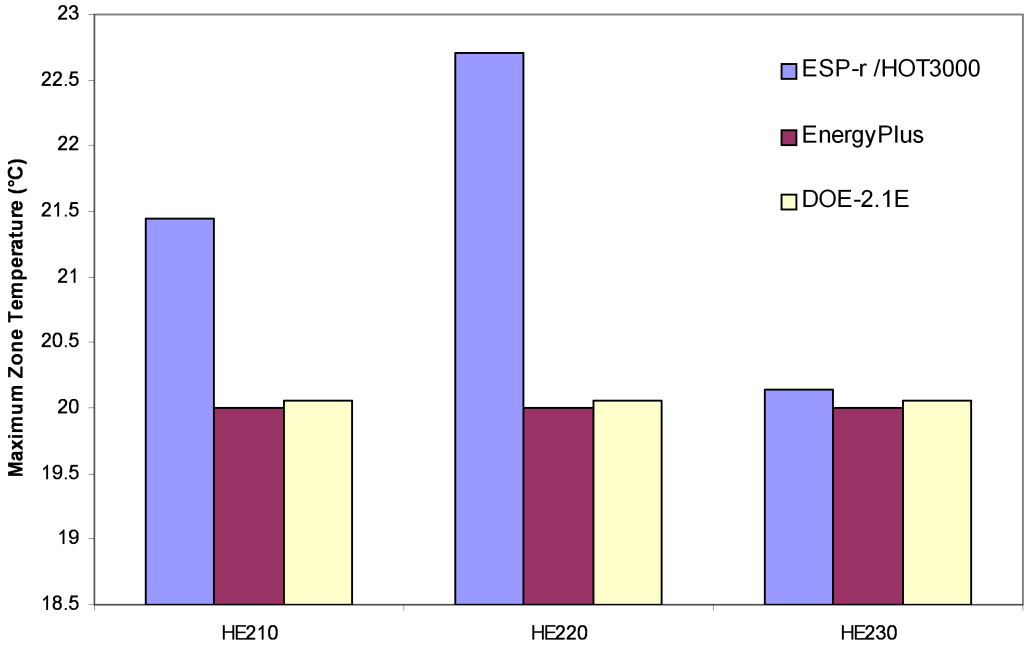
Comparison of the fuel consumed for fuel-fired furnace test cases (in m^3/s).



Comparison of the fan energy for fuel-fired furnace test cases (in kWh).

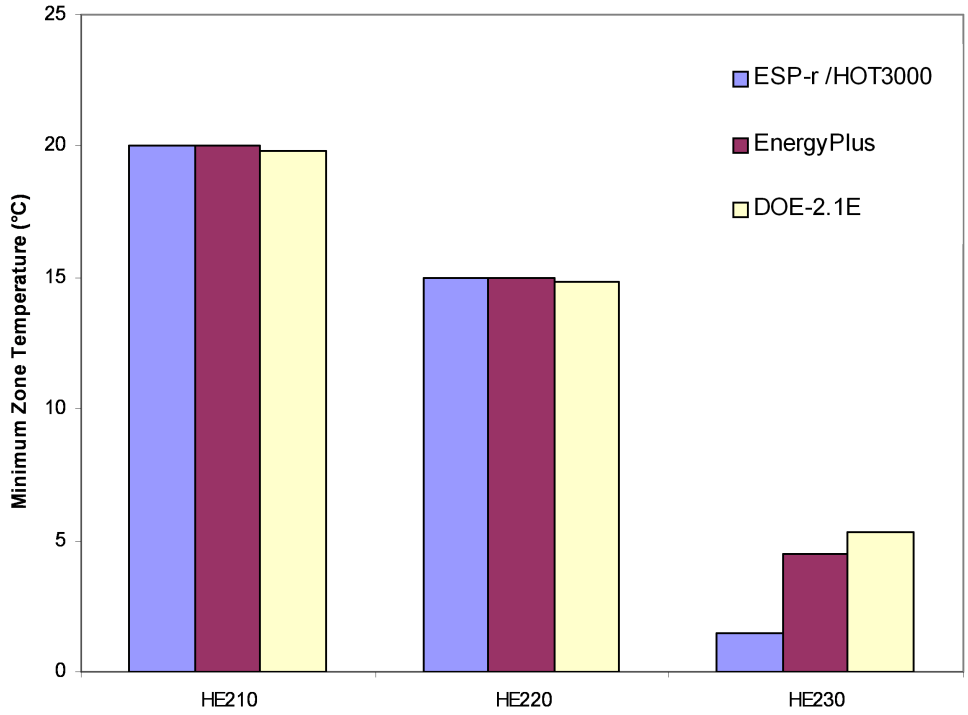


Comparison of the mean zone temperature for fuel-fired furnace test cases (in °C).



Comparison of the maximum zone temperature for fuel-fired furnace test cases (in °C).*

*ESP-r's finite-difference discretization scheme with respect to time can be fully explicit, fully implicit, or any weighting in between. The program's default 50/50 weighting was employed for the simulations reported here and was found to produce some temperature solution oscillations for particular cases. However, subsequent analysis revealed that these oscillations had no effect upon the predicted fuel and electricity consumptions, the metrics of primary interest in these test cases.



Comparison of the minimum zone temperature for fuel-fired furnace test cases (in °C).

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ANNEX B17
PRODUCTION OF QUASI-ANALYTICAL SOLUTION RESULTS AND EXAMPLE SIMULATION RESULTS FOR HVAC EQUIPMENT PERFORMANCE TESTS

[Informative Note: Revise Section B17.1 in Annex B17 as follows to prepare for addition of new section B17.2.]

B17.1 For Space-Cooling Equipment Cases (E100–E200)

B17.1.1 Introduction

[Informative Note: Revise as shown to modify reference to Section 17.1.2, revise in table the reference letters for Authoring Organization for ENERGYPLUS, and revise footnote on DOE-OBT.]

The full discussion regarding production of quasi-analytical solution results and example simulation results is included in *HVAC BESTEST*.[8] Portions of that discussion have been included here. The quasi-analytical solutions and programs used to generate the example simulation results are described in Table B17-1.

The first column of Table B17-1 ("Model") indicates the proper program name and version number or indicates a quasi-analytical solution. The second column ("Authoring Organization") indicates the national research facility or university with expertise in building science that wrote the simulation software or did the quasi-analytical solutions. The third column ("Implemented By") indicates the national research facility or university with expertise in building science that performed the simulations or did the quasi-analytical solutions. The entries in the fourth column are the abbreviations for the simulations and quasi-analytical solutions generally used in Annex B16 and elsewhere in the informative annexes. The majority of participating organizations that performed simulations ran software that their organization either authored or coauthored.

The availability of quasi-analytical solutions (see Section B17.1.2) greatly helped to identify and correct errors in the simulations such that errors are minimized in the final simulation results. Also, to minimize the potential for user error in the simulations, when feasible, more than one modeler developed input files for each program. This was done for DOE-2.1E, and where disagreement in the inputs or results was found, the modelers worked to resolve the differences. Additionally, one of the participants (TUD) developed quasi-analytical solutions and ran separate controller models within TRNSYS; this allowed for greater understanding of the test specification and of their simulation model. Where only a single modeler was involved, we strongly recommended that another modeler familiar with the program check the inputs carefully.

TABLE B17-1 Participating Organizations and Computer Programs

Model	Authoring Organization	Implemented By	Abbreviation
Quasi-analytical solution with ideal controller model	Hochschule Technik & Architektur Luzern, Switzerland (HTAL)	Hochschule Technik & Architektur Luzern, Switzerland	HTAL1
Quasi-analytical solution with realistic controller model	Hochschule Technik & Architektur Luzern, Switzerland	Hochschule Technik & Architektur Luzern, Switzerland	HTAL2
Quasi-analytical solution with ideal controller model	Technische Universität Dresden, Germany (TUD)	Technische Universität Dresden, Germany	TUD
CA-SIS V1	Electricité de France, France (EDF)	Electricité de France, France	CA-SIS
CLIM2000 2.1.6	Electricité de France, France	Electricité de France, France	CLM2000
DOE-2.1E-088	LANL/LBNL/ESTSC[a,b,c] USA	CIEMAT,[d] Spain	DOE21E/CIEMAT
DOE-2.1E-133	LANL/LBNL/JJH[a,b,e] USA	NREL/JNA,[f] USA	DOE21E/NREL
ENERGYPLUS 1.0.0.023	LBNL/UIUC/CERL/OSU/GARD Analytics/ FSEC/DOE-OBT[a,b,g,h,i,j,k]	GARD Analytics, USA	Energy+
TRNSYS 14.2-TUD with ideal controller model	University of Wisconsin, USA; Technische Universität Dresden, Ger.	Technische Universität Dresden, Germany	TRN-id TRNSYS-ideal
TRNSYS 14.2-TUD with real controller model	University of Wisconsin, USA; Technische Universität Dresden, Ger.	Technische Universität Dresden, Germany	TRN-re TRNSYS-real

[a]LANL: Los Alamos National Laboratory
[b]LBNL: Lawrence Berkeley National Laboratory
[c]ESTSC: Energy Science and Technology Software Center (at Oak Ridge National Laboratory, USA)
[d]CIEMAT: Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas
[e]JJH: James J. Hirsch & Associates
[f]NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates
[g]UIUC: University of Illinois Urbana/Champaign
[h]CERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories
[i]OSU: Oklahoma State University
[j]FSEC: University of Central Florida, Florida Solar Energy Center
[k]DOE-OBT: ~~U.S. Department of Energy,~~ Office of Building Technologies~~y~~, ~~State and Community Programs,~~ Energy Efficiency and Renewable Energy, US Department of Energy

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. Also, all improvements were required to be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results was not allowed.

Input decks used to generate the simulation results are provided in the files accompanying this standard; see the README.DOC file. International Energy Agency participants that ran simulations for CA-SIS and CLIM2000 did not supply input decks with their results.

B17.1.2 Quasi-Analytical Solution Results

B17.1.3 Selection of Programs for Producing Example Simulation Results

[Informative Note: Add new Section B17.2 in Annex B17.]

B17.2 For Space-Heating Equipment Cases (HE100-HE170)

B17.2.1 Analytical Solutions. The configuration used for tests HE100–HE130 is well posed for analytical solutions. The results can be used for comparison with the software being tested.

B17.2.1.1 Case HE100: Base Case. A simple schematic of the heat transfer through the roof heat transfer surface is shown in Figure B17.1. The following section describes the simple heat transfer calculation for the analytic solution of the base case. Based on the building description given above, convective and conductive heat transfer will be considered, but radiation will be neglected since the radiative coefficients were defined as zero.

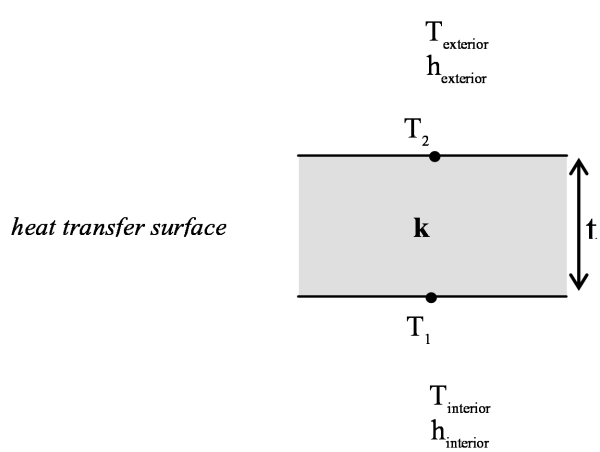

Figure B17.1 Heat flows through heat transfer surface.

The convective flux from the interior of the zone to the interior surface can be defined as

$$q_{interior} = h_{interior}(T_{interior} - T_1) \; . \qquad \text{(B17.1)}$$

The conductive flux through the heat transfer surface can be defined as

$$q_{conduction} = \frac{k}{t}(T_1 - T_2) \; . \qquad \text{(B17.2)}$$

The convective flux from the exterior surface to the exterior ambient can be defined as

$$q_{exterior} = h_{exterior}(T_2 - T_{exterior}) \; . \qquad \text{(B17.3)}$$

Combining Equations B3.1–B3.3 gives the total heat flux through the surface:

$$q_{total} = [(T_{interior} - T_1) + (T_1 - T_2) + (T_2 - T_{exterior})] \times \left[\frac{1}{h_{interior}} + \frac{t}{k} + \frac{1}{h_{exterior}}\right]^{-1} \qquad \text{(B17.4)}$$

which can be reduced to:

$$q_{total} = (T_{interior} - T_{exterior}) \times \left[\frac{1}{h_{interior}} + \frac{t}{k} + \frac{1}{h_{exterior}}\right]^{-1} \qquad \text{(B17.5)}$$

Using the values defined in the previous sections and Equation B17.5, the heat flux becomes q_{total} = 208.28 W/m^2. The heat transfer surface is 48 m^2; therefore, the heat transfer through this surface is $\boldsymbol{Q_{total}}$ **= 9998 W**. The rate of energy transfer from the furnace to the zone air required to meet this load is $\boldsymbol{Q_{delivered}}$ **= 9998 W**.

The rate of fuel consumption of the furnace can be calculated as

$$C = \frac{Q_{fuel}}{\text{HHV}} \; , \qquad \text{(B17.6)}$$

where C is the rate of fuel consumption of the furnace in m^3/s, Q_{fuel} is the rate at which the fuel's chemical energy is converted to thermal energy (MW), and HHV is the higher heating value of natural gas—defined as 38 MJ/m^3 in Section 5.4.1.10.5.

Q_{fuel} can be calculated using the definition of the furnace steady-state efficiency, η:

$$\eta = \frac{Q_{delivered}}{Q_{fuel}} \qquad \text{(B17.7)}$$

As the furnace is 100% efficient, the heat delivered by the furnace is equal to the rate at which the furnace consumed fuel, as calculated with Equation B17.7, i.e., $\boldsymbol{Q_{delivered} = Q_{fuel}}$ **= 9998 W**. Using Equation B17.6, the rate of fuel consumption is **0.000263 m^3/s**.

B17.2.1.2 Case HE110. As with the base case, the energy delivered to the zone by the furnace is $\boldsymbol{Q_{delivered}}$ **= 9998 W**. In this case, the furnace is 80% efficient; therefore, the furnace will have to consume more fuel than the base case.

Equation B17.7 gives $\boldsymbol{Q_{fuel}}$ **= 12497.5 W**; therefore, the rate of fuel consumption can be calculated with Equation B17.6 as **0.000329 m^3/s**.

B17.2.1.3 Case HE120. Given that the outdoor temperature is now 0°C and using the equations defined in Section B.17.2.1.1, the heat load on the furnace can be calculated as $\boldsymbol{Q_{delivered}}$ **= 3999 W**, 40% of the design capacity.

Residential furnaces cycle on and off to meet their load at off-design conditions. The furnace part-load ratio (PLR_f) is used to predict the energy use of a furnace under part-load conditions and is defined as

$$\text{PLR}_f = \frac{\text{Load Placed on Furnace}}{\text{Furnace Capacity}} \; , \qquad \text{(B17.8)}$$

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

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

$$\text{PLF} = \frac{\text{Part-Load Efficiency}}{\text{Steady-State Efficiency}} = \frac{\eta_{part\ load}}{\eta} \qquad \text{(B17.9)}$$

Using Equations B17.8, B17.9, and B17.6, the part-load efficiency can be calculated as $\boldsymbol{\eta_{part\ load}}$ **= 0.8125**. Therefore, the rate of fuel consumption is **0.0001295 m^3/s**.

B17.2.1.4 Case HE130. The zone temperatures should remain at a constant value of 20°C, the same value as the outdoor temperature (ΔT = 0°C), and there should be no sensible heat load, energy, or fuel consumption by the furnace.

B17.2.2 Quasi-Analytical Solutions. For Cases HE140–HE170, analytic solutions are not possible, and as such, the reference results are calculated using a discrete time-step calculation, similar to the approach applied by most building simulation programs. As the thermal mass of the building is effectively zero, a solution can be found on a time-step basis. The following details this one-hour time-step approach.

A spreadsheet[A-6] was created with each row representing one hour of the three-month simulation period. The "hours" column was filled sequentially with 1 to 24 for each day, beginning again with 1 for the next day. In this way, the exterior dry-bulb temperature can be calculated for each hour using

$$T = 20 \times \left(\sin\left(\frac{\pi}{12} \times t\right)\right) \; , \qquad \text{(B17.10)}$$

where t is the hour of the day.

The load placed on the furnace, Q_{Total}, is then calculated using

$$Q_{Total} = q_{Total} \times Area \; ,$$

where q_{Total} is calculated using

$$q_{total} = (T_{interior} - T_{exterior}) \times \left[\frac{1}{h_{interior}} + \frac{t}{k} + \frac{1}{h_{exterior}}\right]^{-1} \; . \qquad \text{(B17.11)}$$

The part-load ratio (PLR_f) is then calculated using equation (B17.8):

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

where *Furnace Capacity* has been previously defined as 10 kW, and the part-load factor (PLF) can then be calculated using:

$$PLF = \frac{PLR_f}{HIR(PLR_f)} \qquad \text{(B17.12)}$$

$$HIR(PLR_f) = a + b \times PLR_f + c \times PLR_f^2 + d \times PLR_f^3 \qquad \text{(B17.13)}$$

where the coefficients have been previously defined as

a = 0.0080472574;
b = 0.87564457;
c = 0.29249943; and
d = –0.17624156.

The part-load efficiency is a function of the steady-state efficiency and the part-load factor (PLF), as defined in Equation (B17.9),

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

which can be rearranged to give

$$\eta_{part\ load} = \eta \times PLF .$$

$Q_{furnace}$, the rate at which the fuel's chemical energy is converted to thermal mass in the furnace, can be calculated using the definition of the furnace steady-state efficiency,

$$\eta = \frac{Q_{Total}}{Q_{furnace}}, \qquad \text{(B17.14)}$$

which can be rearranged to give

$$Q_{furnace} = Q_{delivered} \times \eta .$$

The rate of fuel consumption of the furnace is then calculated using Equation B17.6:

$$C = \frac{Q_{fuel}}{HHV}$$

where C is the rate of fuel consumption of the furnace in m^3/s and HHV is the higher heating value of natural gas, defined as 38 MJ/m^3 in Section 5.4.1.10.5.

The electrical consumption of the fans that run continuously is simply calculated as a constant consumption. If, for example, a 200 W fan runs continuously, then 200 W is applied for that time step. If, on the other hand, the fan cycles with the furnace burner operation, then the fan power is multiplied by the part-load ratio (PLR) for that time step.

B17.2.2.1 Case HE140. The calculation of the heating load on the furnace and the fuel consumption over a 24-hour period is required to examine the impact of the varying outdoor dry-bulb temperature. Table B17.2 shows the calculated sensible heat load to be delivered by the furnace, $Q_{delivered}$, the part-load efficiency, $\eta_{part\ load}$, the rate of fuel consumption of the furnace, Q_{fuel}, and the resulting fuel consumption over a 24-hour period. A description of the semi-analytical calculation method is presented in Section B17.2.2.

The average hourly calculated heat delivered by the furnace is **4998.45 W**, and the rate of fuel consumption is **0.000132 m^3/s**.

B17.2.2.2 Case HE150. As the circulation fan runs constantly, 200 W of fan heat is continuously added to the heated airstream. This reduces the energy required from fuel combustion while maintaining the constant zone temperature. This has the impact of affecting the part-load factor and fuel consumption.

The average hourly value calculated for the heat to be delivered by the furnace is **4759.67 W**, and the rate of fuel consumption is **0.0001253 m^3/s**. The total electricity consumption is calculated to be 432 kWh or **1.56 GJ** for the three-month period. Table B17.3 gives the results for a 24-hour period.

B17.2.2.3 Case HE160. This calculated solution assumes that the PLR_f is equal to the fraction of time during which the fan operates for a given time step. In addition, it assumes that there are no effects from fan start-up or shutdown, i.e., when the fan is on, it draws 200 W. It is recognized that some building simulation programs may apply different assumptions in the modeling of circulation fans. In this case, results would be expected to disagree with these calculated results by a small amount.

As the circulating fan cycles with the burner operation, its hourly energy varies based on the load on the furnace. It can be calculated as

$$Energy_{circ,fan} = \Delta t \times Power_{circ,fan} \times PLF_f, \qquad \text{(B17.15)}$$

where Δt is the time step, $Power_{circ,fan}$ is the rated circulation fan power (200 W in this case), and PLR_f is

$$PLR_f = \frac{\text{Load Placed on Furnace}}{\text{Furnace Capacity}}, \qquad \text{(B17.8)}$$

where the available *Furnace Capacity* includes the fan power.

The average hourly value calculated for the heat to be delivered by the furnace is **4898.48 W** and the rate of fuel consumption is **0.0001289 m^3/s**. These values are higher than the previous case where the circulating fan ran constantly.

The total electricity consumption is 172.76 kWh or **0.62 GJ** for the three-month period, which is lower than in the previous case. Table B17.4 gives the results for a 24-hour period.

B17.2.2.4 Case HE170. The circulating fan operates continuously at 200 W, whereas the draft fan cycles with the burner operation. Implicit in this calculation is that the PLR_f is equal to the fraction of time during which the draft fan operates for a given time step. In addition, it is assumed that there are no effects from fan start-up or shut-down, i.e., when the draft fan is on, it draws 50 W. The draft fan's hourly energy varies based on the load on the furnace and can be calculated as

$$Energy_{draft,fan} = \Delta t \times Power_{draft,fan} \times PLF_f, \qquad \text{(B17.16)}$$

where Δt is the time step, $Power_{draft,fan}$ is the rated draft fan power (50 W in this case), and PLR_f is

$$PLR_f = \frac{\text{Load Placed on Furnace}}{\text{Furnace Capacity}}. \qquad \text{(B17.8)}$$

TABLE B17.2 Heat Load, Efficiency, and Fuel Consumption for the Complex Part-Load Test

Hour of Day	Temperature (°C)	$Q_{delivered}$ (W)	$\eta_{part\ load}$	Q_{fuel} (W)	Rate of Fuel Consumption (m^3/s)
1	5.18	2964.03	0.821	3608.74	0.000095
2	10.00	1999.53	0.827	2417.76	0.000064
3	14.14	1171.30	0.820	1429.26	0.000038
4	17.32	535.77	0.768	697.18	0.000018
5	19.32	136.26	0.544	250.41	0.000007
6	20.00	0.0	0.0	0.0	0.0
7	19.32	136.26	0.544	250.41	0.000007
8	17.32	535.77	0.768	697.18	0.000018
9	14.14	1171.30	0.820	1429.26	0.000038
10	10.00	1999.53	0.827	2417.76	0.000064
11	5.18	2964.03	0.821	3608.74	0.000095
12	0.00	3999.07	0.813	4921.62	0.000130
13	–5.18	5034.10	0.805	6256.22	0.000165
14	–10.00	5998.60	0.799	7506.51	0.000198
15	–14.14	6826.83	0.796	8576.02	0.000226
16	–17.32	7462.36	0.795	9389.13	0.000247
17	–19.32	7861.87	0.795	9895.21	0.000260
18	–20.00	7998.13	0.795	10066.74	0.000265
19	–19.32	7861.87	0.795	9895.21	0.000260
20	–17.32	7462.36	0.795	9389.13	0.000247
21	–14.14	6826.83	0.796	8576.02	0.000226
22	–10.00	5998.60	0.799	7506.51	0.000198
23	–5.18	5034.10	0.805	6256.22	0.000165
24	0.00	3999.07	0.813	4921.62	0.000130

The heat output of the draft fan should not be added to the zone energy balance; therefore, there should be no impact on the energy balance of the zone. The average hourly value calculated for the heat to be delivered by the furnace is **4759.67 W**, and the rate of fuel consumption is **0.0001253 m^3/s**.

The electrical consumption of the furnace system should increase with an additional load of the draft fan. The total electricity consumption is calculated as 473.18 kWh or 1.70 GJ for the three-month period of this test. Table B17.5 gives the results for a 24-hour period.

B17.2.3 Analytical Solution For Alternate Cases. These alternate test cases, described in Section 5.4.1.9, are designed for those simulation programs that do not allow the definition of convective heat transfer coefficients. In this approach, the heating loads are driven by infiltration of outdoor air into the zone.

The rate of energy consumption due to the required sensible heating of the incoming outdoor air, Q_{Total}, can be defined as

$$Q_{Total} = \dot{m} \times c_p \times \Delta T \,, \qquad \text{(B17.17)}$$

where

$\dot{m}$ ≡ air mass flow rate, kg/s;

c_p ≡ specific heat of the air, J/(kg·K); and

ΔT ≡ temperature difference between the indoor and outdoor air, K.

Using the values defined in the previous sections and Equation B17.17, the heat transfer rate required to maintain the interior setpoint temperature is Q_{total} **= 9997 W**. The rate of energy transfer from the furnace to the zone air required to meet this load is $Q_{delivered}$ **= 9997 W**.

As the furnace is 100% efficient, the heat delivered by the furnace is equal to the rate at which the furnace consumed fuel, as calculated with Equation B17.7, i.e., $Q_{delivered} = Q_{fuel}$ **= 9997 W**. Using Equation B17.6, the rate of fuel consumption is **0.000263 m^3/s**.

The remaining test cases differ from the originals only in the analytical/calculated solutions. Table B17.6 describes the numerical results calculated for the infiltration cases.

TABLE B17.3 Heat Load, Efficiency, Fuel and Electricity Consumption for the Circulating Fan Test

Hour of Day	Temperature (°C)	$Q_{delivered}$ (W)	$\eta_{part\ load}$	Q_{fuel} (W)	Rate of Fuel Consumption (m^3/s)	Electricity (kWh)
1	5.18	2764.03	0.82	3358.79	0.0000884	0.2
2	10	1799.53	0.83	2175.84	0.0000573	0.2
3	14.14	971.30	0.81	1196.21	0.0000315	0.2
4	17.32	335.77	0.71	472.15	0.0000124	0.2
5	19.32	0	0	0	0	0.2
6	20	0	0	0	0	0.2
7	19.32	0	0	0	0	0.2
8	17.32	335.77	0.71	472.15	0.0000124	0.2
9	14.14	971.30	0.81	1196.21	0.0000315	0.2
10	10.00	1799.53	0.83	2175.84	0.0000573	0.2
11	5.18	2764.03	0.82	3358.79	0.0000884	0.2
12	0	3799.07	0.81	4665.79	0.0001228	0.2
13	–5.18	4834.10	0.81	5997.33	0.0001578	0.2
14	–10	5798.60	0.80	7247.32	0.0001907	0.2
15	–14.14	6626.83	0.80	8318.55	0.0002189	0.2
16	–17.32	7262.36	0.80	9134.20	0.0002404	0.2
17	–19.32	7661.87	0.79	9642.42	0.0002537	0.2
18	–20	7798.13	0.79	9814.78	0.0002583	0.2
19	–19.32	7661.87	0.79	9642.42	0.0002537	0.2
20	–17.32	7262.36	0.80	9134.20	0.0002404	0.2
21	–14.14	6626.83	0.80	8318.55	0.0002189	0.2
22	–10	5798.60	0.80	7247.32	0.0001907	0.2
23	–5.18	4834.10	0.81	5997.33	0.0001578	0.2
24	0	3799.07	0.81	4665.79	0.0001228	0.2

(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 B18
VALIDATION METHODOLOGIES AND OTHER RESEARCH RELEVANT TO STANDARD 140

[Informative Note: Revise Section B18.2 as shown.]

B18.2 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—Building Fabric"[39]

b. "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)"[40]

c. ASHRAE RP-865, "Development of Accuracy Tests for Mechanical System Simulation"[41]

~~d. "Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air Conditioning Equipment Models (HVAC BESTEST), Fuel Fired Furnace Test Suite"[42]~~

~~e~~d. International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 2: Cases E300-E545" [A-5]

~~f~~e. "RADTEST Radiant Heating and Cooling Test Cases"[43]

~~g~~f. "Proposed IEA BESTEST Ground-Coupled Cases"

~~h~~g. ETNA BESTEST Empirical Validation Test Specification

~~i~~h. "Daylighting—HVAC Interaction Tests for the Empirical Validation of Building Energy Analysis Tools"[44]

TABLE B17.4 Heat Load, Efficiency, Fan Power, Fuel and Electricity Consumption for Cycling Fan Case

Hour of Day	Temperature (°C)	Q_{Total} (W)	$\eta_{part\ load}$	$Q_{Furnace}$ (W)	Fuel Consumption (m^3/h)	Electricity (kWh)
1	5.18	2964.03	0.82	3536.57	0.0000931	0.059
2	10.00	1999.53	0.83	2369.41	0.0000624	0.040
3	14.14	1171.30	0.82	1400.68	0.0000369	0.023
4	17.32	535.77	0.77	683.24	0.0000180	0.011
5	19.32	136.26	0.54	245.41	0.0000065	0.003
6	20	0	0	0	0	0.000
7	19.32	136.26	0.54	245.41	0.0000065	0.003
8	17.32	535.77	0.77	683.24	0.0000180	0.011
9	14.14	1171.30	0.82	1400.68	0.0000369	0.023
10	10.00	1999.53	0.83	2369.41	0.0000624	0.040
11	5.18	2964.03	0.82	3536.57	0.0000931	0.059
12	0	3999.07	0.81	4823.19	0.0001269	0.080
13	–5.18	5034.10	0.80	6131.09	0.0001613	0.101
14	–10	5998.60	0.80	7356.38	0.0001936	0.120
15	–14.14	6826.83	0.80	8404.50	0.0002212	0.137
16	–17.32	7462.36	0.79	9201.35	0.0002421	0.149
17	–19.32	7861.87	0.79	9697.30	0.0002552	0.157
18	–20	7998.13	0.79	9865.41	0.0002596	0.160
19	–19.32	7861.87	0.79	9697.30	0.0002552	0.157
20	–17.32	7462.36	0.79	9201.35	0.0002421	0.149
21	–14.14	6826.83	0.80	8404.50	0.0002212	0.137
22	–10	5998.60	0.80	7356.38	0.0001936	0.120
23	–5.18	5034.10	0.80	6131.09	0.0001613	0.101
24	0	3999.07	0.81	4823.19	0.0001269	0.080

~~j~~i. "Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools"[A-4]

~~k~~j. A number of test suites that are being developed by National Renewable Energy Laboratory and researchers in International Energy Agency (IEA) member nations under auspices of IEA Solar Heating and Cooling Programme Task 34 and IEA Energy Conservation in Buildings and Community Systems Programme Annex 43 (IEA SHC 34/ECBCS 43)[45]

Note: Since items f and g are works in progress, no references can yet be cited for them.

B18.2.1 ASHRAE RP-1052.[39] 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 BESTEST. HERS BESTEST[40] is similar to the current test 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. As such, it goes into less detail in testing specific building physics algorithms than Standard 140 and uses more realistic test cases.

B18.2.3 ASHRAE RP-865.[41] 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.

TABLE B17.5 Heat Load, Efficiency, Fan Power, Fuel and Electricity Consumption for Draft Fan Case

Hour of Day	Temperature (°C)	Q_{Total} (W)	$\eta_{part\ load}$	$Q_{Furnace}$ (W)	Fuel Consumption (m^3/h)	Electricity (kWh)
1	5.18	2764.03	0.82	3358.79	0.0000884	0.214
2	10.00	1799.53	0.83	2175.84	0.0000573	0.209
3	14.14	971.30	0.81	1196.21	0.0000315	0.205
4	17.32	335.77	0.71	472.15	0.0000124	0.202
5	19.32	0	0	0	0	0.200
6	20	0	0	0	0	0.200
7	19.32	0	0	0	0	0.200
8	17.32	335.77	0.71	472.15	0.0000124	0.202
9	14.14	971.30	0.81	1196.21	0.0000315	0.205
10	10.00	1799.53	0.83	2175.84	0.0000573	0.209
11	5.18	2764.03	0.82	3358.79	0.0000884	0.214
12	0	3799.07	0.81	4665.79	0.0001228	0.219
13	–5.18	4834.10	0.81	5997.33	0.0001578	0.224
14	–10	5798.60	0.80	7247.32	0.0001907	0.229
15	–14.14	6626.83	0.80	8318.55	0.0002189	0.233
16	–17.32	7262.36	0.80	9134.20	0.0002404	0.236
17	–19.32	7661.87	0.79	9642.42	0.0002537	0.238
18	–20	7798.13	0.79	9814.78	0.0002583	0.239
19	–19.32	7661.87	0.79	9642.42	0.0002537	0.238
20	–17.32	7262.36	0.80	9134.20	0.0002404	0.236
21	–14.14	6626.83	0.80	8318.55	0.0002189	0.233
22	–10	5798.60	0.80	7247.32	0.0001907	0.229
23	–5.18	4834.10	0.81	5997.33	0.0001578	0.224
24	0	3799.07	0.81	4665.79	0.0001228	0.219

[Informative Note: Remove Section B18.2.4 (HVAC BESTEST Fuel-Fired Furnace Test Suite) and renumber the following sections accordingly.]

~~**B18.2.4 HVAC BESTEST Fuel-Fired Furnace Test Suite**[42] is an analytical verification test that also has some comparative test components, developed by the CANMET Energy Technology Centre of Natural Resources Canada in conjunction with the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme Task 22. This test focuses on the ability to model residential fuel-fired furnace mechanical equipment and could directly append the unitary mechanical equipment cases of Section 5.3. Cases allow the comparison of quasi-analytical solutions to program results for the purpose of testing the ability of programs to model steady-state efficiency, fuel consumption, variation of furnace performance with part-load ratio, air distribution fan operation, and combustion air fan operation.~~

B18.2.4~~5~~ HVAC BESTEST Cases E300-E545[A-5] is a comparative test being developed by the National Renewable Energy Laboratory in conjunction with the International Energy Agency Solar Heating and Cooling Programme Task 22. This test suite extends the unitary space cooling equipment tests of Section 5.3. The cases are more realistic (including more dynamic loading and weather conditions) and cannot be solved analytically or quasi-analytically. Cases include variation of PLR, ODB, and EDB for both dry-coil and wet-coil conditions. Also tested in the dynamic context is the ability of programs to model equipment performance with outside air mixing, infiltration loading, thermostat set-up, undersized equipment, and economizers with various temperature and enthalpy controls.

B18.2.5~~6~~ RADTEST[43] is a comparative test developed by Hochschule fur Technik + Architektur Luzern in conjunction with the IEA ~~SHC~~ 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.).

B18.2.6~~7~~ Proposed IEA BESTEST Ground-Coupled Cases is a comparative test being developed by the National Renewable Energy Laboratory in conjunction with the IEA Solar Heating and Cooling (SHC) Programme Task 22 and IEA

TABLE B17.6 Energy Delivered and Consumed by Fuel-Fired Furnace for Alternate Tests, in GJ

Case	Analytical/Semi-Analytical Results		Difference versus Heat Transfer Surface Method
	Energy Delivered (GJ)	Rate of Fuel Consumption (m^3/s)	
HE100	77.77	0.000263	0.04%
HE110	77.77	0.000329	0.04%
HE120	31.11	0.0001296	0.03%
HE130	0	0	0%
HE140	31.11	0.000132	0.03%
HE150	29.66	0.0001253	0.03%
HE160	31.11	0.000129	0.03%
HE170	29.66	0.0001253	0.03%

SHC Programme Task 34/Energy Conservation in Buildings and Community Systems (BCS) Programme Annex 43~~IEA Solar Heating and Cooling Programme~~. 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. Additional in-depth cases are being developed to determine the causes for disagreements among detailed model results found in the preceding test cases. The new test cases compare ground models integrated with whole-building simulations to independent detailed models. There is also an analytical verification test case for checking the independent detailed models and for checking that such models are properly applied by users. Parametric variations versus a steady-state slab-on-grade base case include periodic ground surface temperature variation (versus steady-state), floor slab aspect ratio, slab size, deep ground temperature depth, and interior and exterior convective coefficients (realistic versus high values to test the effect of surface temperature uniformity).

B18.2.7~~8~~ ETNA BESTEST is an empirical validation test being 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 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.

B18.2.8~~9~~ Daylighting—HVAC Interaction Tests for the Empirical Validation of Building Energy Analysis Tools[44] 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.

B18.2.9~~10~~ Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools[A-4] are being 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 air, and outside air versus return air enthalpy comparison with 0% minimum outside air.

B18.3 Recommended Additional Research. The additional tests listed in B18.2 do not cover the following areas:

a. Comparative Tests – Mechanical Equipment (Additional tests beyond those in HVAC BESTEST unitary cooling and heating equipment cases)
b. Analytical Verification – Mechanical Equipment (Additional tests beyond those in RP-865 and HVAC BESTEST unitary cooling and heating equipment cases)
c. Empirical Validation – Mechanical Equipment (Additional tests beyond those in IEA SHC Task 22 described above).

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 B19
INFORMATIVE REFERENCES

[Informative Note: Add the following references to Annex B19 as shown.]

A-1 Crawley, D.B., L.K. Lawrie, C.O. Pedersen, R.K. Strand, R.J. Liesen, F.C. Winkelmann, W.F. Buhl, Y.J. Huang, A.E. Erdem, D.E. Fisher, M.J. Witte, and J. Glazer. (2001). Creating a New-Generation Building Energy Simulation Program. *Energy & Buildings*, Vol. 33, No. 4 (April), pp. 319–331.

A-2 ESRU (2000). The ESP-r System for Building Energy Simulations: User Guide Version 9 Series, ESRU Manual U00/1. University of Strathclyde, Glasgow UK

A-3 Henderson H. (1998). Part-Load Curves for Use in DOE-2. Prepared for the Lawrence Berkley Laboratory, CDH Energy Corporation, Cazenovia.

A-4 Maxwell, G., P. Loutzenhiser, and C. Klaassen. (2004). *Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools*. Ames Iowa: Iowa State University, Department of Mechanical Engineering. Ankeny, Iowa: Iowa Energy Center.

A-5 Neymark, J., and R. Judkoff. (2004). *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST)*, Volume 2: Cases E300-E545. NREL/TP/550-36754. Golden, Colorado: National Renewable Energy Laboratory. http://www.nrel.gov.docs/fy05osti/36754.pdf.

A-6 Purdy, J., and I. Beausoleil-Morrison. (2002). *Building Energy Simulation Test for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST). IEA Fuel-Fired Furnace.* Ottawa, Energy Technology Centre.

A-7 Winkelmann F., B. Birdsall, W. Buhl, K. Ellington, A. Erdem, J. Hirsch, and S. Gates. (1994). *DOE-2 Supplement: Version 2.1E*. U. California, Berkeley.

A-8 Augustyn, J., R. Perez, and C. Barnaby. (1996). *WYEC 2 Weather Year for Energy Calculations*. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta.

[Informative Note: In general, the 2007 edition of the standard will be editorially revised to improve the standard's consistency in the use of table footnotes (preferring alpha-type notes), multiplication symbols (preferring the "times" multiplication sign), units (preferring "W/(m·K)" to "W/m·K," for example), and italics (preferring italics for symbols such as* **k** *for thermal conductivity), especially where the current styles for these items are conflicting or otherwise confusing. Wording such as "your program" and "your software" will be replaced with "the software being tested" (e.g., see Section 5.1.5).]

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the standards and guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards and guidelines where appropriate and adopt, recommend, and promote those new and revised standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating standards and guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.