ANSI/ASHRAE Addendum *a* to
ANSI/ASHRAE Standard 140-2001

ASHRAE® STANDARD

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

Approved by the ASHRAE Standards Committee on June 26, 2004; by the ASHRAE Board of Directors on July 1, 2004; and by the American National Standards Institute on July 1, 2004.

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ISSN 1041-2336

Approved American National Standard
ANSI

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REFRIGERATING AND
AIR-CONDITIONING ENGINEERS, INC.
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CONTENTS

[Informative Note: Revise the table of contents as indicated.]

Foreword

1. Purpose
2. Scope
3. Definitions, Abbreviations and Acronyms
4. Methods of Testing
5. Test Procedures
6. Output Requirements

Normative Annexes

Annex A1 Weather Data
Annex A2 Standard Output Reports

Informative Annexes

Annex B1 Tabular Summary of Test Cases
Annex B2 About Typical Meteorological Year (TMY) Weather Data
Annex B3 Infiltration and Fan Adjustments for Altitude
Annex B4 Exterior Combined Radiative and Convective Surface Coefficients
Annex B5 Infrared Portion of Film Coefficients
Annex B6 Incident Angle Dependent Window Optical Property Calculations
Annex B7 Detailed Calculation of Solar Fractions
Annex B8 Example Results
Annex B9 Diagnosing the Results Using the Flow Diagrams
Annex B10 Instructions for Working with Results Spreadsheets Provided with the Standard
Annex B11 Production of Example Results
Annex B12 Temperature Bin Conversion Program
Annex B13 COP Degradation Factor (CDF) as a Function of Part Load Ratio (PLR)
Annex B14 Cooling Coil Bypass Factor
Annex B15 Indoor Fan Data Equivalence
Annex B16 Quasi-Analytical Solution Results and Example Simulation Results for HVAC Equipment Performance Tests
Annex B17 Production of Quasi-Analytical Solution Results and Example Simulation Results
Annex B18~~3~~ Validation Methodologies and Other Research Relevant to Standard 140
Annex B19~~4~~ References

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

[Informative Note: This new foreword replaces the previous foreword.]

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 examine many of the thermal models relevant to simulating the energy performance of a building and its mechanical equipment. However, because building energy simulation software operates in an immense parameter space, it is not practical to test every combination of parameters over every possible range of function.

The tests consist of a series of carefully described test case building plans and mechanical equipment specifications. Output values for the cases are compared and used in conjunction with diagnostic logic to determine the sources of predictive differences. 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 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 tests have a variety of uses including:

(a) *comparing the predictions from other building energy programs to the example results provided in the informative Annexes B8 and B16 and/or to other results that were generated using this SMOT;*
(b) *checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted;*
(c) *checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms; and*
(d) *diagnosing the algorithmic sources and other sources of prediction differences (diagnostic logic flow diagrams are included in the informative Annex B9).*

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

- *user input error, where the user misinterpreted or incorrectly entered one or more program inputs;*
- *a problem with a particular algorithm in the program;*
- *one or more program algorithms used outside their intended range.*

Also, for any given case, a program that yields values in the middle of the range established by the Annex B8 example results should not be perceived as better or worse than a program that yields values at the borders of the range.

The Annex B16 results for the HVAC equipment performance tests include both quasi-analytical solutions and simulation results. 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 Section 5.3 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 those doing the simulation (the simulationists).

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. The primary purpose of also including simulation results for the Section 5.3 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 the sort of agreement that 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 sources of differences as noted above.

3. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

3.1 Terms Defined for This Standard

[Informative Note: Add the following new definitions to Section 3.1.]

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

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

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

apparatus dew point (ADP): the effective coil surface temperature when there is dehumidification; this is the temperature to which all the supply air would be cooled if 100% of the supply air contacted the coil. On the psychrometric chart, this is the intersection of the condition line and the saturation curve, where the condition line is the line going through entering air conditions with slope defined by the sensible heat ratio ([gross sensible capacity]/[gross total capacity]). (Also see *gross sensible capacity* and *gross total capacity.*)

building thermal envelope and fabric**:** includes the building thermal envelope as defined in ASHRAE Terminology, [A-1] as well as internal thermal capacitance and heat and mass transfer between internal zones.

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

coefficient of performance (COP): for a cooling (refrigeration) system, the ratio, using the same units in the numerator as in the denominator, of the net refrigeration effect to the cooling energy consumption. (Also see *net refrigeration effect* and *cooling energy consumption.*)

cooling energy consumption: the site electric energy consumption of the mechanical cooling equipment including the compressor, air distribution fan, condenser fan, and related auxiliaries.

COP_{SEER}: the seasonal energy efficiency ratio (dimensionless).

COP degradation factor (CDF): multiplier (≤1) applied to the full-load system COP. CDF is a function of part-load ratio. (Also see *part-load ratio*.)

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

energy efficiency ratio (EER): the ratio of net refrigeration effect (in Btu per hour) to cooling energy consumption (in watts) so that EER is stated in units of (Btu/h)/W. (Also see *net refrigeration effec*t and *cooling energy consumption*.)

entering dry-bulb temperature (EDB): the temperature that a thermometer would measure for air entering the evaporator coil. For a draw-through fan configuration with no heat gains or losses in the ductwork, EDB equals the indoor dry-bulb temperature.

entering wet-bulb temperature (EWB): the temperature that the wet-bulb portion of a psychrometer would measure if exposed to air entering the evaporator coil. For a draw-through fan with no heat gains or losses in the ductwork, this would also be the zone air wet-bulb temperature. For mixtures of water vapor and dry air at atmospheric temperatures and pressures, the wet-bulb temperature is approximately equal to the adiabatic saturation temperature (temperature of the air after undergoing a theoretical adiabatic saturation process). The wet-bulb temperature given in psychrometric charts is really the adiabatic saturation temperature.

evaporator coil loads: the actual sensible heat and latent heat removed from the distribution air by the evaporator coil. These loads include indoor air distribution fan heat for times when the compressor is operating, and they are limited by the system capacity (where system capacity is a function of operating conditions). (Also see *sensible hea*t and *latent heat*.)

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

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

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

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

indoor dry-bulb temperature (IDB): the temperature that a thermometer would measure if exposed to indoor air.

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

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

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

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

outdoor dry-bulb temperature (ODB): the temperature that a thermometer would measure if exposed to outdoor air. This is the temperature of air entering the condenser coil.

part-load ratio (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.*)

quasi-analytical solution: mathematical solution of a model of reality for a given set of parameters and boundary conditions; such a result may be computed by generally accepted numerical method calculations, provided that such calculations occur outside the environment of a whole-building energy simulation program and can be scrutinized.

seasonal energy efficiency ratio (SEER): the ratio of net refrigeration effect in Btu to the cooling energy consumption in watt-hours for a refrigerating device over its normal annual usage period as determined using ANSI/ARI Standard 210/240-89.[A-2] This parameter is commonly used for simplified estimates of energy consumption based on a given load and is not generally useful for detailed simulations of mechanical systems. (Also see *net refrigeration effect* and *cooling energy consumption*.)

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

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

zone cooling loads: sensible heat and latent heat loads associated with heat and moisture exchange between the building envelope and its surroundings as well as internal heat and moisture gains within the building. These loads do not include internal gains associated with operating the mechanical system (e.g., air distribution fan heat).

3.2 Abbreviations and Acronyms Used in This Standard

[Informative Note: Add the following acronyms to Section 3.2.]

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
EDB	entering dry-bulb temperature
EER	energy efficiency ratio
EWB	entering wet-bulb temperature
HVAC	heating, ventilating, and air-conditioning
I.D.	inside diameter
IDB	indoor dry-bulb temperature
NOAA	National Oceanic and Atmospheric Administration
NSRDB	National Solar Radiation Database
O.D.	outside diameter
ODB	outdoor dry-bulb temperature
PLR	part-load ratio
SEER	seasonal energy efficiency ratio
SHR	sensible heat ratio
SI	Système Internationale
TMY2	Typical Meteorological Year 2
TUD	Technische Universität Dresden
WBAN	Weather Bureau Army Navy
wg	water gauge

[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 comparisons. ~~This is a comparative test that~~ 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 informative Annex B8, to the example quasi-analytical solution and simulation results in the informative Annex B16, and/or to other results (simulations or 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; and
- diagnosing the algorithmic sources of prediction differences (diagnostic logic flow diagrams are included in the informative Annex B9).

4.2 Organization of Test Cases

The specifications for determining input values are provided case by case in Section 5~~.2~~. Weather data required for use with the test cases are provided in Annex A1. Annex B1 provides an informative 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 informative Annex B9 on diagnostic logic. In some instances (e.g., Case 620, Section 5.2.2.1.2), a case developed from modifications to 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) HVAC Equipment Performance Base Case (see 4.2.4)

(e) HVAC Equipment Performance Parameter Variation Tests (see 4.2.5)

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 floor 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 system. They analyze the ability of software to model zone temperature in both low mass and high mass configurations with and without night ventilation. The tests are presented in detail in Section 5.2.2.3.

4.2.3 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 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 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.

4.3 Reporting Results

The Standard Output Reports provided in the files that accompany this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) 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 ~~S140OUT2~~"S140outNotes.TXT" in the accompanying files, and

(c) results for simulated cases using ~~S140OUT2.WK3~~ the following files (available at http://www.ashrae.org/template/PDFDetail?assetID=34505):~~.~~

- Sec5-2out.XLS for the building thermal envelope and fabric load tests of Section 5.2,
- Sec5-3out.XLS for the HVAC equipment performance tests of Section 5.3.

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.

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 as informative Annex B11 and Annex B17. For the convenience of users who wish to plot or tabulate their results along with the example results, ~~an~~ electronic versions of the example results ~~has~~have been included with the accompanying files RESULTS5-2.XLS~~WK3~~ (for Annex B8) and RESULTS5-3.XLS (for Annex B16). Documentation regarding RESULTS5-2.XLS~~WK3~~ and RESULTS5-3.XLS have ~~has~~ 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 equipment performance tests of Section 5.3, the degree of disagreement that occurred for other simulation results in Annex B16 versus the 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 informative Annex B9.

5. TEST PROCEDURES

[Informative Note: Make revisions to sections 5.1 and 5.2 as noted.]

5.1 Modeling Approach

This modeling approach shall apply to all the test cases presented in Sections 5.2 and 5.3.

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 to1 a.m.* Do not use daylight savings time or holidays for scheduling. The required TMY weather data are in hourly bins corresponding to solar time as described in Annex A1. TMY2 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 m × 8 m × 2.7 m = 129.6 m^3). Make the thicknesses extend exterior to the currently defined internal volume.

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

5.2 Input Specifications for Building Thermal Envelope and Fabric Load Tests

5.2.1 Case 600: Base Case

Begin with Case 600. Case 600 shall be modeled as detailed in this section and its subsections.

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

5.2.1.1 Weather Data. Use weather data provided on the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) as described in Annex A1, Section A1.1. These weather data shall be used for all cases described in Section 5.2.

5.2.1.6 Infiltration. Infiltration rate = 0.5 ACH, continuously (24 hours per day for the full year).

The weather data file provided in Annex A1 (Section A1.1) represents a high-altitude site (1609 m above sea level) with an air density roughly 80% of that at sea level. If the program being tested does not use barometric pressure from the weather data, or otherwise automatically correct for the change in air density due to altitude, then adjust the specified infiltration rates to yield mass flows equivalent to what would occur at the 1609 m altitude as shown in Table 2. The listed infiltration rate is independent of wind speed, indoor/outdoor temperature difference, etc. The calculation technique used to develop Table 2 is provided as background information in informative Annex B3.

5.2.3.1.4 High Conductance Wall/Opaque Window. An element, which may be thought of as a highly conductive wall or an opaque window, replaces the 12 m^2 of transparent window on the south wall.

The properties of the high-conductance wall are as follows:

(a) Shortwave transmittance = 0.
(b) Infrared emittances and solar absorptances are as listed in Table 15.
(c) The exterior surface coefficient is in accordance with Section 5.2.1.9 (Case 600); if combined coefficients are applied, use 21.0 W/m^{2}K. The surface texture for the high-conductance wall is very smooth, same as glass.
(d) The interior surface coefficient is in accordance with Section 5.2.1.10 (Case 600).
(e) Conductance, density, specific heat, and surface texture (very smooth) are the same as for the transparent window listed in Table 16.

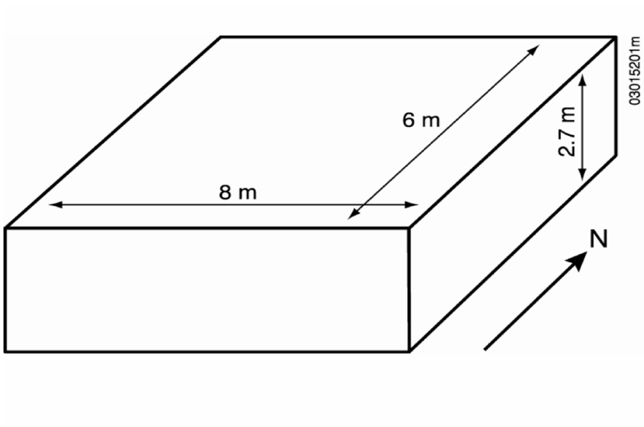

Figure 8 HVAC-BESTEST: Near-adiabatic envelope geometry.

5.3 Input Specifications for HVAC Equipment Performance Tests

[Informative Note: Add entirely new Section 5.3.]

5.3.1 Case E100: Base Case Building and Mechanical System

Begin with Case E100. Case E100 shall be modeled as detailed in this section and its subsections.

The bulk of the work for implementing the Section 5.3 tests is assembling an accurate base building model. It is recommended that base building inputs be double-checked and results disagreements be diagnosed before going on to the other cases.

5.3.1.1 Weather Data. This case requires either HVBT461.TMY or HVBT461A.TM2 data provided on the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) as described in Annex A1. *Note:* Other cases call for different weather files as needed.

5.3.1.2 Output Requirements. Case E100 requires all of the output described in Section 6.3. *Note:* All of the Section 5.3 tests have the same output requirements.

5.3.1.3 Building Geometry. The base building plan is a 48 m^2 floor area, single-story, low-mass building with rectangular-prism geometry as shown in Figure 8. Zone air volume is 129.6 m^3.

5.3.1.4 Building Envelope Thermal Properties. The base building zone is intended as a near-adiabatic test cell with cooling load driven by user-specified internal gains. Tables 23a and 23b list material properties in Système Internationale (SI) and inch-pound units, respectively.

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

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

5.3.1.4.3 Air density at sea level is 1.201 kg/m^3.

5.3.1.4.4 The floor has the same exterior film coefficient as the other walls, as if the entire zone were suspended above the ground.

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

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

TABLE 23a
Material Specifications Base Case (SI Units)

mspec4.xls; May 20, 2004

EXTERIOR WALL (inside to outside)

ELEMENT	k (W/(m*K))	Thickness (m)	U (W/(m^2*K))	R (m^2*K/W)
Int Surf Coef			8.290	0.121
Insulation (Note 1)	0.010	1.000	0.010	100.000
Ext Surf Coef			29.300	0.034
Total air - air			0.010	100.155
Total surf - surf			0.010	100.000

FLOOR (inside to outside)

ELEMENT	k (W/(m*K))	Thickness (m)	U (W/(m^2*K))	R (m^2*K/W)
Int Surf Coef (Note 2)			8.290	0.121
Insulation (Note 1)	0.010	1.000	0.010	100.000
Ext Surf Coef			29.300	0.034
Total air - air			0.010	100.155
Total surf - surf			0.010	100.000

ROOF (inside to outside)

ELEMENT	k (W/(m*K))	Thickness (m)	U (W/(m^2*K))	R (m^2*K/W)
Int Surf Coef (Note 2)			8.290	0.121
Insulation (Note 1)	0.010	1.000	0.010	100.000
Ext Surf Coef			29.300	0.034
Total air - air			0.010	100.155
Total surf - surf			0.010	100.000

SUMMARY

COMPONENT	AREA (m^2)	UA (W/K)
Wall	75.600	0.755
Floor	48.000	0.479
Roof	48.000	0.479
Infiltration (Note 3)		0.000
Total UA		1.713

ACH	VOLUME (m^3)	ALTITUDE (m)
0.00	129.6	2.0

Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are < 1% of the total cooling load. If your software does not allow this much insulation, then reduce the floor, roof and wall areas to achieve the listed UA values.

Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.

Note 3: Infiltration derived from:
ACH*Volume*(specific heat of air)*(density of air at specified altitude)

TABLE 23b
Material Specifications Base Case (English Units)

mspec4.xls; May 20, 2004

EXTERIOR WALL (inside to outside)				
	k	Thickness	U	R
ELEMENT	(Btu/(h*ft*F))	(ft)	(Btu/(h*ft²*F))	(h*ft²*F/Btu)
Int Surf Coef			1.461	0.684
Insulation (Note 1)	0.00578	3.281	0.002	567.447
Ext Surf Coef			5.163	0.194
Total air - air			0.00176	568.325
Total surf - surf			0.00176	567.447

FLOOR (inside to outside)				
	k	Thickness	U	R
ELEMENT	(Btu/(h*ft*F))	(ft)	(Btu/(h*ft²*F))	(h*ft²*F/Btu)
Int Surf Coef (Note 2)			1.461	0.684
Insulation (Note 1)	0.00578	3.281	0.002	567.447
Ext Surf Coef			5.163	0.194
Total air - air			0.00176	568.325
Total surf - surf			0.00176	567.447

ROOF (inside to outside)				
	k	Thickness	U	R
ELEMENT	(Btu/(h*ft*F))	(ft)	(Btu/(h*ft²*F))	(h*ft²*F/Btu)
Int Surf Coef (Note 2)			1.461	0.684
Insulation (Note 1)	0.00578	3.281	0.002	567.447
Ext Surf Coef			5.163	0.194
Total air - air			0.00176	568.325
Total surf - surf			0.00176	567.447

SUMMARY		
	AREA	UA
COMPONENT	(ft²)	(Btu/(h*F))
Wall	813.752	1.432
Floor	516.668	0.909
Roof	516.668	0.909
Infiltration		0.000
Total UA		3.250

	ACH	VOLUME	ALTITUDE	UAinf (Note 3)
		(ft³)	(ft)	(Btu/(h*F))
	0.000	4577	6.56	0.000

Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are < 1% of the total cooling load. If your software does not allow this much insulation, then reduce the floor, roof and wall areas to achieve the listed UA values.

Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.

Note 3: Infiltration derived from:
ACH*Volume*(specific heat of air)*(density of air at specified altitude)

TABLE 24
Opaque Surface Radiative Properties

	Interior Surface	Exterior Surface
Solar Absorptance	0.6	0.1
Infrared Emittance	0.9	0.9

TABLE 25
Interior Combined Surface Coefficient versus Surface Orientation

Orientation of Surface and Heat Flow	Interior Combined Surface Coefficient
Horizontal heat transfer on vertical surfaces	8.29 W/m^{2}K (1.46 Btu/(hft^{2}F))
Upward heat transfer on horizontal surfaces	9.26 W/m^{2}K (1.63 Btu/(hft^{2}F))
Downward heat transfer on horizontal surfaces	6.13 W/m^{2}K (1.08 Btu/(hft^{2}F))

5.3.1.5 Infiltration.

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

5.3.1.6 Internal Heat Gains.

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

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

Sensible internal gains are 100% convective.

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

5.3.1.7 Opaque Surface Radiative Properties. Interior and exterior opaque surface solar (visible and ultraviolet wavelengths) absorptances and infrared emittances are included in Table 24.

5.3.1.8 Exterior Combined Radiative and Convective Surface Coefficients. If the program being tested automatically calculates exterior surface radiation and convection, this section may be disregarded. If the program being tested does not calculate this effect, then use 29.3 W/m^{2}K for all exterior surfaces. This value is based on a mean annual wind speed of 4.02 m/s for a surface with roughness equivalent to rough plaster or brick and is consistent with informative Annex B4.

5.3.1.9 Interior Combined Radiative and Convective Surface Coefficients. If the program being tested automatically calculates interior surface radiation and convection, then this section can be disregarded. If the program being tested does not calculate these effects, then use the constant combined radiative and convective surface coefficients given in Table 25.

The radiative portion of these combined coefficients may be taken as 5.13 W/m^{2}K [0.90 Btu/(hft^{2}F)] for an interior infrared emissivity of 0.9.

If the program being tested does not allow you to schedule these coefficients, then use 8.29 W/m^{2}K [1.46 Btu/(hft^{2}F)] for all horizontal surfaces. If different values can be justified, then use different values.

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

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

5.3.1.10.1 General Information.

- 100% convective air system
- Zone air is perfectly mixed
- No outside air; no exhaust air
- Single-speed, draw-through air distribution fan
- Indoor and outdoor fans cycle on and off together with compressor
- Air-cooled condenser

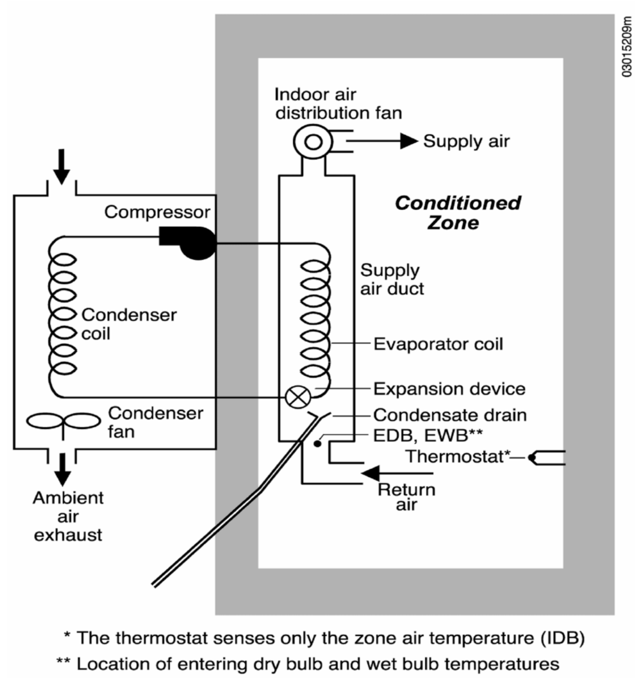

Figure 9 Unitary split air-conditioning system consisting of an air-cooled condensing unit and indoor evaporator coil.

- Single-speed reciprocating compressor, R-22 refrigerant, no cylinder unloading
- No system hot gas bypass
- The compressor, condenser, and condenser fan are located outside the conditioned zone
- All zone air moisture that condenses on the evaporator coil (latent load) leaves the system through a condensate drain
- Crankcase heater and other auxiliary energy = 0

Note that, in one of the field-trial simulations, simultaneous use of “0” outside air and “0” infiltration caused an error in the simulations. We worked around this by specifying minimum outside air = 0.000001 ft^3/min. We recommend doing a sensitivity test to check that using 0 for both these inputs does not cause a problem.

5.3.1.10.2 Thermostat Control Strategy.

Heat = off

Cool = on if zone air temperature > 22.2°C (72.0°F); otherwise cool = off.

There is no zone humidity control. This means that the zone humidity level will float in accordance with zone latent loads and moisture removal by the mechanical system.

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

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

The thermostat is nonproportional in the sense that when the conditioned zone air temperature exceeds the thermostat cooling setpoint, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment 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 COP = f(PLR) curve is given in Section 5.3.1.10.4 to account for equipment cycling.

5.3.1.10.3 Full-Load Cooling System Performance Data. Equipment full-load capacity and full-load performance data [A-3] are given in six formats in Tables 26a through 26f. Before using these tables, read all of the discussion in this section (5.3.1.10.3) and its subsections (5.3.1.10.3.1 through 5.3.1.10.3.6). Use the table that most closely matches the input requirements of the software being tested. The tables contain similar information with the following differences:

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

5.3.1.10.3.1 For convenience, an electronic file (PERFMAP140.XLS) that contains these tables is included in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505).

5.3.1.10.3.2 The meaning of the various ways to represent system capacity is discussed below; specific terms are also defined in Section 3. These tables use outdoor dry-bulb temperature (ODB), entering dry-bulb temperature (EDB), and entering wet-bulb temperature (EWB) as independent variables for performance data; the location of EDB and EWB is shown in Figure 9.

Listed capacities of Tables 26a and 26b are net values after subtracting manufacturer default fan heat based on 365 W per 1,000 cubic feet per minute (CFM), so the default fan heat for the 900 CFM fan is 329 W. For example, in Table 26a the listed net total capacity at Air-Conditioning and Refrigeration Institute (ARI) rating conditions (EDB = 26.7°C, outdoor dry-bulb temperature [ODB] = 35.0°C, EWB = 19.4°C) is 7852 W, and the assumed fan heat is 329 W. Therefore, the gross total capacity (see Table 26c) of the system at ARI rating conditions—including both the net total capacity and the distribution system fan heat—is 7,852 + 329 = 8,181 W. Similarly, the gross sensible capacity—including both the net sensible capacity and air distribution system fan heat—is 6,040 + 329 = 6,369 W.

The unit as described actually uses a 230 W fan. Therefore, the “real” net capacity is actually an adjusted net capacity, $(\text{net cap})_{adj}$, which is determined by

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

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

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

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

5.3.1.10.3.3 Validity of Listed Data (VERY IMPORTANT). Compressor kW (kilowatts) and apparatus dew point, along with net total, gross total, and adjusted net total capacities given in Tables 26a through 26f, are valid

TABLE 26a

Equipment Full-Load Performance[1] (SI Units)

ODB (°C)	EWB (°C)	Net Total Capacity[2,3,4] (kW)	Net Sensible Capacity[2,3] (kW) at entering drybulb temperature (EDB, °C) 22.2	23.3	24.4	25.6	26.7	Compressor Power[4] (kW)	Apparatus Dew Point[4] (°C)
	15.0	7.09	6.21	6.77	7.18	7.38	7.56	1.62	8.9
	17.2	7.68	5.16	5.71	6.27	6.80	7.35	1.66	11.1
29.4	19.4	8.32	4.01	4.57	5.13	5.65	6.21	1.71	13.4
	21.7	8.97	2.87	3.40	3.96	4.48	5.04	1.76	15.8
	15.0	6.91	6.12	6.68	7.03	7.21	7.41	1.69	9.1
	17.2	7.47	5.10	5.63	6.18	6.71	7.27	1.74	11.3
32.2	19.4	8.09	3.93	4.48	5.04	5.57	6.12	1.79	13.6
	21.7	8.70	2.75	3.31	3.87	4.39	4.95	1.84	15.9
	15.0	6.71	6.07	6.59	6.89	7.06	7.24	1.77	9.3
	17.2	7.27	5.01	5.54	6.09	6.62	7.18	1.81	11.4
35.0	19.4	7.85	3.84	4.39	4.95	5.48	6.04	1.86	13.8
	21.7	8.47	2.67	3.22	3.75	4.31	4.86	1.91	16.2
	15.0	6.53	5.98	6.53	6.71	6.89	7.06	1.85	9.4
	17.2	7.06	4.92	5.45	6.01	6.53	7.06	1.89	11.6
37.8	19.4	7.62	3.75	4.31	4.83	5.39	5.95	1.94	13.9
	21.7	8.17	2.58	3.14	3.66	4.22	4.75	1.98	16.3
	15.0	6.33	5.89	6.39	6.53	6.71	6.89	1.94	9.6
	17.2	6.83	4.83	5.36	5.92	6.45	6.89	1.98	11.8
40.6	19.4	7.35	3.66	4.22	4.75	5.30	5.83	2.02	14.2
	21.7	7.91	2.49	3.02	3.57	4.13	4.66	2.06	16.6
	15.0	5.92	5.71	6.04	6.21	6.36	6.50	2.11	10.0
	17.2	6.39	4.66	5.19	5.74	6.27	6.50	2.14	12.2
46.1	19.4	6.89	3.49	4.04	4.57	5.13	5.65	2.18	14.6
	21.7	7.38	2.31	2.84	3.40	3.93	4.48	2.21	16.9

Values at ARI Rating Conditions (EDB = 26.7°C, EWB = 19.4°C, ODB = 35.0°C)

Net Total Capacity	7852	W
Airflow	0.425	m^3/s
Apparatus Dew Point	13.8	°C
Compressor Power	1858	W
Indoor Fan Power	230	W
Outdoor Fan Power	108	W
COP	3.62	

Seasonal Efficiency Rating

COP_{SEER}	3.78

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; COP = coefficient of performance; COP_{SEER} = dimensionless Seasonal Energy Efficiency Ratio.

Notes:

[1] Full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

[2] Listed net total and net sensible capacities are gross total and gross sensible capacities respectively, with manufacturer default fan heat (329 W) deducted.

[3] Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

[4] Compressor kW, Apparatus Dew Point, and Net Total Capacity valid only for wet coil.

perfmap140.xls, b:a4..j55; Oct 08, 2002

TABLE 26b

Equipment Full-Load Performance[1] (I-P Units)

ODB (°F)	EWB (°F)	Net Total Capacity[2,3,4] (kBtu/h)	Net Sensible Capacity[2,3] (kBtu/h) at entering drybulb temperature (EDB, °F) 72	74	76	78	80	Compressor Power[4] (kW)	Apparatus Dew Point[4] (°F)
85	59	24.2	21.2	23.1	24.5	25.2	25.8	1.62	48.1
	63	26.2	17.6	19.5	21.4	23.2	25.1	1.66	52.0
	67	28.4	13.7	15.6	17.5	19.3	21.2	1.71	56.1
	71	30.6	9.8	11.6	13.5	15.3	17.2	1.76	60.4
90	59	23.6	20.9	22.8	24.0	24.6	25.3	1.69	48.4
	63	25.5	17.4	19.2	21.1	22.9	24.8	1.74	52.3
	67	27.6	13.4	15.3	17.2	19.0	20.9	1.79	56.5
	71	29.7	9.4	11.3	13.2	15.0	16.9	1.84	60.7
95	59	22.9	20.7	22.5	23.5	24.1	24.7	1.77	48.7
	63	24.8	17.1	18.9	20.8	22.6	24.5	1.81	52.6
	67	26.8	13.1	15.0	16.9	18.7	20.6	1.86	56.8
	71	28.9	9.1	11.0	12.8	14.7	16.6	1.91	61.1
100	59	22.3	20.4	22.3	22.9	23.5	24.1	1.85	49.0
	63	24.1	16.8	18.6	20.5	22.3	24.1	1.89	52.9
	67	26.0	12.8	14.7	16.5	18.4	20.3	1.94	57.1
	71	27.9	8.8	10.7	12.5	14.4	16.2	1.98	61.4
105	59	21.6	20.1	21.8	22.3	22.9	23.5	1.94	49.3
	63	23.3	16.5	18.3	20.2	22.0	23.5	1.98	53.2
	67	25.1	12.5	14.4	16.2	18.1	19.9	2.02	57.5
	71	27.0	8.5	10.3	12.2	14.1	15.9	2.06	61.8
115	59	20.2	19.5	20.6	21.2	21.7	22.2	2.11	50.0
	63	21.8	15.9	17.7	19.6	21.4	22.2	2.14	53.9
	67	23.5	11.9	13.8	15.6	17.5	19.3	2.18	58.2
	71	25.2	7.9	9.7	11.6	13.4	15.3	2.21	62.5

Values at ARI Rating Conditions (EDB = 80°F, EWB = 67°F, ODB = 95°F)

Net Total Capacity	26800	Btu/h
Airflow	900	CFM
Apparatus Dew Pt	56.8	°F
Compressor Power	1858	W
Indoor Fan Power	230	W
Outdoor Fan Power	108	W
EER	12.36	(Btu/h)/W

Seasonal Efficiency Rating

SEER	12.90	(Btu/h)/W

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; EER = energy efficiency ration; SEER = seasonal energy efficiency ratio.

Notes:

[1] Full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

[2] Listed net total and net sensible capacities are gross total and gross sensible capacities respectively, with manufacturer default fan heat (1.12 kBtu/h) deducted.

[3] Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

[4] Compressor kW, Apparatus Dew Point, and Net Total Capacity valid only for wet coil.

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TABLE 26c

Equipment Full-Load Performance with Gross Capacities[1] (SI Units)

ODB (°C)	EWB (°C)	Gross Total Capacity[2,3,4] (kW)	Gross Sensible Capacity[2,3] (kW) at entering drybulb temperature (EDB, °C) 22.2	23.3	24.4	25.6	26.7	Compressor Power[4] (kW)	Apparatus Dew Point[4] (°C)
29.4	15.0	7.42	6.54	7.10	7.51	7.71	7.89	1.62	8.9
	17.2	8.01	5.49	6.04	6.60	7.13	7.68	1.66	11.1
	19.4	8.65	4.34	4.90	5.46	5.98	6.54	1.71	13.4
	21.7	9.29	3.20	3.73	4.28	4.81	5.37	1.76	15.8
32.2	15.0	7.24	6.45	7.01	7.36	7.54	7.74	1.69	9.1
	17.2	7.80	5.43	5.95	6.51	7.04	7.60	1.74	11.3
	19.4	8.42	4.26	4.81	5.37	5.90	6.45	1.79	13.6
	21.7	9.03	3.08	3.64	4.20	4.72	5.28	1.84	15.9
35.0	15.0	7.04	6.39	6.92	7.21	7.39	7.57	1.77	9.3
	17.2	7.60	5.34	5.87	6.42	6.95	7.51	1.81	11.4
	19.4	8.18	4.17	4.72	5.28	5.81	6.36	1.86	13.8
	21.7	8.80	3.00	3.55	4.08	4.64	5.19	1.91	16.2
37.8	15.0	6.86	6.31	6.86	7.04	7.21	7.39	1.85	9.4
	17.2	7.39	5.25	5.78	6.34	6.86	7.39	1.89	11.6
	19.4	7.95	4.08	4.64	5.16	5.72	6.28	1.94	13.9
	21.7	8.50	2.91	3.46	3.99	4.55	5.08	1.98	16.3
40.6	15.0	6.66	6.22	6.72	6.86	7.04	7.21	1.94	9.6
	17.2	7.16	5.16	5.69	6.25	6.77	7.21	1.98	11.8
	19.4	7.68	3.99	4.55	5.08	5.63	6.16	2.02	14.2
	21.7	8.24	2.82	3.35	3.90	4.46	4.99	2.06	16.6
46.1	15.0	6.25	6.04	6.36	6.54	6.69	6.83	2.11	10.0
	17.2	6.72	4.99	5.52	6.07	6.60	6.83	2.14	12.2
	19.4	7.21	3.82	4.37	4.90	5.46	5.98	2.18	14.6
	21.7	7.71	2.64	3.17	3.73	4.26	4.81	2.21	16.9

Values at ARI Rating Conditions (EDB = 26.7°C, EWB = 19.4°C, ODB = 35.0°C)

Gross Total Capacity	8181 W
Airflow	0.425 m^3/s
Apparatus Dew Point	13.8 °C
Compressor Power	1858 W
Indoor Fan Power	230 W
Outdoor Fan Power	108 W
COP	3.62

Seasonal Efficiency Rating

COP_{SEER}	3.78

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; COP = coefficient of performance; COP_{SEER} = dimensionless Seasonal Energy Efficiency Ratio.

Notes:

1 Based on full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

2 Listed gross total and gross sensible capacities include manufacturer default fan heat of 329 W.

3 Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

4 Compressor kW, Apparatus Dew Point, and Gross Total Capacity valid only for wet coil.

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TABLE 26d
Equipment Full-Load Performance with Gross Capacities[1] (I-P Units)

ODB (°F)	EWB (°F)	Gross Total Capacity[2,3,4] (kBtu/h)	Gross Sensible Capacity[2,3] (kBtu/h) at entering drybulb temperature (EDB, °F) 72	74	76	78	80	Compressor Power[4] (kW)	Apparatus Dew Point[4] (°F)
	59	25.3	22.3	24.2	25.6	26.3	26.9	1.62	48.1
	63	27.3	18.7	20.6	22.5	24.3	26.2	1.66	52.0
85	67	29.5	14.8	16.7	18.6	20.4	22.3	1.71	56.1
	71	31.7	10.9	12.7	14.6	16.4	18.3	1.76	60.4
	59	24.7	22.0	23.9	25.1	25.7	26.4	1.69	48.4
	63	26.6	18.5	20.3	22.2	24.0	25.9	1.74	52.3
90	67	28.7	14.5	16.4	18.3	20.1	22.0	1.79	56.5
	71	30.8	10.5	12.4	14.3	16.1	18.0	1.84	60.7
	59	24.0	21.8	23.6	24.6	25.2	25.8	1.77	48.7
	63	25.9	18.2	20.0	21.9	23.7	25.6	1.81	52.6
95	67	27.9	14.2	16.1	18.0	19.8	21.7	1.86	56.8
	71	30.0	10.2	12.1	13.9	15.8	17.7	1.91	61.1
	59	23.4	21.5	23.4	24.0	24.6	25.2	1.85	49.0
	63	25.2	17.9	19.7	21.6	23.4	25.2	1.89	52.9
100	67	27.1	13.9	15.8	17.6	19.5	21.4	1.94	57.1
	71	29.0	9.9	11.8	13.6	15.5	17.3	1.98	61.4
	59	22.7	21.2	22.9	23.4	24.0	24.6	1.94	49.3
	63	24.4	17.6	19.4	21.3	23.1	24.6	1.98	53.2
105	67	26.2	13.6	15.5	17.3	19.2	21.0	2.02	57.5
	71	28.1	9.6	11.4	13.3	15.2	17.0	2.06	61.8
	59	21.3	20.6	21.7	22.3	22.8	23.3	2.11	50.0
	63	22.9	17.0	18.8	20.7	22.5	23.3	2.14	53.9
115	67	24.6	13.0	14.9	16.7	18.6	20.4	2.18	58.2
	71	26.3	9.0	10.8	12.7	14.5	16.4	2.21	62.5

Values at ARI Rating Conditions (EDB = 80°F, EWB = 67°F, ODB = 95°F)

Gross Total Capacity	27920	Btu/h
Airflow	900	CFM
Apparatus Dew Pt	56.8	°F
Compressor Power	1858	W
Indoor Fan Power	230	W
Outdoor Fan Power	108	W
EER	12.36	(Btu/h)/W

Seasonal Efficiency Rating

SEER	12.90	(Btu/h)/W

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; EER = energy efficiency ration; SEER = seasonal energy efficiency ratio.

Notes:

1 Based on full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

2 Listed gross total and gross sensible capacities include manufacturer default fan heat of 1.12 kBtu/h.

3 Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

4 Compressor kW, Apparatus Dew Point, and Gross Total Capacity valid only for wet coil.

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TABLE 26e
Equipment Full-Load Performance with Adjusted Net Capacities[1] (SI Units)

ODB (°C)	EWB (°C)	Adj Net Total Capacity[2,3,4] (kW)	Adjusted Net Sensible Capacity[2,3] (kW) at entering drybulb temperature (EDB, °C)					Compressor Power[4] (kW)	Apparatus Dew Point[4] (°C)
			22.2	23.3	24.4	25.6	26.7		
29.4	15.0	7.19	6.31	6.87	7.28	7.48	7.66	1.62	8.9
	17.2	7.78	5.26	5.81	6.37	6.90	7.45	1.66	11.1
	19.4	8.42	4.11	4.67	5.23	5.75	6.31	1.71	13.4
	21.7	9.06	2.97	3.50	4.05	4.58	5.14	1.76	15.8
32.2	15.0	7.01	6.22	6.78	7.13	7.31	7.51	1.69	9.1
	17.2	7.57	5.20	5.72	6.28	6.81	7.37	1.74	11.3
	19.4	8.19	4.03	4.58	5.14	5.67	6.22	1.79	13.6
	21.7	8.80	2.85	3.41	3.97	4.49	5.05	1.84	15.9
35.0	15.0	6.81	6.16	6.69	6.98	7.16	7.34	1.77	9.3
	17.2	7.37	5.11	5.64	6.19	6.72	7.28	1.81	11.4
	19.4	7.95	3.94	4.49	5.05	5.58	6.13	1.86	13.8
	21.7	8.57	2.77	3.32	3.85	4.41	4.96	1.91	16.2
37.8	15.0	6.63	6.08	6.63	6.81	6.98	7.16	1.85	9.4
	17.2	7.16	5.02	5.55	6.11	6.63	7.16	1.89	11.6
	19.4	7.72	3.85	4.41	4.93	5.49	6.05	1.94	13.9
	21.7	8.27	2.68	3.23	3.76	4.32	4.85	1.98	16.3
40.6	15.0	6.43	5.99	6.49	6.63	6.81	6.98	1.94	9.6
	17.2	6.93	4.93	5.46	6.02	6.54	6.98	1.98	11.8
	19.4	7.45	3.76	4.32	4.85	5.40	5.93	2.02	14.2
	21.7	8.01	2.59	3.12	3.67	4.23	4.76	2.06	16.6
46.1	15.0	6.02	5.81	6.13	6.31	6.46	6.60	2.11	10.0
	17.2	6.49	4.76	5.29	5.84	6.37	6.60	2.14	12.2
	19.4	6.98	3.59	4.14	4.67	5.23	5.75	2.18	14.6
	21.7	7.48	2.41	2.94	3.50	4.03	4.58	2.21	16.9

Values at ARI Rating Conditions (EDB = 26.7°C, EWB = 19.4°C, ODB = 35.0°C)

Adj Net Total Capacity	7951	W
Airflow	0.4248	m^3/s
Apparatus Dew Point	13.8	°C
Compressor Power	1858	W
Indoor Fan Power	230	W
Outdoor Fan Power	108	W
COP	3.62	

Seasonal Efficiency Rating

COP_{SEER}	3.78	

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; COP = coefficient of performance; COP_{SEER} = dimensionless Seasonal Energy Efficiency Ratio.

Notes:

1 Based on full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

2 Listed adjusted net total and adjusted net sensible capacities are gross capacities with actual fan heat (230 W) subtracted.

3 Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

4 Compressor kW, Apparatus Dew Point, and Adjusted Net Total Capacity valid only for wet coil.

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TABLE 26f
Equipment Full-Load Performance with Adjusted Net Capacities[1] (I-P Units)

ODB (°F)	EWB (°F)	Adj Net Total Capacity[2,3,4] (kBtu/h)	Adjusted Net Sensible Capacity[2,3] (kBtu/h) at entering drybulb temperature (EDB, °F)					Compressor Power[4] (kW)	Apparatus Dew Point[4] (°F)
			72	74	76	78	80		
	59	24.5	21.5	23.4	24.8	25.5	26.1	1.62	48.1
	63	26.5	17.9	19.8	21.7	23.5	25.4	1.66	52.0
85	67	28.7	14.0	15.9	17.8	19.6	21.5	1.71	56.1
	71	30.9	10.1	11.9	13.8	15.6	17.5	1.76	60.4
	59	23.9	21.2	23.1	24.3	24.9	25.6	1.69	48.4
	63	25.8	17.7	19.5	21.4	23.2	25.1	1.74	52.3
90	67	27.9	13.7	15.6	17.5	19.3	21.2	1.79	56.5
	71	30.0	9.7	11.6	13.5	15.3	17.2	1.84	60.7
	59	23.2	21.0	22.8	23.8	24.4	25.0	1.77	48.7
	63	25.1	17.4	19.2	21.1	22.9	24.8	1.81	52.6
95	67	27.1	13.4	15.3	17.2	19.0	20.9	1.86	56.8
	71	29.2	9.4	11.3	13.1	15.0	16.9	1.91	61.1
	59	22.6	20.7	22.6	23.2	23.8	24.4	1.85	49.0
	63	24.4	17.1	18.9	20.8	22.6	24.4	1.89	52.9
100	67	26.3	13.1	15.0	16.8	18.7	20.6	1.94	57.1
	71	28.2	9.1	11.0	12.8	14.7	16.5	1.98	61.4
	59	21.9	20.4	22.1	22.6	23.2	23.8	1.94	49.3
	63	23.6	16.8	18.6	20.5	22.3	23.8	1.98	53.2
105	67	25.4	12.8	14.7	16.5	18.4	20.2	2.02	57.5
	71	27.3	8.8	10.6	12.5	14.4	16.2	2.06	61.8
	59	20.5	19.8	20.9	21.5	22.0	22.5	2.11	50.0
	63	22.1	16.2	18.0	19.9	21.7	22.5	2.14	53.9
115	67	23.8	12.2	14.1	15.9	17.8	19.6	2.18	58.2
	71	25.5	8.2	10.0	11.9	13.7	15.6	2.21	62.5

Values at ARI Rating Conditions (EDB = 80°F, EWB = 67°F, ODB = 95°F)

Adj Net Total Capacity	27140	Btu/h
Airflow	900	CFM
Apparatus Dew Pt	56.8	°F
Compressor Power	1858	W
Indoor Fan Power	230	W
Outdoor Fan Power	108	W
EER	12.36	(Btu/h)/W

Seasonal Efficiency Rating

SEER	12.90	(Btu/h)/W

Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature; EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute; EER = energy efficiency ration; SEER = seasonal energy efficiency ratio.

Notes:

1 Based on full-load performance data, courtesy Trane Co., Tyler, Texas, USA. Data is for "TTP024C with TWH039P15-C" at 900 CFM, published April 1993. Performance rated with 25 feet of 3/4" suction and 5/16" liquid lines.

2 Listed adjusted net total and adjusted net sensible capacities are gross capacities with actual fan heat (785 Btu/h) subtracted.

3 Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).

4 Compressor kW, Apparatus Dew Point, and Adjusted Net Total Capacity valid only for wet coil.

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only for “wet” coils (when dehumidification is occurring). A dry-coil condition—no dehumidification—occurs when the entering air humidity ratio is decreased to the point where the entering air dew-point temperature is less than the effective coil surface temperature (apparatus dew point). In Tables 26a through 26f, the dry-coil condition is evident from a given table for conditions where the listed sensible capacity is greater than the corresponding total capacity. For such a dry-coil condition, set total capacity equal to sensible capacity.

For a given EDB and ODB, the compressor power, total capacity, sensible capacity, and apparatus dew point for wet coils change only with varying EWB. Once the coil becomes dry—which is apparent for a given EDB and ODB from the maximum EWB where total and sensible capacities are equal— for a given EDB, compressor power and capacities remain constant with decreasing EWB.[A-4]

To evaluate equipment performance for a dry-coil condition, establish the performance at the maximum EWB where total and sensible capacities are equal. Make this determination by interpolating or extrapolating with EWB for a given EDB and ODB. For example, to determine the dry-coil compressor power for ODB/EDB = 29.4°C/26.7°C, find the “maximum EWB” dry-coil condition (net sensible capacity = net total capacity) using the data shown in Table 27 (extracted from Table 26e):

At the dry-coil condition:

Adjusted net total capacity = adjusted net sensible capacity = 7.66 kW

Linear interpolation based on adjusted net total capacity gives

Maximum EWB for the dry-coil condition = 16.75°C

Compressor power = 1.652 kW

Note that in this example linear interpolation was used to find the “maximum EWB” dry-coil condition. Use of other or additional performance data points (e.g., to develop more generalized curve fits) is also possible for the purpose of interpolation or extrapolation. Also see informative Annex B17, Section B17.2, regarding analytical solution results.

5.3.1.10.3.4 Extrapolation of Performance Data. For Cases E100–E200, allow your software to perform the necessary extrapolations of the performance data as may be required by these cases, if it has that capability. Cases E100, E110, E130, and E140 require some extrapolation of data for EWB <15.0°C (<59°F). Additionally, Case E180 may require (depending on the model) a small amount of extrapolation of data for EWB >21.7°C (>71°F). Case E200 may require (depending on the model) some extrapolation of data for EDB >26.7°C (>80°F).

In cases where the maximum-EWB dry-coil condition occurs at EWB <15.0°C, extrapolate the total capacity and sensible capacity to the intersection point where they are both equal. For example, use the data shown in Table 28 (extracted from Table 26e) to find the maximum EWB dry-coil condition for ODB/EDB = 29.4°C/22.2°C:

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

Adjusted net total capacity = adjusted net sensible capacity = 6.87 kW

Maximum dry-coil EWB = 13.8°C

Resulting compressor power = 1.598 kW.

TABLE 27
Determination of Maximum Dry-Coil EWB Using Interpolation

EWB (°C)	Adjusted Net Total Capacity (kW)	Adjusted Net Sensible Capacity (kW)	Compressor Power (kW)
15.0	7.19	7.66	1.62
*Maximum dry EWB 16.75**	*7.66**	*7.66**	*1.652**
17.2	7.78	7.45	1.66

* Italicized values are not specifically listed with Table 26e; they are determined based on the accompanying discussion. Other data in this table are from Table 26e.

TABLE 28
Determination of Maximum Dry-Coil EWB Using Extrapolation

EWB (°C)	Adjusted Net Total Capacity (kW)	Adjusted Net Sensible Capacity (kW)	Compressor Power (kW)
*Maximum dry EWB 13.8**	*6.87**	*6.87**	*1.598**
15.0	7.19	6.31	1.62
17.2	7.78	5.26	1.66

* Italicized values are not specifically listed with Table 26e; they are determined based on the accompanying discussion. Other data in this table are from Table 26e.

Note that in this example linear extrapolation was used to find the “maximum EWB” dry-coil condition. Use of other or additional performance data points (e.g., to develop more generalized curve fits) is also possible for the purpose of interpolation or extrapolation. Also see informative Annex B17, Section B17.2, regarding analytical solution results.

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

5.3.1.10.3.6 Values at ARI Rating Conditions. In Tables 26a through 26f, nominal values at ARI rating conditions are useful to system designers for comparing the capabilities of one system to those of another. Some detailed simulation programs utilize inputs for ARI rating conditions in conjunction with the full performance maps of Tables 26a through 26f. For simplified simulation programs and other programs that do not allow performance maps of certain parameters, appropriate values at ARI conditions may be used and assumed constant.

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

5.3.1.10.3.8 Cooling Coil Bypass Factor. If your software does not require an input for bypass factor (BF) or automatically calculates it based on other inputs, ignore this information.

BF at ARI rating conditions is *approximately* $0.049 \le BF \le 0.080$.

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

Calculations based on the listed performance data indicate that BF varies as a function of EDB, EWB, and ODB. Incorporate this aspect of equipment performance into your model if your software allows it, using a consistent method for developing all points of the BF variation map.

5.3.1.10.3.9 Minimum Supply Air Temperature. This system is a variable temperature system, meaning that the supply air temperature varies with the operating conditions. If your software requires an input for minimum allowable supply air temperature, use

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

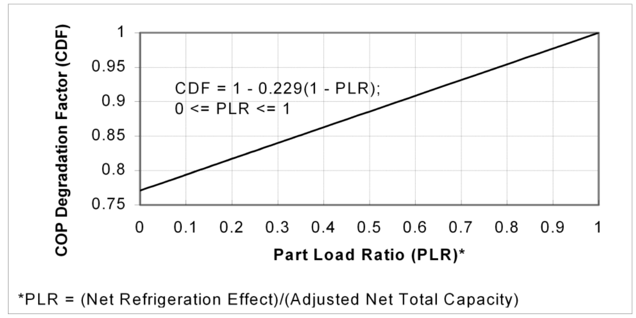

Figure 10 Cooling equipment part load performance (COP degradation factor versus PLR).

This value is the lowest value of ADP that occurs in the Section 5.3 test cases based on the quasi-analytical solutions for Case E110 presented in HVAC BESTEST.[A-5]

If your software does not require this input, ignore this information.

5.3.1.10.4 Part-Load Operation. The system COP degradation that results from part-load operation is described in Figure 10. In this figure the COP degradation factor (CDF) is a multiplier to be applied to the full-load system COP (as defined in Section 3) at a given part-load ratio (PLR), where

$$COP(PLR) = (\text{full load } COP(ODB,EWB,EDB)) * CDF(PLR).$$

This representation is based on information provided by the equipment manufacturer. It might be helpful to think of the efficiency degradation as being caused by additional start-up run time required to bring the evaporator coil temperature down to its equilibrium temperature for the time(s) when the compressor is required to operate during an hour with part load. Then, because the controller is ideal ON/OFF cycling (see Section 5.3.1.10.2),

Hourly fractional run time = PLR/CDF.

In Figure 10, the PLR is calculated by

(Net refrigeration effect) / (Adjusted net total capacity) ,

where the net refrigeration effect and the adjusted net total capacity are as defined in Section 3.

PLR may be alternatively calculated as

(Gross total coil load) / (Gross total capacity) ,

where the gross total coil load and gross total capacity are as defined in Section 3. Demonstration of the similarity of these definitions of PLR is included in Annex B13, Section B13.2.

Simplifying assumptions in Figure 10 are:

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

Annex B13 includes additional details about how Figure 10 was derived.

If your software utilizes the cooling coil bypass factor, model the BF as independent of (not varying with) the PLR.

5.3.1.10.5 Evaporator Coil. Geometry of the evaporator coil is included in Figures 11 and 12. Evaporator coil fins are actually contoured to enhance heat transfer, but further design details about fin geometry are proprietary and therefore unavailable.

5.3.1.10.5.1 Frontal Dimensions (also see Figure 11).

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

5.3.1.10.5.2 Tubes.

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

5.3.1.10.5.3 Fins.

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

5.3.1.10.6 Fans.

5.3.1.10.6.1 Indoor Air Distribution Fan.

- Indoor fan power = 230 W
- Airflow rate = 0.425 m^3/s = 1529 m^3/h = 900 CFM
- Total combined fan and motor efficiency = 0.5
- Total fan pressure = 271 Pa = 1.09 in. w.g. (water gauge)
- Supply air temperature rise from fan heat = 0.44°C = 0.8°F
- Air distribution efficiency = 100% (adiabatic ducts)

For further discussion of these inputs, see Annex B15.

The draw-through indoor air distribution fan cycles on and off with the compressor. For calculating additional heating of the distribution air related to waste heat from the indoor distribution fan, assume that the distribution fan motor is mounted in the distribution airstream so that **100% of the heat from fan energy use goes to the distribution (supply) air**.

5.3.1.10.6.2 Outdoor Condenser Fan.

- Outdoor fan power = 108 W.

The draw-through outdoor condenser fan cycles on and off with the compressor.

5.3.2 HVAC Equipment Performance Parameter Variation Tests

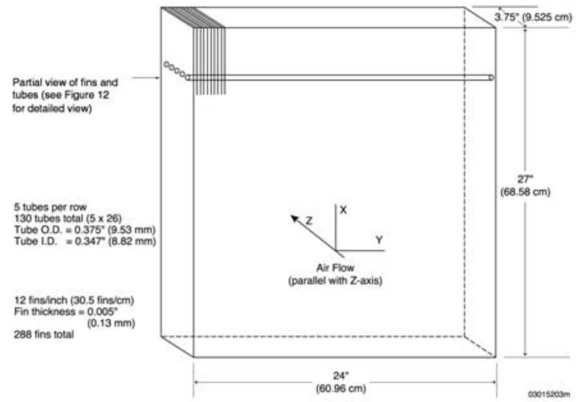

Figure 11 Evaporator coil overall dimensions.

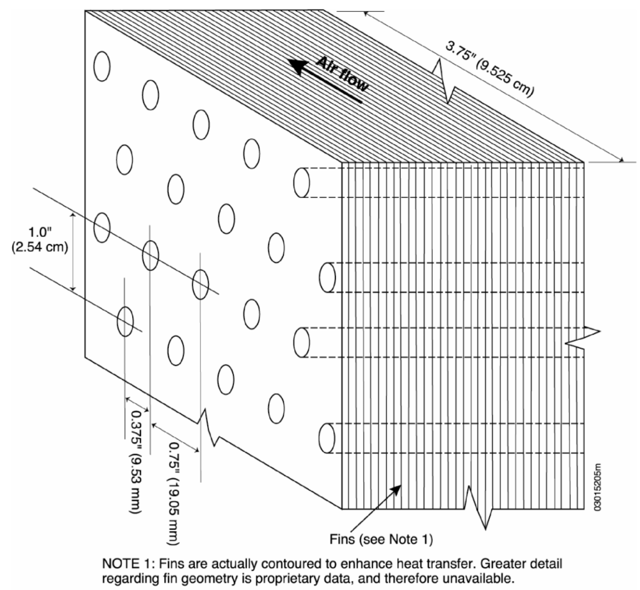

Figure 12 Evaporator coil detail, tube and fin geometry.

5.3.2.1 Additional Dry Coil Test Cases

It is recommended to double check the Case E100 base case inputs and to diagnose Case E100 results disagreements before going on to the other test cases.

This section describes sequential revisions to the base case required to model additional dry-coil cases. The dry-coil cases have no latent load in the zone. In many instances the base case for a given case is not Case E100; appropriate base cases for a given dry-coil case are:

Case	Basis for That Case
E110	E100
E120	E110
E130	E100
E140	E130

5.3.2.1.1 Case E110: Reduced Outdoor Dry-Bulb Temperature. Case E110 is exactly the same as Case E100 except the applicable weather data file is

HVBT294.TMY or HVBT294A.TM2.

These data are provided in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) as described in Annex A1, Section A1.2.

5.3.2.1.2 Case E120: Increased Thermostat Setpoint. Case E120 is exactly the same as Case E110 except the thermostat control strategy is:

Heat = off

Cool = on if zone air temperature >26.7°C (80.0°F); otherwise cool = off

All other features of the thermostat remain as before.

5.3.2.1.3 Case E130: Low Part-Load Ratio. Case E130 is exactly the same as Case E100 except the internal heat gains are:

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

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

Sensible internal gains remain as 100% convective.

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

5.3.2.1.4 Case E140: Reduced Outdoor Dry-Bulb Temperature at Low Part-Load Ratio. Case E140 is exactly the same as Case E130 except the weather applicable weather data file is

HVBT294.TMY or HVBT294A.TM2.

These data are provided in the files accompanying this standard as described in Annex A1, Section A1.2.

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

Case	**Basis for That Case**
E150	E110
E160	E150
E165	E160
E170	E150
E180	E170
E185	E180
E190	E180
E195	E190
E200	E150

5.3.2.2.1 Case E150: Latent Load at High Sensible Heat Ratio. Case E150 is exactly as Case E110 except the internal heat gains are:

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

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

Sensible gains remain as 100% convective.

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

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

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

5.3.2.2.2 Case E160: Increased Thermostat Setpoint at High Sensible Heat Ratio. Case E160 is exactly the same as Case E150 except the thermostat control strategy is:

Heat = off

Cool = on if zone air temperature >26.7°C (80.0°F); otherwise cool = off

All other features of the thermostat remain as before.

5.3.2.2.3 Case E165: Variation of Thermostat Setpoint and Outdoor Dry-Bulb Temperature at High Sensible Heat Ratio. Case E165 is exactly the same as Case E160 except the thermostat control strategy and weather data are changed as noted below.

5.3.2.2.3.1 Weather Data

HVBT406.TMY or HVBT406A.TM2

These data are provided in the files accompanying this standard as described in Annex A1, Section A1.2.

5.3.2.2.3.2 Thermostat control strategy

Heat = off

Cool = on if zone air temperature >23.3°C (74.0°F); otherwise cool = off

All other features of the thermostat remain as before.

5.3.2.2.4 Case E170: Reduced Sensible Load. Case E170 is exactly the same as Case E150 except the internal heat gains are:

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

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

Sensible gains remain as 100% convective.

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

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

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

5.3.2.2.5 Case E180: Increased Latent Load. Case E180 is exactly the same as Case E170 except the internal heat gains are:

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

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

Sensible gains remain as 100% convective.

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

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

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

5.3.2.2.6 Case E185: Increased Outdoor Dry-Bulb Temperature at Low Sensible Heat Ratio. Case E185 is exactly the same as Case E180 except the weather applicable weather data file is

HVBT461.TMY or HVBT461A.TM2.

These data are provided in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) as described in Annex A1, Section A1.2.

5.3.2.2.7 Case E190: Low Part-Load Ratio at Low Sensible Heat Ratio. Case E190 is exactly the same as Case E180 except the internal heat gains are:

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

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

Sensible gains remain as 100% convective.

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

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

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

5.3.2.2.8 Case E195: Increased Outdoor Dry-Bulb Temperature at Low Sensible Heat Ratio and Low Part-Load Ratio. Case E195 is exactly the same as Case E190 except the weather applicable weather data file is

HVBT461.TMY or HVBT461A.TM2.

These data are provided in the files accompanying this standard as described in Annex A1, Section A1.2.

5.3.2.2.9 Case E200: Full-Load Test at ARI Conditions. This case compares simulated performance of mechanical equipment to the manufacturer's listed performance at full load and at ARI-specified operating conditions. Case E200 is exactly the same as Case E150 except for the changes noted below.

5.3.2.2.9.1 Weather Data

HVBT350.TMY or HVBT350A.TM2.

These data are provided in the files accompanying this standard as described in Annex A1, Section A1.2.

5.3.2.2.9.2 Internal heat gains

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

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

Sensible gains remain as 100% convective.

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

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

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

5.3.2.2.9.3 Thermostat Control Strategy

Heat = off.

Cool = on if zone air temperature > 26.7°C (80.0°F); otherwise cool = off.

All other features of the thermostat remain as before.

6. OUTPUT REQUIREMENTS

[Informative Note: Make the following revisions to Section 6.]

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

6.1.1 All Non-Free-Float Cases. In this description, the term “free-float cases” refers to cases designated with FF in the case description (i.e., 600FF, 650FF, 900FF, 950FF); non-free-float cases are all the other cases described in Section 5.2 (Annex B1 includes an informative summary listing of all the cases). Required outputs for the non-free-float cases are:

6.1.1.5 All heating and cooling loads listed in 6.1.1.1 through 6.1.1.4 shall be entered into the appropriate standard output report (see Annex A2) as positive values (≥0).

6.2 Daily Hourly Output for Building Thermal Envelope and Fabric Load Tests of Section 5.2

If the program being tested can produce hourly outputs, then produce the following hourly values for the specified days. To produce this output, run the program for a normal annual run. Do not just run the required days because the results could contain temperature history errors. Required outputs are listed for specific cases in Table 29~~3~~.

Table 29~~3~~
Daily Hourly Output Requirements for Building Thermal Envelope and Fabric Load Tests of Section 5.2

6.3 Output Requirements for HVAC Equipment Performance Tests of Section 5.3

6.3.1 The outputs listed immediately below are to include loads or consumptions (as appropriate) for the entire month of February (the second month in the weather data sets). The terms *cooling energy consumption*, *evaporator coil loads*, *zone cooling loads*, and *coefficient of performance* are defined in Section 3.

6.3.1.1 Cooling energy consumptions (kWh)

(a) Total consumption (compressor and fans)
(b) Disaggregated compressor consumption
(c) Disaggregated indoor air distribution fan consumption
(d) Disaggregated outdoor condenser fan consumption

6.3.1.2 Evaporator coil loads (kWh)

(a) Total evaporator coil load (sensible + latent)
(b) Disaggregated sensible evaporator coil load
(c) Disaggregated latent evaporator coil load

6.3.1.3 Zone cooling loads (kWh)

(a) Total cooling load (sensible + latent)
(b) Disaggregated sensible cooling load
(c) Disaggregated latent cooling load.

6.3.2 The outputs listed immediately below are to include the mean value for the month of February and the hourly integrated maximum and minimum values for the month of February.

(a) Calculated coefficient of performance (COP) (dimensionless)

((Net refrigeration effect)/(total cooling energy consumption))

(b) Zone dry- bulb temperature (°C)
(c) Zone humidity ratio (kg moisture/kg dry air).

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

ANNEX A1

WEATHER DATA

[Informative Note: Create new Section A1.1 by combining the first paragraph of Annex A1 and the first sentence of the second paragraph and revising as follows.]

A1.1 Weather Data for Building Thermal Envelope and Fabric Load Tests

The full-year weather data (DRYCOLD.TMY) in the files accompanying this standard method of test (available at http://www.ashrae.org/template/PDFDetail?assetID=34505) shall be used for performing the tests called out in Section 5.2. Site and weather characteristics are summarized in Table A1-1.

A1.2 Weather Data for 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 and A1.4 respectively.

[Informative Note: Revise the title of Table A1-1 as follows.]

TABLE A1-1
Site and Weather Summary for DRYCOLD.TMY Weather Data Used with Building Thermal Envelope and Fabric Load Tests

[Informative Note: Add entirely new Tables A1-2, A1-3a, and A1-3b as noted.]

TABLE A1-2
Weather Data for HVAC Equipment Performance Tests

Data Files	Applicable Cases	Applicable Cases' Sections
HVBT294.TMY or HVBT294A.TM2	E110, E120, E140, E150, E160, E170, E180, E190	5.3.2.1.1; 5.3.2.1.2; 5.3.2.1.4; 5.3.2.2.1; 5.3.2.2.2; 5.3.2.2.4; 5.3.2.2.5; 5.3.2.2.7
HVBT350.TMY or HVBT350A.TM2	E200	5.3.2.2.9
HVBT406.TMY or HVBT406A.TM2	E165	5.3.2.2.3
HVBT461.TMY or HVBT461A.TM2	E100, E130, E185, E195	5.3.1; 5.3.2.1.3; 5.3.2.2.6; 5.3.2.2.8

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

Weather Type		Artificial Conditions
Weather Format		TMY
Latitude		25.8° North
Longitude (local site)		80.3° West
Altitude		2 m (6.6 ft)
Time Zone (Standard Meridian Longitude)		5 (75° West)
Ground Reflectivity		0.2
Site		Flat, unobstructed, located exactly at weather station
Dew Point Temperature (constant)		14.0°C (57.2°F)
Humidity Ratio		0.010 kg moisture/kg dry air (0.010 lb moisture/lb dry air)
Mean 3-Month Wind Speed		4.4 m/s (9.8 miles/h)
Maximum 3-Month Wind Speed		12.4 m/s (27.7 miles/h)
Global Horizontal Solar Radiation 3-Month Total		1354 MJ/m² (119.2 kBtu/ft²)
Direct Normal Solar Radiation 3-Month Total		1350 MJ/m² (118.8 kBtu/ft²)
Direct Horizontal Solar Radiation 3-Month Total		817 MJ/m² (71.9 kBtu/ft²)
Diffuse Horizontal Solar Radiation 3-Month Total		536 MJ/m² (47.2 kBtu/ft²)
Quantities That Vary Between Data Sets	Ambient Dry Bulb Temperature (constant)	Ambient Relative Humidity
HVBT294.TMY	29.4°C (85.0°F)	39%
HVBT350.TMY	35.0°C (95.0°F)	28%
HVBT406.TMY	40.6°C (105.0°F)	21%
HVBT461.TMY	46.1°C (115.0°F)	16%

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

Weather Type		Artificial Conditions
Weather Format		TMY2
Latitude		25.8° North
Longitude (local site)		80.3° West
Altitude		2 m (6.6 ft)
Time Zone (Standard Meridian Longitude)		5 (75° West)
Ground Reflectivity		0.2
Site		Flat, unobstructed, located exactly at weather station
Dew Point Temperature (constant)		14.0°C (57.2°F)
Humidity Ratio		0.010 kg moisture/kg dry air (0.010 lb moisture/lb dry air)
Mean Annual Wind Speed		4.3 m/s (9.7 miles/h)
Maximum Annual Wind Speed		13.9 m/s (31.1 miles/h)
Global Horizontal Solar Radiation Annual Total		6453 MJ/m² (568 kBtu/ft²)
Direct Normal Solar Radiation Annual Total		5418 MJ/m² (477 kBtu/ft²)
Diffuse Horizontal Solar Radiation Annual Total		2914 MJ/m² (257 kBtu/ft²)
Quantities That Vary Between Data Sets	Ambient Dry Bulb Temperature (constant)	Ambient Relative Humidity
HVBT294A.TM2	29.4°C (85.0°F)	39%
HVBT350A.TM2	35.0°C (95.0°F)	28%
HVBT406A.TM2	40.6°C (105.0°F)	21%
HVBT461A.TM2	46.1°C (115.0°F)	16%

[Informative Note: Revise Section A1.3 as follows.]

A1.3 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~~2~~. 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[8] can be obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina. The address is Federal Building, Asheville, NC 28801-2733; telephone 828-271-4800. Informative Annex B2 contains additional background information regarding TMY weather data.

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

Solar Time = Standard Time + (4 minutes / degree) x (Lst - Lloc) + E

and where

Lst ≡ standard meridian longitude (degrees)

Lloc ≡ local site longitude (degrees)

E = ~~9.87 sin 2B - 7.53 cos B - 1.5 sin B~~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)/~~364~~365 (degrees)

n ≡ day of the year, 1 ≤ n ≤ 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.[4]

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

[Informative Note: Add entirely new Section A1.4 as below.]

A1.4 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[A-6] can be obtained at http://rredc.nrel.gov/solar/pubs/tmy2.

A1.4.1 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, 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.

A1.4.2 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 provides field positions, element definitions, and sample FORTRAN and C formats for reading the hourly records.

Each hourly record begins with the year (field positions 2-3) from which the typical month was chosen, followed by the month, day, and hour information in field positions 4-9. ***The times are in local standard time (previous TMYs based on SOLMET/ERSATZ data are in solar time).***

For solar radiation and illuminance elements, the data values represent the energy received during the 60 minutes *preceding the hour indicated*. For meteorological elements (with a few exceptions), observations or measurements were made *at the hour indicated*. A few of the meteorological elements had observations, measurements, or estimates made at daily, instead of hourly, intervals. Consequently, the data values for broadband aerosol optical depth, snow depth, and days since last snowfall represent the values available for the day indicated.

[Informative Note: Add Figure A1-1. Change the designation of Table A1-2, Typical Meteorological Year Data Format, to Table A1-4 on all pages on which the table appears. Add tables A1-5 and A1-6.]

```
14944 SIOUX_FALLS           SD  -6 N 43 34 W  96 44   435
85010101000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-211A7060A70975A7360A7052A70161A700945A70999099999004E7050F8000A700E7
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85010113056214150387G40806G40067G50407I40767I40101I50139I500A700A7-156A7-244A7047A70978A7320A7067A70193A777777A70999999999003E7050F8000A700E7
85010114053014150359G40788G40064G50377I40742I40098I50131I500A700A7-144A7-239A7045A70978A7310A7062A70193A777777A70999999999003E7050F8000A700E7
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                                                                                                                        1         1         1         1         1
         1         2         3         4         5         6         7         8         9         0         1         2         3         4
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
                                                                       (for field position identification only)
```

Figure A1-1 Sample file header and data in the TMY2 format for January 1

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

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1 of Marion and Urban [1995])[A-6]
008 - 029	City	City where the station is located (maximum of 22 characters)
031 - 032	State	State where the station is located (abbreviated to two letters)
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time is ahead of or behind Universal Time. For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time.
038 - 044 038 040 - 041 043 - 044	Latitude	Latitude of the station N = North of equator Degrees Minutes
046 - 053 046 048 - 050 052 - 053	Longitude	Longitude of the station W = West, E = East Degrees Minutes
056 - 059	Elevation	Elevation of station in meters above sea level

FORTRAN Sample Format:
`(1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4)`
C Sample Format:
`(%s %s %s %d %s %d %d %s %d %d %d)`		

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

Field Position	Element	Values	Definition
002 - 009 002 - 003 004 - 005 006 - 007 008 - 009	Local Standard Time Year Month Day Hour	 61 - 90 1 - 12 1 - 31 1 - 24	 Year, 1961-1990 Month Day of month Hour of day in local standard time
010 - 013	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
014 - 017	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
018 - 023 018 - 021 022 023	Global Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1200 A - H, ? 0 - 9	Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated
024 - 029 024 - 027 028 029	Direct Normal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1100 A - H, ? 0 - 9	Amount of solar radiation in Wh/m^2 received within a 5.7° field of view centered on the sun, during the 60 minutes preceding the hour indicated
030 - 035 030 - 033 034 035	Diffuse Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 700 A - H, ? 0 - 9	Amount of solar radiation in Wh/m^2 received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
036 - 041 036 - 039 040 041	Global Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1,300 I, ? 0 - 9	Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1,300 = 0 to 130,000 lux
042 - 047 042 - 045 046 047	Direct Normal Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1,100 I, ? 0 - 9	Average amount of direct normal illuminance in hundreds of lux received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1,100 = 0 to 110,000 lux
048 - 053 048 - 051 052 053	Diffuse Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 800 I, ? 0 - 9	Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
054 - 059 054 - 057 058 059	Zenith Luminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 7,000 I, ? 0 - 9	Average amount of luminance at the sky's zenith in tens of Cd/m^2 during the 60 minutes preceding the hour indicated. 0 to 7,000 = 0 to 70,000 Cd/m^2
060 - 063 060 - 061 062 063	Total Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F, ? 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
064 - 067 064 - 065 066 067	Opaque Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated
068 - 073 068 - 071 072 073	Dry Bulb Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -500 to 500 A - F 0 - 9	Dry bulb temperature in tenths of °C at the hour indicated. -500 to 500 = -50.0 to 50.0 degrees C
074 - 079 074 - 077 078 079	Dew Point Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -600 to 300 A - F 0 - 9	Dew point temperature in tenths of °C at the hour indicated. -600 to 300 = -60.0 to 30.0 °C

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

Field Position	Element	Values	Definition
080 - 084 080 - 082 083 084	Relative Humidity Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Relative humidity in percent at the hour indicated
085 - 090 085 - 088 089 090	Atmospheric Pressure Data Value Flag for Data Source Flag for Data Uncertainty	 700 - 1100 A - F 0 - 9	Atmospheric pressure at station in millibars at the hour indicated
091 - 095 091 - 093 094 095	Wind Direction Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 360 A - F 0 - 9	Wind direction in degrees at the hour indicated. (N = 0 or 360, E = 90, S = 180, W = 270). For calm winds, wind direction equals zero.
096 - 100 096 - 98 99 100	Wind Speed Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 400 A - F 0 - 9	Wind speed in tenths of meters per second at the hour indicated. 0 to 400 = 0 to 40.0 m/s
101 - 106 101 - 104 105 106	Visibility Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1609 A - F, ? 0 - 9	Horizontal visibility in tenths of kilometers at the hour indicated. 7777 = unlimited visibility 0 to 1609 = 0.0 to 160.9 km 9999 = missing data
107 - 113 107 - 111 112 113	Ceiling Height Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 30450 A - F, ? 0 - 9	Ceiling height in meters at the hour indicated. 77777 = unlimited ceiling height 88888 = cirroform 99999 = missing data
114 - 123	Present Weather	See Appendix B of Marion and Urban (1995)[A-6]	Present weather conditions denoted by a 10-digit number. See Appendix B of Marion and Urban (1995)[A-6] for key to present weather elements.
124 - 128 124 - 126 127 128	Precipitable Water Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Precipitable water in millimeters at the hour indicated
129 - 133 129 - 131 132 133	Aerosol Optical Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 240 A - F 0 - 9	Broadband aerosol optical depth (broad-band turbidity) in thousandths on the day indicated. 0 to 240 = 0.0 to 0.240
134 - 138 134 - 136 137 138	Snow Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 150 A - F, ? 0 - 9	Snow depth in centimeters on the day indicated. 999 = missing data
139 - 142 139 - 140 141 142	Days Since Last Snowfall Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 88 A - F, ? 0 - 9	Number of days since last snowfall 88 = 88 or greater days 99 = missing data

FORTRAN Sample Format:

```
(1X,4I2,2I4,7(I4,A1,I1),2(I2,A1,I1),2(I4,A1,I1),1(I3,A1,I1),
 1(I4,A1,I1),2(I3,A1,I1),1(I4,A1,I1),1(I5,A1,I1),10I1,3(I3,A1,I1),
 1(I2,A1,I1))
```

C Sample Format:

```
(%2d%2d%2d%2d%4d%4d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s
 %1d%4d%1s%1d%2d%1s%1d%2d%1s%1d%4d%1s%1d%4d%1s%1d%3d%1s%1d%4d%1s%1d%3d
 %1s%1d%3d%1s%1d%4d%1s%1d%5ld%1s%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%3d%1s
 %1d%3d%1s%1d%3d%1s%1d%2d%1s%1d)
```

Note: For ceiling height data, integer variable should accept data values as large as 99999.

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

ANNEX A2

STANDARD OUTPUT REPORTS

[Informative Note: Replace item (b) in alphabetized list below with new item (b), change old item (b) to item (c), and revise items (a) and (c) as shown.]

The standard output report consists of ~~two~~ three forms provided in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505):

(a) Output Results for Section 5.2 Cases (~~S140OUT~~2Sec5-2out.XLS~~WK3~~, spreadsheet file)

(b) Output Results for Section 5.3 Cases (Sec5-3out.XLS, spreadsheet file)

(c) Modeling Notes (~~S140OUT2~~S140outNotes.TXT, text file reprinted as Attachment A2.3~~A2.1~~)

For entering output results into ~~S140OUT2~~Sec5-2out.XLS~~WK3~~ and Sec5-2out.XLS, follow the instructions provided at the top of the appropriate electronic spreadsheet files. These instructions are reprinted as Attachments A2.1 and A2.2 respectively~~A2.2~~ within this section.

For entering modeling notes into ~~S140OUT2~~S140outNotes.TXT, use the format of the following examples given as Attachments ~~A2.3 and~~ A2.4 and A2.5 within this section.

[Informative Note: Change Attachment A2.2 to A2.1 and revise heading as follows. Move it ahead of the former A2.1.]

Attachment ~~A2.2~~A2.1 Instructions for Entering Results into ~~S140OUT2~~Sec5-2out.XLS~~WK3~~

[Informative Note: Revise results as follows.]

STANDARD 140 OUTPUT FORM - RESULTS ~~17 DEC 1997; S140OUT2~~Sec5-2out.XLS~~WK3~~

[Informative Note: Delete the following paragraph in A2.2 (formerly A2.1).]

When dates are input in this format, they are converted to a 5-digit date code (04-Jan = 33607) which appears in the data cell. To convert this five-digit code back into a date, the cell must have an appropriate format. Thus, for S140OUT2.WK3 the format command "/ **W**orksheet **R**ange **F**ormat **D**ate 2" is already applied to the cells that require the entry of dates.

[Informative Note: Add entirely new Attachment A2.2.]

Attachment A2.2 Instructions for Entering Results into Sec5-3out.XLS

HVAC BESTEST Cases E100-E200 Output Form, Sec5-3out.XLS

Instructions:

1. Use specified units.
2. Data entry is restricted to columns B through T and rows 25 through 38. The protection option has been employed to help ensure that data are input in the correct cells.
3. February totals are consumptions and loads just for the month of February. Similarly, February means and maxima are those values just for the month of February.
4. Cooling energy consumption, evaporator coil load, zone load, and COP are defined in Section 3.

[Informative Note: Change Section A2.1 to A2.3 and move it to the correct sequence (heading change only).]

Attachment ~~A2.1~~A2.3 Standard 140 Output Form - Modeling Notes

[Informative Note: Change Section A2.3 to A2.4 (heading change only).]

Attachment ~~A2.3~~A2.4 Example of Modeling Notes for BLAST 3.0[3]

[Informative Note: Change Section A2.4 to A2.5 (heading change only).]

Attachment ~~A2.4~~A2.5 Example of Modeling Notes for DOE-2.1E[5]

(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.)

ANNEX B1

TABULAR SUMMARY OF TEST CASES

[Informative Note: Revise the introductory paragraph for Annex B1 as follows.]

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 HVAC Equipment Performance test cases described in Section 5.3, in SI and I-P units respectively.

NOMENCLATURE

[Informative Note: Add the following abbreviations to the nomenclature used in Tables B1-1A and B1-1B.]

ARI	Air Conditioning and Refrigeration Institute
EDB	entering dry-bulb temperature
ODB	outdoor dry-bulb temperature
PLR	part-load ratio
SHR	sensible heat ratio

[Informative Note: Add new tables B1-2a and B1-2b.]

TABLE B1-2a
HVAC BESTEST Case Descriptions (SI Units).

	Zone			Weather	
	Internal Gains*		Setpoint		
	Sensible	Latent	EDB	ODB	
Case #	(W)	(W)	(°C)	(°C)	Comments
dry zone series					
E100	5400	0	22.2	46.1	Base case, dry coil. High PLR.
E110	5400	0	22.2	29.4	High PLR. Tests low ODB versus E100.
E120	5400	0	26.7	29.4	High PLR. Tests high EDB versus E110. Tests ODB & EDB interaction versus E100.
E130	270	0	22.2	46.1	Low PLR test versus E100.
E140	270	0	22.2	29.4	Tests ODB at low PLR vs E130. Tests PLR at low ODB vs E110.
humid zone series					
E150	5400	1100	22.2	29.4	High PLR. High SHR. Tests latent load versus E110.
E160	5400	1100	26.7	29.4	High PLR. High SHR. Tests EDB versus E150.
E165	5400	1100	23.3	40.6	High PLR. High SHR. Tests ODB & EDB interaction with latent load versus E160.
E170	2100	1100	22.2	29.4	Mid PLR. Mid SHR. Tests low sensible load versus E150.
E180	2100	4400	22.2	29.4	High PLR. Low SHR. Tests SHR versus E150. Tests high latent load versus E170.
E185	2100	4400	22.2	46.1	High PLR. Low SHR. Tests ODB versus E180.
E190	270	550	22.2	29.4	Low PLR. Low SHR Tests low PLR at constant SHR vs E180. Tests latent load at low PLR versus E140.
E195	270	550	22.2	46.1	Low PLR. Low SHR Tests ODB at low PLR & SHR versus E190. Tests low PLR at constant SHR vs E185. Tests latent load at low PLR versus E130.
full load test at ARI conditions					
E200	6120	1817	26.7	35.0	Tests for ARI indoor wetbulb temperature at full sensible and latent loads.

Abbreviations: PLR = Part Load Ratio; ODB = outdoor drybulb temperature;
EDB = entering drybulb temperature; vs = versus;
SHR = Sensible Heat Ratio; ARI = Air Conditioning and Refrigeration Institute.

*Internal Gains are internally generated sources of heat and humidity that are not related to operation of the mechanical cooling system or its air distribution fan.

i22case4.xls, a:a1..h48; May 30, 2000

TABLE B1-2b
HVAC BESTEST Case Descriptions (I-P Units).

	Zone			Weather	
	Internal Gains*		Setpoint		
	Sensible	Latent	EDB	ODB	
Case #	(Btu/h)	(Btu/h)	(°F)	(°F)	Comments
dry zone series					
E100	18430	0	72.0	115.0	Base case, dry coil. High PLR.
E110	18430	0	72.0	85.0	High PLR. Tests low ODB versus E100.
E120	18430	0	80.0	85.0	High PLR. Tests high EDB versus E110. Tests ODB & EDB interaction versus E100.
E130	922	0	72.0	115.0	Low PLR test versus E100.
E140	922	0	72.0	85.0	Tests ODB at low PLR vs E130. Tests PLR at low ODB vs E110.
humid zone series					
E150	18430	3754	72.0	85.0	High PLR. High SHR. Tests latent load versus E110.
E160	18430	3754	80.0	85.0	High PLR. High SHR. Tests EDB versus E150.
E165	18430	3754	74.0	105.0	High PLR. High SHR. Tests ODB & EDB interaction with latent load versus E160.
E170	7166	3754	72.0	85.0	Mid PLR. Mid SHR. Tests low sensible load versus E150.
E180	7166	15018	72.0	85.0	High PLR. Low SHR. Tests SHR versus E150. Tests high latent load versus E170.
E185	7166	15018	72.0	115.0	High PLR. Low SHR. Tests ODB versus E180.
E190	922	1877	72.0	85.0	Low PLR. Low SHR Tests low PLR at constant SHR vs E180. Tests latent load at low PLR versus E140.
E195	922	1877	72.0	115.0	Low PLR. Low SHR Tests ODB at low PLR & SHR versus E190. Tests low PLR at constant SHR vs E185. Tests latent load at low PLR versus E130.
full load test at ARI conditions					
E200	20890	6200	80.0	95.0	Tests for ARI indoor wetbulb temperature at full sensible and latent loads.

Abbreviations: PLR = Part Load Ratio; ODB = outdoor drybulb temperature;
EDB = entering drybulb temperature; vs = versus;
SHR = Sensible Heat Ratio; ARI = Air Conditioning and Refrigeration Institute.

*Internal Gains are internally generated sources of heat and humidity that are not related to operation of the mechanical cooling system or its air distribution fan.

i22case4.xls, b:a1..h48; May 10, 2001

(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.)

ANNEX B2

ABOUT TYPICAL METEOROLOGICAL YEAR (TMY) WEATHER DATA

[Informative Note: Revise Annex B2 as follows.]

TMY data are used in Standard 140, Section 5.2 for the following reasons:

- The original research that is the foundation of Standard 140, IEA BESTEST, was performed by the International Energy Agency.[14] ~~(Judkoff and Neymark, 1995)~~ The underlying research used in this standard began in 1990 and was completed in 1993. At that time TMY data represented the state of the art regarding hourly weather data.
- During the process of converting the original IEA work into a Standard Method of Test, SPC 140 considered changing the weather data file and format. The problems with this were that:

    1. Some parts of the test specification are based on the specific TMY data file provided with Standard 140. For example, the convective portion of annual average exterior combined surface coefficients – provided for those programs that do not calculate exterior convection hourly – are related to the average annual wind speed from the original weather data file. This means that some inputs in the test specification would need to be changed.
    2. The example results of informative Annex B8 would not be consistent with user-generated results if new weather data were used—unless the test cases were rerun for all the programs shown. For many users of Standard 140, the evaluation of results will be facilitated by being able to compare the results for their program with the example results presented in Annex B8, which requires using consistent testing methods and weather data.

For these reasons, SPC 140 decided to keep the original TMY weather data and the detailed documentation of the TMY weather data format. For Section 5.3, either TMY-format data or TMY2-format data may be used as described in Annex A1, Section A1.2.

(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.)

ANNEX B8

EXAMPLE RESULTS FOR BUILDING THERMAL ENVELOPE AND FABRIC LOAD TESTS

[Informative Note: Revise Annex B8 as noted.]

The example results from various detailed building energy simulation programs that applied the tests of Section 5.2 are presented here in tabular and graphic form. These results can be used for a comparison with the software being tested. Alternatively, a user can run a number of different programs through the Standard Method of Test and draw comparisons from those results independently or in conjunction with the results listed here. In either case, when making comparisons the user should employ the diagnostic logic presented in informative Annex B9, Section B9.4.

The building energy simulation computer programs used to generate example results are described in informative Annex B11. These computer programs have been subjected to a number of analytical verification, empirical validation, and comparative testing studies. However, there is no such thing as a completely validated building energy simulation computer program. All building models are simplifications of reality. The philosophy here is to generate a range of results from several programs that are generally accepted as representing the state of the art in whole building energy simulation programs. Regarding the results presented, to the extent possible, input errors or differences have been eliminated. Thus, for a given case the range of differences between results presented in the informative Annex B8 represents algorithmic differences among these computer programs for comparative envelope tests. For any given case, a tested program may fall outside this range without necessarily being incorrect. However, it is worthwhile to investigate the source of significant differences, as the collective experience of the authors of this standard is that such differences often indicate problems with the software or its usage, including, but not limited to:

(a) user input error, where the user misinterpreted or mis-entered one or more program inputs;
(b) problem with a particular algorithm in the program;
(c) one or more program algorithms used outside their intended range.

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

For the convenience to users who wish to plot or tabulate their results along with the example results, an electronic version of the example results has been included with the file RESULTS5-2.XLS~~WK3~~ in the files accompanying this standard. Documentation regarding RESULTS5-2.XLS~~WK3~~ has been included with the file and is printed out in informative Annex B10, Section B10.1, for convenience.

For generating these results, along with using consistent modeling methods, simulationists were requested to use the most detailed modeling methods their software allows. For a summary of how example results were developed see informative Annex B11. For more detailed information about the example results see *IEA BESTEST*[14].

(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.)

ANNEX B9

DIAGNOSING THE RESULTS USING THE FLOW DIAGRAMS

[Informative Note: Revise Sections B9.1 – B9.4 as noted.]

B9.1 General Description. Figures B9-1 through B9-5~~B9-4~~ contain a set of flow diagrams that serve as a guide for diagnosing the cause of disagreeing results that may arise from using this method of test. These flow diagrams list the feature(s) being tested, thus indicating potential sources of algorithmic differences.

B9.2 Comparing Tested Software Results to Other Example Results

B9.2.1 "Example results" are either results presented in informative Annexes B8 and B16 or other results that were generated using this Standard Method of Test.

B9.2.2 In this annex we provide 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 equipment performance tests of Section 5.3, the degree of disagreement that occurred for other simulation results in Annex B16 versus the quasi-analytical solution results.

B9.2.3 Check the program being tested for agreement (see Section B9.2.2) with example results for both the absolute outputs and the sensitivity (or "delta") outputs. For example, when comparing to the example results shown in informative Annex B8, for Case "610-600" in the "low mass basic" flow diagram (Figure B9-1), the program results are compared with both the Case 610 example results and the Case 610-600 example sensitivity results.

B9.2.4 Compare all available output types specified for each case that can be produced by the program being tested. For the tests of Section 5.2, ~~T~~this includes appropriate calculated solar radiation, free float, and hourly results if the software being tested is capable of producing that type of output. For the tests of Section 5.3, this includes appropriate energy consumption, coil load, zone load, zone temperature, and humidity ratio results if the software being tested is capable of producing that type of output. A disagreement with any one of the output types may be cause for concern.

B9.2.5 There are some cases where it is possible to proceed even if disagreements were uncovered in the previous case. For example, using Figure B9-1, in Case 610, inability to model a shading overhang would not affect the usefulness of the program for modeling buildings with unshaded windows. Thus, the flow diagram has an extra arrow connecting Case 610 and Case 620, which denotes that you may proceed regardless of the results for Case 610. Where cases are connected by a single arrow, a satisfactory result is required in order to proceed to the next case. For example, in Case 620, the inability to model transmitted radiation through an unshaded east window makes it difficult to proceed with these tests until the disagreement is reconciled.

B9.3 If Tested Software Results Disagree with Example Results. If the tested program shows disagreement (as defined above in informative Section B9.2.2) with the example results, then recheck the inputs against the specified values. Use the diagnostic logic flow diagrams to help isolate the source of the difference. If no input error can be found, then look for an error in the software. If an error is found, then fix it and rerun the tests. If in the engineering judgment of the user, the disagreement is due to a reasonable difference in algorithms between the tested software and the example results or other tested software, then continue with the next test case.

B9.4 Diagnostic Logic Flow Diagrams for Building Thermal Envelope and Fabric Load Tests (Section 5.2)

B9.4.1 Low-Mass and High-Mass Basic Tests. The first flow diagram (Figure B9-1) begins with the base building (Case 600). It is very important to have confidence in your Case 600 results before proceeding to the other cases. If output from the tested program agrees satisfactorily with other example results for Case 600, then check other output according to the flow diagram. Once the low-mass basic cases have been checked, proceed with the high-mass basic (900-series) cases (Figure B9-3).

~~B9.5~~B9.4.2 In-Depth Tests. These tests provide detailed diagnostic capability. The "in-depth test" flow diagram (Figure B9-2) indicates two possible diagnostic paths, A1 through A11 or B1 through B10. Selecting path A versus path B depends on the capabilities of the program being tested. Path A is the preferable diagnostic path. Use Path A if the software being tested is literal enough in its treatment of building physics to allow input of those cases. Otherwise, Path B will still help to identify algorithmic sources of differences but less definitively because of interacting effects.

~~B9.6~~B9.4.3 Mass Interaction Tests Further diagnostic information can be obtained regarding thermal mass interactions using the diagnostic logic flow diagram of Figure B9-4. When disagreement among results occurs, this diagram sometimes returns to the low-mass, in-depth diagnostics (Figure B9-3) even though the program may have already showed agreement in the low-mass basic tests. The reason for this is that the high-mass cases may reveal disagreements that the low-mass cases did not expose because

(a) the disagreement is more readily detectable when mass is present,
(b) the disagreement was not previously detectable because of compensating differences,
(c) the disagreement was not previously detectable because of other unknown interactions.

[Informative Note: Add new Section B9.5.]

B9.5 Diagnostic Logic Flow Diagram for HVAC Equipment Performance Tests (Section 5.3)

B9.5.1 General Description. The E100 series cases (E100 through E200) are steady-state cases that test basic performance map modeling capabilities and utilize comparisons with quasi-analytical solutions. The diagnostic logic flow diagram for these cases (Figure B9-5) indicates similar diagnostics for dry-coil and wet-coil (without and with dehumidification) cases. This is really one continuous diagnostic path to be implemented for both dry-coil and wet-coil cases. Performing and analyzing results of the E100 series tests in blocks, such as E100–E140 and E150–E200, or E100–E200, all at once is recommended. For the E100 series cases if a disagreement is uncovered for one of the cases, then fix it and rerun all the E100 series cases.

B9.5.2 Consideration of Quasi-Analytical Solution Results. As a minimum, the user should compare output with the quasi-analytical solution results found in Annex B16. The user may also choose to compare output with the example simulation results in Annex B16 or with other results that were generated using Section 5.3 of this test procedure. Information about how the quasi-analytical solutions and example simulation results were produced is included in Annex B17. For convenience to users who wish to plot or tabulate their results along with the quasi-analytical solution or example simulation results, or both, an electronic version of the example results has been included with the file RESULTS5-3.XLS on the accompanying electronic media (available at http://www.ashrae.org/template/PDFDetail?assetID=34505). Regarding determination of agreement of results discussed in B9.2.2, in making this determination for the HVAC equipment performance tests of Section 5.3, the user should consider that the quasi-analytical solution results given in Annex B16 represent a "mathematical truth standard" (i.e., a mathematically provable and deterministic set of results based on acceptance of the underlying physical assumptions represented by the case specifications). Note that although the underlying physical assumptions of the case definitions of the mechanical equipment are consistent with those of typical_manufacturer equipment performance data, they are by definition a simplification of reality and may not fully represent real empirical behavior.

[Informative Note: Renumber current Section B9.7 as B9.6 and revise as follows.]

B9.~~7~~6 Examples

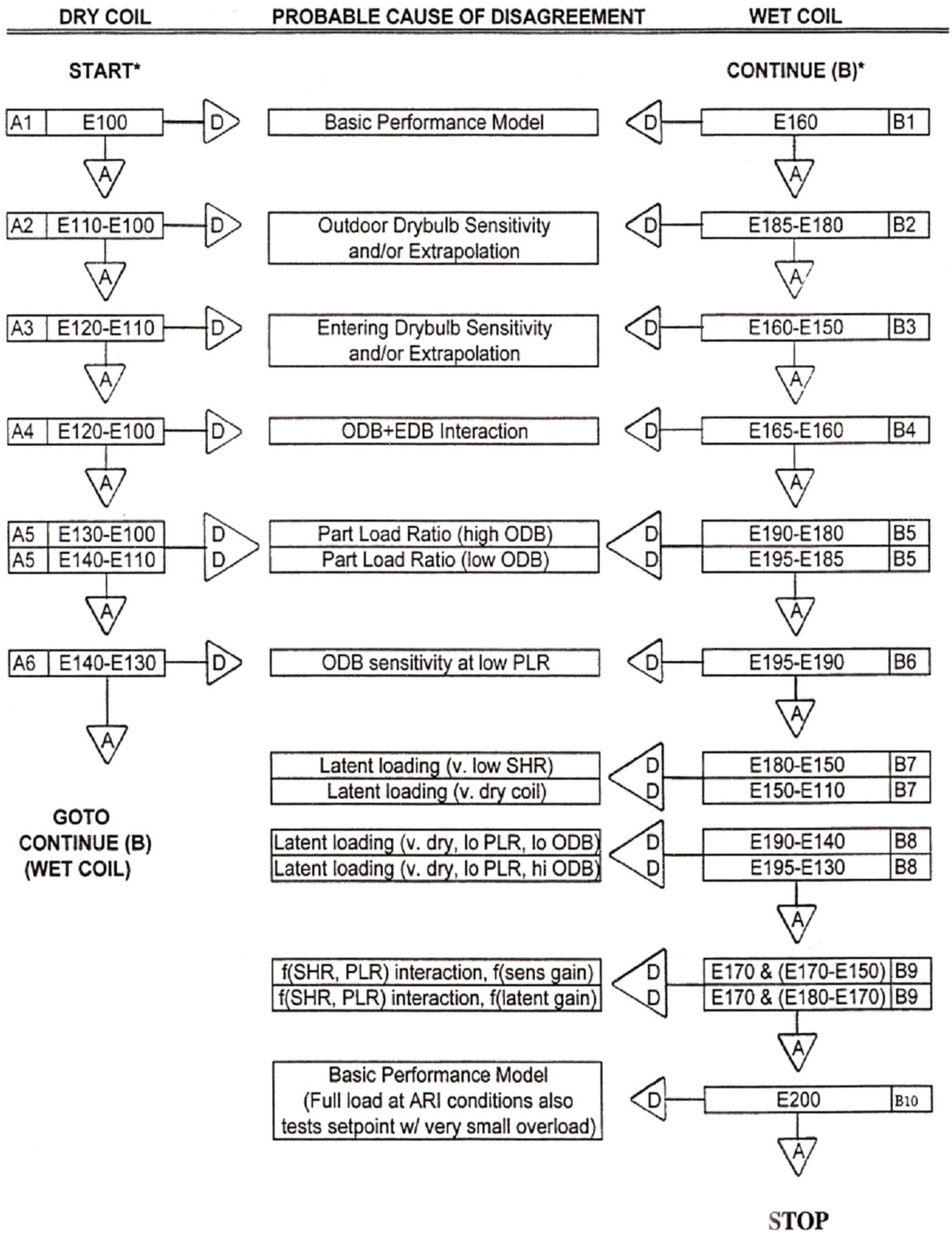
B9.6.1 Example Using Flow Diagrams for Building Thermal Envelope and Fabric Load Tests (Section 5.2). A program shows agreement with Case 600 but shows large disagreement with the example results of annual sensible cooling load predictions for Case 610. Figure B9-1 suggests the potential algorithmic source of the difference is with the shading algorithm and directs the user to look at the sensitivity results for shading as represented by the difference between the output values from Cases 600 and 610. The flow diagram then directs the user to diagnostic A12. Diagnostic A12 will either confirm shading as the source of the difference or direct the user to additional diagnostics if the shading algorithm is okay. The logic is sequential in that to show disagreement with 610-600 and to show agreement with A12 indicates differences elsewhere in 610-600 and, therefore, possible compensating differences in 600. To show disagreement with both 610-600 and A12 confirms a shading algorithm as the source of the difference.

IEA BESTEST[14] gives examples of how the tests were used to trace and correct specific algorithmic and input errors in the programs used to produce example results of informative Annex B8.

B9.6.2 Example using Flow Diagrams for HVAC Equipment Performance Tests (Section 5.3). A program shows agreement with Case E100, but shows large disagreement with the quasi-analytical solution results of energy consumption predictions for Case E130. Figure B9-5 suggests the potential algorithmic source of the difference is with the algorithm for incorporating part-load operating effects into the energy consumption for a dry coil.

HVAC BESTEST[A-5] gives examples of how the tests were used to trace and correct specific algorithmic and input errors in the programs used in the field trials for which results are given in informative Annex B16.

[Informative Note: Add new Figure B9-5.]



ABBREVIATIONS
A = Agree, i.e., agree with analytical solution results for the case itself and the sensitivity case. E.g., to check for agreement regarding Case E130, compare exampe results for Case E130 and E130-E100 sensitivity.
D = Disagree, i.e., show disagreement with analytical solution results.
NOTES
*It is better to perform/analyze results of these tests in blocks such as E100-E140 and E150-E200.

Figure B9-5 E100-E200 series (steady-state analytical verification) diagnostic logic flow diagram.

(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.)

ANNEX B10

INSTRUCTIONS FOR WORKING WITH RESULTS SPREADSHEETS PROVIDED ~~ON CD~~ WITH THE STANDARD

[Informative Note: Revise introductory paragraph and Section B10.1 as follows.]

For the convenience of users, a printout of documentation ~~included with~~ for navigating the example results files ~~on the CD (RESULTS2.WK3)~~ is included below.

B10.1 Documentation for RESULTS5-2.XLS~~WK3~~ ~~21 APR 1998~~

This spreadsheet contains the IEA 12B/21C participant results that are presented in informative Annex B8. These data are provided for the convenience of users who wish to plot or tabulate their results along with the example results.

This spreadsheet was originally created with Lotus 1-2-3 version 3.1 for DOS.

The spreadsheet contains only values and text (no formulas).

The Standard Output Report spreadsheet (~~S140OUT2~~Sec5-2out.XLS~~WK3~~) has been designed such that values input to Column B of ~~S140OUT2~~Sec5-2out.XLS~~WK3~~ can be directly transferred to Column J of this spreadsheet.

[Informative Note: Add new Section B10.2.]

B10.2 Documentation for RESULTS5-3.XLS (given in RESULTS5-3.DOC)

Import data so that Cell A1 of Sec5-3out.XLS is in A1 of Sheet "YD" (your data). Check that the first value (Total Consumption kWh for E100) is in YD!B25. See Sheet A (rows 13-26) for tabulation of results locations. Your data will then appear in column L of Sheet A, in the rightmost column of each table on Sheet Q, and on the right side of the last 5 sheets (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' – 'G', 'L'	Results from each simulation program. 'E' is blank.
'H' – 'J'	Results from the quasi-analytical solutions.
'Q'	Formatted summary results tables including quasi-analytical solutions, simulations and statistics. "Your data" automatically appears on the right side of each table. See below for Sheet Q table locations.
'R'	Formatted summary results tables and statistics for quasi-analytical solutions only. See below for Sheet 'R' table locations. (Sheet 'R' is not reproduced in the hardcopy.)
'COP' thru 'QCL-QZL' (26 sheets)	26 summary charts (one per sheet). Import of "your data" into these charts is not automated. However the data does automatically appear on the right side of the tables used for making the charts. See below.
'"Data"-x' (last 5 sheets)	5 data sheets that the 26 data charts are linked to. "Your data" automatically appears on the right side of each data table.

Contents of Sheet Q:

Description	Cell Range
Space Cooling Electricity Consumption (Total, Compressor, Supply Fan, Condenser Fan)	A6 – P75
COP including (Max-Min)/Mean	A185 – P220
Coil Loads: Total, Sensible, Latent, and (Sensible Coil)-(Sensible Zone)	BC77 – BR147
Zone Loads: Total, Sensible, Latent, and (Latent Coil)-(Latent Zone)	BT77 – CI147
Sensitivities for Space Cooling Electricity Consumption (Total, Compressor, ID fan, OD fan)	CK491 – CZ580
Sensitivities for COP and Coil Loads (Total, Sensible, and Latent)	DB491 – DQ580
Zone IDB and Humidity Ratio including (Max-Min)/Mean	BC233 – BR304

Contents of Sheet R:

Description	Cell Range
COP, IDB and Humidity Ratio including (Max-Min)/Mean	A85 – K141
Space Cooling Electricity Consumption, Coil Loads, Zone Loads, Fan Heat and Latent Loads Check	AM06 – BE81
Sensitivities for Space Cooling Electricity Consumption, COP and Coil Loads	S145 – AK192

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ANNEX B11

PRODUCTION OF EXAMPLE RESULTS FOR BUILDING THERMAL ENVELOPE AND FABRIC LOAD TESTS

[Informative Note: Revise selected paragraphs in Annex B11 as follows.]

To minimize the potential for user error, when feasible, more than one modeler developed input files for each program. This was done for BLAST, SERIRES, and TRNSYS. Where disagreement in the inputs or results was found, the modelers were requested to resolve the differences. Where only a single modeler was involved, it was strongly recommended that inputs be carefully checked by another modeler familiar with the program.

Input decks used to generate the results are provided in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505); see the README.DOC~~TXT~~ file. The IEA participants that ran SERIRES 1.2 only provided two input decks with their results. IEA participants that ran simulations for ESP, S3PAS, and TASE did not supply input decks with their results.

B11.3 Hourly Time Convention

Details of differences in modeling methods utilized by various software are given in Part II of *IEA BESTEST*[14]. That reference does not discuss how the specified time convention is modeled by various simulation software. For Standard 140, the time convention for the input specification and hourly outputs is standard time, while the time convention for Typical Meteorological Year (TMY) weather data is solar time (see Annex A1, Section A1.3, for discussion of the difference between solar time and standard time). The time convention is therefore most correctly modeled by software which re-bins TMY data into hourly data based on local standard time. A tabulation of how the time convention was modeled by some of the software used to generate the example results given in informative Annex B8 is noted in Table B11-3.

Since software being tested by Standard 140 may not be re-binning TMY data, it is important to understand the potential differences in Standard 140 results that can be generated by applying a time convention different from that specified in Section 5.1.1. In Standard 140 such differences are minimized and are primarily related to the equation of time (see Annex A1, Section A1.3) because the building site has been located within 0.1° longitude of the standard meridian. For this reason Standard 140 does not provide a good test for the ability to calculate solar incidence angles for longitudes far away from the standard meridian.

[Informative Note: Add new Annexes B13 through B17.]

(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.)

ANNEX B13

COP DEGRADATION FACTOR (CDF) AS A FUNCTION OF PART-LOAD RATIO (PLR)

B13.1 Derivation of CDF Based on Performance Data

Per the equipment manufacturer (D Cawley),

CDF = 1 - Cd(1-PLR), 0 <= PLR <= 1
CDF = 1, PLR => 1 (1)

where Cd is assumed constant for a given unit.

Cd can be determined from listed performance data using:

SEER = EERb (1 - 0.5Cd) which solves for Cd as,

Cd = (1 - SEER/EERb)/0.5 (2)

where EERb = (Adjusted Net Total Capacity)/(Cooling Energy Consumption) at EDB = 80 F, EWB = 67 F, ODB =82 F; listed SEER = 12.90

Adjusted Net Total Capacity (Qnetcap,adj) is used to account for fan heat assumed for gross capacity calculation being different from actual fan heat.

Note: The procedures for independently calculating Cd and EERb from measured data are given in ANSI/ARI 210/240-89.

Calculations to obtain EERb

Extrapolate performance based on manufacturer data (Qnetcap,list), for EDB = 80, EWB = 67.

	Total Capacities				
ODB (°F)	Qnetcap,list (kBtu/h)	Qnetcap,adj (kBtu/h)	Qcomp (kW)	Qfans (kW)	EER
90	27.6	27.9	1.79	0.34	13.13
85	28.4	28.7	1.71	0.34	14.03
					extrap
82					14.57

Eqn (2) implies Cd =	0.229

So for some points along the CDF f(PLR) linear curve using Equation (1)

PLR	CDF
1.0	1.000
0.9	0.977
0.8	0.954
0.7	0.931
0.6	0.908
0.5	0.885
0.4	0.862
0.3	0.840
0.2	0.817
0.1	0.794
0.0	0.771

cdfvplr.xls; May 14, 2001

For real equipment, the representation of Figure 10 is reasonable for PLR greater than or equal to approximately 0.1; for PLR less than or equal to approximately 0.1, Figure 10 indicates less efficiency degradation than that suggested by more detailed information.[A-7] However, real equipment that cycles ON/OFF has controls that prevent operation at PLR less than or equal to approximately 0.05. For the purpose of testing simulation software in the context of these analytical verification tests, Figure 10 is reasonable.

B13.2 PLR Definition Similarity

We have defined PLR in cases E100-E200 based on guidance from the equipment manufacturer as

$$PLR1 = Qnet / CAPnet$$

where

$$Qnet = \text{net refrigeration effect,}$$

$$CAPnet = \text{adjusted net total capacity.}$$

We wish to check the equivalence of defining PLR as

$$PLR2 = Qgtc / CAPgtc$$

where

$$Qgtc = \text{gross total coil load,}$$

$$CAPgtc = \text{gross total capacity.}$$

The net refrigeration effect = Qgtc – Qfan
where Qfan is the air distribution fan heat.

The adjusted net capacity = CAPgtc – Pfan
where Pfan = fan rated power.

Then, for PLR1 = PLR2 to be true implies

$$Qgtc / CAPgtc = (Qgtc - Qfan) / (CAPgtc - Pfan),$$

which is true if

$$Qfan / Pfan = Qgtc / CAPgtc,$$

that is, if the fan heat for a given period is the fan's run-time fraction for that period multiplied by the fan power, where Qgtc/CAPgtc inherently defines the required fraction of a time period that the evaporator coil is to be removing heat at a given capacity. The above relation is true if there is no additional fan run time (and fan heat) associated with additional compressor start-up run time, which occurs during part-load operation.

For cases E100-E200, because the indoor fan cycles on/off with the compressor, we originally defined the net refrigeration effect to subtract out fan heat for the time when the compressor is operating (which is longer than the time that the coil is actually removing heat at rated capacity).

For that situation, it is useful to think of

$$Qfan / Pfan = PLR / CDF.$$

However, this relation implies

$$Qfan / Pfan \neq Qgtc / CAPgtc$$

with the theoretical result that PLR1 ≠ PLR2.

An analysis of the difference between PLR1 and PLR2 and corresponding resultant CDF1 and CDF2 that could be used in evaluating part-load performance is shown below in the spreadsheet table. This analysis applies values of coil capacity and fan power for the equipment at ARI rating conditions. From this analysis we observe (see far right column of the spreadsheet table) that the resulting difference between CDF1 and CDF2 and, therefore, the compressor energy consumptions related to applying those CDFs, is <0.05%, which is negligible. Thus, we conclude that for the purpose of calculating CDF, either PLR1 or PLR2 may be used.

PLR2	CAPgtc (Btu/h)	Qgtc (Btu/h)	Pfan (Btu/h)	CDF2	Qfan (Btu/h)	Qfan/ Pfan	Qnet (Btu/h)	CAPnet (Btu/h)	PLR1= Qnet/ CAPnet	PLR2/ PLR1	PLR2 - PLR1	CDF1	CDF2/ CDF1
0.01	27920	279.2	785	0.7733	10	0.013	269	27135	0.0099	1.0086	0.0001	0.7733	1.00002511
0.1	27920	2792	785	0.7939	99	0.126	2693	27135	0.0992	1.0076	0.0008	0.7937	1.00021661
0.2	27920	5584	785	0.8168	192	0.245	5392	27135	0.1987	1.0065	0.0013	0.8165	1.00036385
0.3	27920	8376	785	0.8397	280	0.357	8096	27135	0.2983	1.0056	0.0017	0.8393	1.00045190
0.39	27920	10889	785	0.8603	356	0.453	10533	27135	0.3882	1.0047	0.0018	0.8599	1.00048772
0.4	27920	11168	785	0.8626	364	0.464	10804	27135	0.3982	1.0046	0.0018	0.8622	**1.00048942**
0.41	27920	11447	785	0.8649	372	0.474	11075	27135	0.4081	1.0045	0.0019	0.8645	1.00049068
0.42	27920	11726	785	0.8672	380	0.484	11346	27135	0.4181	1.0044	0.0019	0.8668	1.00049153
0.43	27920	12006	785	0.8695	388	0.495	11617	27135	0.4281	1.0044	0.0019	0.8690	1.00049195
0.435	27920	12145	785	**0.8706**	**392**	**0.500**	11753	27135	**0.4331**	**1.0043**	**0.0019**	**0.8702**	**1.00049201**
0.44	27920	12285	785	0.8718	396	0.505	11889	27135	0.4381	1.0043	0.0019	0.8713	1.00049197
0.45	27920	12564	785	0.8741	404	0.515	12160	27135	0.4481	1.0042	0.0019	0.8736	1.00049158
0.46	27920	12843	785	0.8763	412	0.525	12431	27135	0.4581	1.0041	0.0019	0.8759	1.00049079
0.47	27920	13122	785	0.8786	420	0.535	12703	27135	0.4681	1.0040	0.0019	0.8782	1.00048961
0.48	27920	13402	785	0.8809	428	0.545	12974	27135	0.4781	1.0039	0.0019	0.8805	1.00048804
0.5	27920	13960	785	0.8855	443	0.565	13517	27135	0.4981	1.0038	0.0019	0.8851	**1.00048378**
0.6	27920	16752	785	0.9084	518	0.661	16234	27135	0.5983	1.0029	0.0017	0.9080	1.00044129
0.7	27920	19544	785	0.9313	590	0.752	18954	27135	0.6985	1.0021	0.0015	0.9310	1.00036734
0.8	27920	22336	785	0.9542	658	0.838	21678	27135	0.7989	1.0014	0.0011	0.9539	1.00026658
0.9	27920	25128	785	0.9771	723	0.921	24405	27135	0.8994	1.0007	0.0006	0.9770	1.00014299
0.99	27920	27641	785	0.9977	779	0.992	26862	27135	0.9899	1.0001	0.0001	0.9977	1.00001508

Note regarding the above spreadsheet table: The total fan run-time fraction, including the additional start-up run time during which no or little cooling occurs, = PLR/CDF. Actually, fan heat should be slightly higher because the additional fan run time due to CDF creates a slight amount of additional fan heat that, in turn, causes slightly more additional run time. In accord with the analytical solution by Dresden University of Technology (discussed in informative Annex B17), the additional run time (fan heat) for mid-PLR Case E170 is 0.5% greater if this effect is taken into account. Since this is a 0.5% effect on a quantity that makes up at most 4% of the total coil load (i.e., 0.02% effect overall), then for the purpose of calculating CDF = f(PLR) we ignore it.

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ANNEX B14

COOLING COIL BYPASS FACTOR

B14.1 Introduction

Calculation techniques provided here are for illustrative purposes. Some models may have slight variations in the calculation, including the use of enthalpy ratios rather than dry-bulb temperature ratios in Equation B14-1 (below), or different specific heat assumptions for leaving air conditions in Equation B14-3 (below), among others.

Cooling coil BF can be thought of as the fraction of the distribution air that does not come into contact with the cooling coil; the remaining air is assumed to exit the coil at the average coil surface temperature (ADP). BF at ARI rating conditions is *approximately*

$$0.049 \leq BF \leq 0.080.$$

The uncertainty surrounding this value is illustrated in the two examples for calculating BF from given manufacturer data that are included in the rest of this annex, as well as from separate calculation results by Technische Universität Dresden (TUD). The uncertainty can be traced to the calculated ADP (56.2°F) being different from the ADP listed by the manufacturer (56.8°F). Because we have been unable to acquire the manufacturer's specific method for determining ADP, we have not been able to determine which ADP number is better. However, the manufacturer has indicated that performance data are only good to within 5% of real equipment performance. So we can hypothesize that the listed versus calculated ADP disagreements could be a consequence of the development of separate correlation equations for each performance parameter within the range of experimental uncertainty. Based on simulation sensitivity tests with DOE-2.1E, the above range of BF inputs causes total electricity consumption to vary by ±1%.

Calculations based on the listed performance data indicate that BF varies as a function of EDB, EWB, and ODB. Incorporate this aspect of equipment performance into your model if your software allows it, using a consistent method for developing all points of the BF variation map. (Note that sensitivity tests for cases E100–E200 using DOE-2.1E indicate that assuming a constant value of BF—versus allowing BF to vary as a function of EWB and ODB—adds an additional ±1% uncertainty to the total energy consumption results for Case E185 and less for the other cases.)

The equipment manufacturer recommends modeling the BF as independent of (*not* varying with) the PLR. This is because the airflow rate over the cooling coil is assumed constant when the compressor is operating (fan cycles on/off with compressor).

B14.2 Calculation of Coil Bypass Factor

B14.2.1 Nomenclature

ADP	apparatus dew point (°F)
BF	bypass factor (dimensionless)
cp_a	specific heat of dry air (Btu/lb°F)
cp_w	specific heat of water vapor (Btu/lb°F)
h_1	enthalpy of air entering cooling coil (Btu/lb dry air)
h_2	enthalpy of air leaving cooling coil (Btu/lb dry air)
q_s	gross sensible capacity (Btu/h)
q_T	gross total capacity (Btu/h)
Q	indoor fan airflow rate (ft^3/min)
T_{db1}	entering dry-bulb temperature (°F)
T_{db2}	leaving dry-bulb temperature (°F)
T_{wb1}	entering wet-bulb temperature (°F)
w	humidity ratio (lb water vapor/lb dry air)
ρ_r	density of standard dry air at fan rating conditions (0.075 lb/ft^3)

B14.2.2 Known Information

Air-Conditioning and Refrigeration Institute (ARI) Conditions:

- T_{db1} = 80°F
- T_{wb1} = 67°F.

From Table 26d at ARI conditions:

- Q = 900 ft^3/min
- q_s = 21700 Btu/h (gross sensible capacity)
- q_T = 27900 Btu/h (gross total capacity)
- ADP = 56.8°F.

B14.2.3 Governing Equations

$$BF = (T_{db2} - ADP)/(T_{db1} - ADP) \qquad \text{(Eq. B14-1)}^{A-8}$$

The following equations and related properties are commonly used approximations for working with volumetric flow rates.[A-9]

$$q_T = \rho_r\, Q\, (60\ \text{min/h})\, (h_1 - h_2) \qquad \text{(Eq. B14-2)}$$

$$q_s = \rho_r\, Q\, (60\ \text{min/h})\, (cp_a + cp_w(w))\, (T_{db1} - T_{db2}) \qquad \text{(Eq. B14-3)}$$

$$\rho_r = 0.075\ \text{lb/ft}^3$$

$$cp_a = 0.24\ \text{Btu/lb°F}$$

$$cp_w = 0.45\ \text{Btu/lb°F}$$

$$w \approx 0.01\ \text{lb water vapor/lb dry air.}$$

So for these English units, Equations (B14-2) and (B14-3) become:

$$q_T = 4.5\, Q\, (h_1 - h_2) \qquad \text{(Eq. B14-2a)}$$

$$q_s = 1.10\, Q\, (T_{db1} - T_{db2}) \qquad \text{(Eq. B14-3a)}$$

B14.2.4 Solution Technique Using ADP Calculated by Extending the Condition Line to the Saturation Curve.

To find ADP, extend the condition line of the system through the saturation curve on the psychrometric chart.[A-10] The condition line is the line going through coil entering conditions with slope determined by sensible heat ratio for the given operating conditions.[A-8] This example is illustrated on the psychrometric chart in Figure B14-2. To draw the condition line, State 2 must be determined; State 1 is ARI conditions (T_{db1} = 80.0°F, T_{wb1} = 67°F). Defining State 2 requires two independent properties that can be identified from Equations (B14-2) and (B14-3).

Solve for h_2 using Equation (B14-2) with q_T = 27,900 Btu/h and Q = 900 ft^3/min. From ideal gas equations commonly used for psychrometrics,[1] at ARI conditions h_1 = 31.45 Btu/lb dry air. These values applied to Equation (B14-2) give:

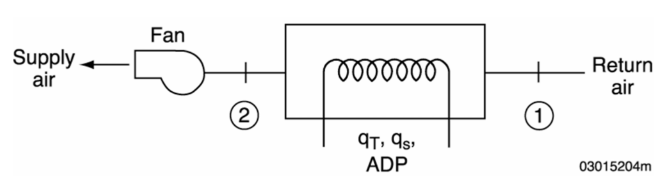

Figure B14-1 System schematic.

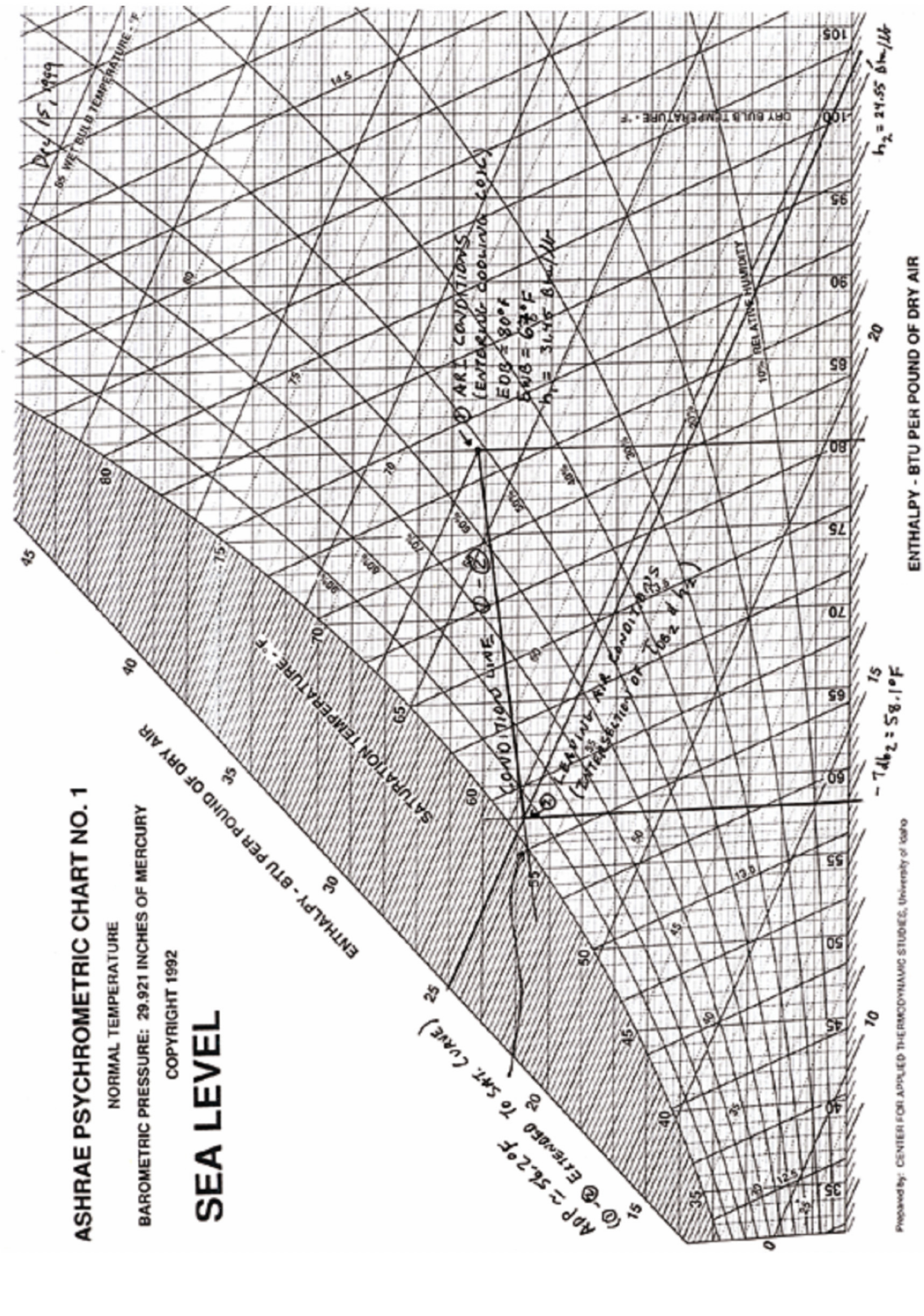

Figure B14-2 ADP calculation.

$$h_2 = 24.55 \text{ Btu/lb dry air.}$$

Solving for T_{db2} using Equation (B14-3) with T_{db1} = 80°F, q_s = 21700 Btu/h, and Q = 900 ft^3/min gives:

$$T_{db2} = 58.1°F.$$

On the psychrometric chart, drawing a line through these two states and extending it to the saturation curve gives:

$$ADP = 56.2°F.$$

Solving Equation (B14-1) using T_{db1} = 80°F, T_{db2} = 58.1°F, and ADP = 56.2°F gives:

BF = 0.080

B14.2.5 Solution Technique Using ADP Listed in Performance Data

Solving Equation (B14-1) using T_{db1} = 80°F, T_{db2} = 58.1°F, and *ADP = 56.8°F* gives:

BF = 0.055

B14.2.6 Solution by TUD

The TRNSYS-TUD modeler report in Part III of HVAC BESTEST[A-5] indicates that:

BF = 0.049

This solution is based on manufacturer-listed values of ADP.

B14.3 Conclusions

The BF for this system at ARI conditions is *approximately* in the range of:

$$0.049 \le BF \le 0.080$$

Some uncertainty is associated with the governing equations and related properties commonly used for calculating leaving air conditions; these equations are approximations. In addition, some uncertainty is associated with using the psychrometric chart to find the ADP (56.2°F) in the first solution. Finally, there may be additional uncertainty related to the methodology for developing ADP. For example, the results of Equation B14-1 can be slightly different if enthalpy ratios are used in place of dry bulb temperature ratios. Also, documentation of how the manufacturer calculated its listed ADP was unavailable, and the source code for manufacturer software used to develop catalog data is proprietary.

Based on sensitivity tests with DOE-2.1E:

- The above range of BF inputs causes total electricity consumption to vary by ±1%.
- Assuming a constant value of BF versus allowing BF to vary as a function of EWB and ODB adds an additional ±1% uncertainty to the total energy consumption results for Case E185, and less for the other cases.

(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.)

ANNEX B15

INDOOR FAN DATA EQUIVALENCE

Fan performance data for indoor fan power (230 W) and airflow rate (900 CFM = 0.425 m^3/s) are based on dry air at standard fan rating conditions. ASHRAE defines a standard condition as 1 atmosphere (101.325 kPa or 14.696 psi) and 68°F (20°C) with a density of 0.075 lb/ft^3 (1.204 kg/m^3).[A-9]

The fan efficiency of 0.5 is based on a discussion with the unitary system manufacturer.

The **total fan pressure** is based on:[A-11]

$$Eff = Q * \Delta P / W$$

where

$Q \equiv$ indoor fan airflow rate (m^3/s)

$\Delta P \equiv$ total fan pressure (Pa)

$W \equiv$ fan electric power input (W)

$Eff \equiv$ total fan plus motor and drive efficiency (motor/drive in air stream).

Solving for ΔP,

$$\Delta P = W * Eff / Q$$

$$= 230 \text{ W} * 0.5 / 0.425 \text{ m}^3/\text{s} = \mathbf{271\ Pa = \Delta P}.$$

The supply air temperature rise from fan heat is based on

$$q_{fan} = \rho * c_p * Q * \Delta T * C$$

where

$q_{fan} \equiv$ fan heat (Btu/h or W),

$\rho \equiv$ standard air density = 0.075 lb/ft^3 (1.204 kg/m^3),

$c_p \equiv$ specific heat of air (Btu/(lb°F) or kJ/(kgK)),

$Q \equiv$ indoor fan airflow rate (ft^3/min or m^3/s),

$\Delta T \equiv$ supply air temperature rise from fan heat (°F or °C),

$C \equiv$ units conversion constant.

Solving for ΔT,

$$\Delta T = q_{fan} / (\rho * c_p * Q * C)$$

where

q_{fan} = 230 W = 785 Btu/h; Q = 900 CFM = 0.425 m^3/s,

c_p = 0.24 Btu/lb F for dry air, or

c_p = 0.2445 Btu/lb F when humidity ratio = 0.01.[A-9]

Then, ΔT = 785 Btu/h / {0.075 lb/ft^3 * 900 ft^3/min * 60 min/h * 0.2445 Btu/(lb°F)}

ΔT = 0.793°F (0.441 °C)

or

for cp = 0.24 Btu/(lb°F), **ΔT = 0.808°F (0.449°C)**.

(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.)

ANNEX B16

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

B16.1 Introduction

The results from quasi-analytical solutions and various detailed building energy simulation programs applied to the tests of Section 5.3 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 quasi-analytical solution results and example simulation results has been included with the spreadsheet file RESULTS5-3.XLS in the accompanying files (available at http://www.ashrae.org/template/PDFDetail?assetID=34505). Spreadsheet navigation instructions are included in RESULTS5-3.DOC and have been printed out in informative Annex B10, Section B10.2 for convenience.

B16.2 Importance of 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 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 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 mis-entered one or more program inputs;
(b) problem with a particular algorithm in the program;
(c) one or more program algorithms used outside their intended range.

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.*[A-5]

B16.4 Nomenclature

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)
dry	dry coil
EDF	Electricité de France
Energy+	EnergyPlus 1.0.0.023 (see Table B17-1)
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

Space Cooling Electricity Consumption

Energy Consumption, Total (kWh,e)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	1531	1530	1521	1519	1520	1522	1512	1512	1531	1.2%	1531	1531	1531
E110	1077	1089	1061	1065	1069	1067	1062	1061	1089	2.6%	1076	1077	1077
E120	1012	1012	1011	1003	1006	1007	1002	1002	1012	1.0%	1013	1011	1011
E130	110	109	105	106	109	109	110	105	110	4.2%	111	110	110
E140	68	69	65	66	68	68	69	65	69	5.8%	69	69	68
E150	1208	1207	1202	1183	1197	1199	1192	1183	1208	2.1%	1206	1207	1207
E160	1140	1139	1138	1107	1132	1137	1133	1107	1140	2.9%	1140	1139	1139
E165	1502	1501	1499	1470	1491	1500	1490	1470	1502	2.1%	1498	1500	1500
E170	638	638	629	620	635	636	636	620	638	2.8%	641	638	638
E180	1083	1082	1077	1080	1082	1081	1080	1077	1083	0.5%	1083	1082	1082
E185	1544	1543	1541	1547	1540	1542	1538	1538	1547	0.6%	1545	1543	1543
E190	164	164	160	160	164	164	165	160	165	3.1%	165	164	164
E195	250	250	245	246	250	250	252	245	252	2.6%	252	250	250
E200	1477	1464	1468	1440	1465	1480	1480	1440	1480	2.7%	1476	1477	1477

Energy Consumption, Compressor (kWh,e)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	1319	1318	1307	1311		1311	1303	1303	1319	1.2%	1319	1319	1319
E110	889	899	866	883		879	876	866	899	3.7%	888	889	889
E120	840	840	850	838		836	832	832	850	2.2%	841	839	839
E130	95	94	93	93		94	95	93	95	2.1%	95	94	94
E140	57	57	55	56		56	57	55	57	3.9%	57	57	56
E150	1000	999	1007	982		992	987	982	1007	2.5%	999	999	999
E160	950	949	963	926		947	944	926	963	3.9%	950	949	949
E165	1283	1281	1291	1256		1280	1272	1256	1291	2.8%	1279	1280	1280
E170	531	530	539	523		528	529	523	539	3.0%	533	530	530
E180	909	908	914	912		907	906	906	914	0.9%	908	908	908
E185	1340	1339	1343	1344		1337	1334	1334	1344	0.7%	1340	1339	1338
E190	138	138	139	138		138	138	138	139	1.4%	138	138	138
E195	217	217	219	217		216	218	216	219	1.1%	219	217	217
E200	1250	1239	1249	1218		1253	1253	1218	1253	2.8%	1249	1250	1250

Energy Consumption, Supply Fan (kWh,e)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	144	144	145	141	144	144	142	141	145	2.9%	144	144	144
E110	128	129	133	122	128	128	127	122	133	8.5%	128	128	128
E120	117	117	110	110	116	117	115	110	117	6.3%	117	117	117
E130	10	10	8	8	10	10	10	8	10	23.0%	10	10	10
E140	8	8	7	6	8	8	8	6	8	26.9%	8	8	8
E150	141	141	133	136	140	141	139	133	141	5.7%	141	141	141
E160	129	129	119	121	128	129	128	119	129	7.8%	129	129	129
E165	149	150	142	145	149	149	148	142	150	5.6%	149	149	149
E170	73	73	61	63	73	73	73	61	73	16.1%	74	73	73
E180	118	119	111	112	118	118	118	111	119	6.9%	119	119	119
E185	139	139	135	137	139	139	139	135	139	3.0%	139	139	139
E190	18	18	14	14	18	18	18	14	18	22.8%	18	18	18
E195	23	23	18	18	23	23	23	18	23	23.1%	23	23	23
E200	154	153	149	151	153	155	155	149	155	3.5%	154	155	155

Energy Consumption, Condenser Fan (kWh,e)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	68	68	68	67		67	67	67	68	2.0%	68	68	68
E110	60	61	62	60		60	59	59	62	4.9%	60	60	60
E120	55	55	51	55		55	54	51	55	6.5%	55	55	55
E130	5	5	4	5		5	5	4	5	22.4%	5	5	5
E140	4	4	3	4		4	4	3	4	19.1%	4	4	4
E150	66	66	62	65		66	65	62	66	5.6%	66	66	66
E160	61	61	56	60		61	60	56	61	8.4%	61	61	61
E165	70	70	67	69		70	69	67	70	5.2%	70	70	70
E170	34	34	29	34		34	34	29	34	16.1%	35	34	34
E180	56	56	52	56		56	55	52	56	7.1%	56	56	56
E185	65	65	63	66		65	65	63	66	3.9%	65	65	65
E190	8	9	7	8		8	9	7	9	27.6%	9	9	9
E195	11	11	8	11		11	11	8	11	25.0%	11	11	11
E200	73	72	70	71		73	73	70	73	4.1%	73	73	73

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COP: Mean, and (Max-Min)/ Mean

Mean COP	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	2.39	2.39	2.43	2.41	2.40	2.40	2.42	2.39	2.43	1.7%	2.39	2.39	2.39
E110	3.38	3.34	3.46	3.41	3.40	3.41	3.43	3.34	3.46	3.5%	3.38	3.38	3.38
E120	3.59	3.59	3.61	3.62	3.61	3.61	3.63	3.59	3.63	1.2%	3.59	3.59	3.59
E130	1.91	1.91	1.98	1.95	1.90	1.92	1.92	1.90	1.98	3.8%	1.89	1.91	1.91
E140	2.77	2.73	2.92	2.85	2.77	2.80	2.80	2.73	2.92	6.6%	2.75	2.77	2.77
E150	3.62	3.63	3.67	3.70	3.65	3.65	3.67	3.62	3.70	2.2%	3.63	3.63	3.63
E160	3.84	3.84	3.87	3.95	3.86	3.85	3.86	3.84	3.95	2.9%	3.83	3.84	3.84
E165	2.92	2.92	2.95	2.99	2.94	2.93	2.94	2.92	2.99	2.2%	2.93	2.93	2.93
E170	3.38	3.39	3.44	3.48	3.40	3.39	3.40	3.38	3.48	2.9%	3.37	3.39	3.39
E180	4.04	4.04	4.08	4.03	4.04	4.05	4.06	4.03	4.08	1.4%	4.04	4.04	4.04
E185	2.85	2.85	2.87	2.82	2.85	2.85	2.86	2.82	2.87	1.8%	2.85	2.85	2.85
E190	3.41	3.41	3.49	3.46	3.39	3.41	3.40	3.39	3.49	2.7%	3.39	3.41	3.41
E195	2.31	2.31	2.36	2.34	2.30	2.32	2.31	2.30	2.36	2.5%	2.29	2.31	2.31
E200	3.62	3.61	3.67	3.71	3.65	3.61	3.61	3.61	3.71	2.7%	3.62	3.62	3.62

(Max - Min)/ Mean COP	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	0.000	0.001	0.002	0.001	0.003	0.000	0.000	0.000	0.003		0.000	0.000	0.000
E110	0.000	0.010	0.002	0.001	0.003	0.000	0.011	0.000	0.011		0.000	0.000	0.000
E120	0.000	0.004	0.001	0.001	0.003	0.000	0.012	0.000	0.012		0.000	0.000	0.000
E130	0.000	0.038	0.013	0.009	0.004	0.000	0.172	0.000	0.172		0.000	0.000	0.000
E140	0.000	0.056	0.011	0.019	0.004	0.000	0.204	0.000	0.204		0.000	0.000	0.000
E150	0.003	0.003	0.001	0.005	0.011	0.000	0.009	0.000	0.011		0.000	0.000	0.001
E160	0.003	0.005	0.001	0.003	0.011	0.000	0.010	0.000	0.011		0.000	0.000	0.000
E165	0.010	0.003	0.001	0.003	0.012	0.000	0.008	0.000	0.012		0.000	0.000	0.000
E170	0.000	0.006	0.002	0.004	0.015	0.000	0.043	0.000	0.043		0.000	0.000	0.000
E180	0.005	0.002	0.002	0.010	0.029	0.000	0.012	0.000	0.029		0.000	0.000	0.000
E185	0.007	0.004	0.002	0.010	0.034	0.000	0.009	0.000	0.034		0.000	0.000	0.000
E190	0.000	0.023	0.007	0.019	0.040	0.000	0.101	0.000	0.101		0.000	0.000	0.000
E195	0.000	0.017	0.008	0.017	0.043	0.000	0.086	0.000	0.086		0.000	0.000	0.000
E200	0.006	0.000	0.000	0.005	0.012	0.000	0.000	0.000	0.012		0.000	0.000	0.000

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Coil Loads: Total, Sensible, and Latent

Coil Load, Total (kWh,thermal)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		(Max-Min)		Analytical	
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	/ Analytical	TUD	HTAL1	HTAL2
E100	3800	3800	3841	3794	3798	3800	3798	3794	3841	1.3%	3800	3800	3800
E110	3765	3766	3804	3756	3763	3765	3763	3756	3804	1.3%	3765	3765	3765
E120	3749	3749	3763	3739	3747	3748	3747	3739	3763	0.6%	3749	3749	3749
E130	219	219	216	215	217	219	220	215	220	2.1%	219	219	219
E140	198	198	196	195	196	198	199	195	199	2.0%	198	198	197
E150	4517	4517	4543	4528	4509	4517	4515	4509	4543	0.8%	4518	4517	4518
E160	4501	4500	4516	4508	4491	4500	4499	4491	4516	0.6%	4501	4500	4500
E165	4538	4538	4567	4549	4529	4537	4535	4529	4567	0.9%	4537	4537	4538
E170	2233	2232	2226	2237	2225	2232	2232	2225	2237	0.5%	2232	2232	2233
E180	4495	4495	4510	4535	4481	4495	4494	4481	4535	1.2%	4495	4495	4494
E185	4507	4535	4565	4583	4523	4535	4534	4507	4583	1.7%	4535	4535	4534
E190	578	577	573	579	574	577	578	573	579	1.0%	578	577	578
E195	602	601	595	602	598	601	601	595	602	1.1%	601	601	601
E200	5498	5436	5534	5522	5484	5498	5498	5436	5534	1.8%	5498	5498	5498

Coil Load, Sensible (kWh,thermal)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		(Max-Min)		Analytical	
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	/ Analytical	TUD	HTAL1	HTAL2
E100	3800	3800	3841	3794	3798	3800	3798	3794	3841	1.3%	3800	3800	3800
E110	3765	3766	3804	3756	3763	3765	3763	3756	3804	1.3%	3765	3765	3765
E120	3749	3749	3763	3739	3747	3748	3747	3739	3763	0.6%	3749	3749	3749
E130	219	219	216	215	217	219	220	215	220	2.1%	219	219	219
E140	198	198	196	195	196	198	199	195	199	2.0%	198	198	197
E150	3778	3778	3804	3786	3776	3778	3776	3776	3804	0.7%	3778	3778	3779
E160	3761	3761	3777	3769	3759	3761	3760	3759	3777	0.5%	3761	3761	3761
E165	3798	3798	3828	3809	3795	3798	3796	3795	3828	0.9%	3798	3798	3799
E170	1493	1493	1487	1498	1491	1492	1492	1487	1498	0.7%	1493	1493	1493
E180	1537	1538	1553	1607	1537	1538	1537	1537	1607	4.5%	1538	1538	1538
E185	1548	1578	1608	1653	1577	1578	1577	1548	1653	6.6%	1578	1578	1578
E190	208	208	203	212	206	208	208	203	212	4.4%	208	208	208
E195	232	232	226	235	230	231	232	226	235	4.1%	232	232	232
E200	4276	4215	4313	4303	4274	4277	4277	4215	4313	2.3%	4277	4277	4277

Coil Load, Latent (kWh,thermal)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		(Max-Min)		Analytical	
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	/ Analytical	TUD	HTAL1	HTAL2
E100	0	0	0	0	0	0	0	0	0		0	0	0
E110	0	0	0	0	0	0	0	0	0		0	0	0
E120	0	0	0	0	0	0	0	0	0		0	0	0
E130	0	0	0	0	0	0	0	0	0		0	0	0
E140	0	0	0	0	0	0	0	0	0		0	0	0
E150	739	739	739	742	733	739	739	733	742	1.2%	739	739	739
E160	740	739	739	739	732	739	739	732	740	1.1%	739	739	739
E165	740	739	739	740	733	739	739	733	740	1.0%	739	739	739
E170	740	739	739	739	734	739	739	734	740	0.9%	739	739	739
E180	2958	2957	2957	2928	2944	2957	2957	2928	2958	1.0%	2957	2957	2956
E185	2959	2957	2957	2930	2946	2957	2957	2930	2959	1.0%	2958	2957	2956
E190	370	370	370	366	368	370	370	366	370	1.0%	370	370	370
E195	370	370	370	367	368	370	370	367	370	0.9%	370	370	370
E200	1222	1221	1221	1219	1210	1221	1221	1210	1222	1.0%	1221	1221	1221

results5-3.xls q:bc77..br147; 10/15/02

Sensible Coil - Zone Load, (Fan Heat) (kWh,thermal)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		(Max-Min)		Analytical	
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	/ Analytical	TUD	HTAL1	HTAL2
E100	144	144	187	139	144	144	142	139	187	33.6%	144	144	144
E110	128	129	168	119	128	128	127	119	168	38.2%	128	128	128
E120	117	117	133	108	116	117	115	108	133	21.8%	117	117	117
E130	10	10	8	8	10	10	10	8	10	26.7%	10	10	10
E140	8	8	7	6	8	8	8	6	8	25.0%	8	8	8
E150	141	141	168	149	140	141	139	139	168	20.2%	141	141	142
E160	129	129	147	137	129	129	128	128	147	14.3%	129	129	129
E165	149	149	181	161	149	149	148	148	181	22.4%	149	149	150
E170	73	73	69	79	73	73	73	69	79	14.2%	74	73	74
E180	117	118	135	188	119	118	118	117	188	60.2%	118	119	118
E185	109	139	171	215	140	139	139	109	215	76.6%	139	139	139
E190	18	18	15	24	18	18	18	15	24	51.1%	18	18	18
E195	23	23	18	28	23	23	23	18	28	40.7%	23	23	23
E200	154	153	193	181	154	155	155	153	193	25.7%	154	155	155

Zone Loads: Total, Sensible, and Latent

Zone Load, Total (kWh,thermal)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) /Analytical	Analytical TUD	HTAL1	HTAL2
E100	3656	3656	3654	3655	3654	3656	3656	3654	3656	0.1%	3656	3656	3656
E110	3637	3637	3636	3637	3636	3637	3637	3636	3637	0.0%	3637	3637	3637
E120	3632	3632	3630	3632	3631	3632	3631	3630	3632	0.0%	3632	3632	3632
E130	209	209	207	208	207	209	209	207	209	1.3%	209	209	209
E140	190	190	189	188	188	190	190	188	190	1.1%	190	190	190
E150	4376	4376	4375	4376	4375	4376	4376	4375	4376	0.0%	4376	4376	4376
E160	4371	4371	4370	4371	4370	4371	4371	4370	4371	0.0%	4371	4371	4371
E165	4388	4388	4386	4387	4386	4388	4387	4386	4388	0.0%	4388	4388	4388
E170	2159	2159	2157	2158	2157	2159	2159	2157	2159	0.1%	2159	2159	2159
E180	4376	4376	4375	4376	4375	4376	4376	4375	4376	0.0%	4376	4376	4376
E185	4396	4396	4394	4395	4393	4395	4395	4393	4396	0.1%	4396	4396	4396
E190	557	559	558	558	558	559	559	557	559	0.4%	559	559	559
E195	576	579	577	577	576	578	579	576	579	0.5%	579	579	579
E200	5343	5283	5342	5343	5342	5343	5343	5283	5343	1.1%	5343	5343	5343

Zone Load, Sensible (kWh,thermal)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) /Analytical	Analytical TUD	HTAL1	HTAL2
E100	3656	3656	3654	3655	3654	3656	3656	3654	3656	0.1%	3656	3656	3656
E110	3637	3637	3636	3637	3636	3637	3637	3636	3637	0.0%	3637	3637	3637
E120	3632	3632	3630	3632	3631	3632	3631	3630	3632	0.0%	3632	3632	3632
E130	209	209	207	208	207	209	209	207	209	1.3%	209	209	209
E140	190	190	189	188	188	190	190	188	190	1.1%	190	190	190
E150	3637	3637	3636	3637	3636	3637	3636	3636	3637	0.0%	3637	3637	3637
E160	3632	3632	3630	3632	3631	3632	3631	3630	3632	0.0%	3632	3632	3632
E165	3649	3649	3647	3648	3647	3649	3648	3647	3649	0.1%	3649	3649	3649
E170	1420	1420	1418	1419	1418	1419	1419	1418	1420	0.1%	1420	1420	1420
E180	1420	1420	1418	1419	1418	1419	1419	1418	1420	0.1%	1420	1420	1420
E185	1439	1439	1437	1437	1437	1438	1438	1437	1439	0.2%	1439	1439	1439
E190	190	190	188	188	188	190	190	188	190	1.0%	190	190	190
E195	209	209	207	208	207	209	209	207	209	1.1%	209	209	209
E200	4122	4062	4121	4122	4121	4122	4122	4062	4122	1.5%	4122	4122	4122

Zone Load, Latent (kWh,thermal)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) /Analytical	Analytical TUD	HTAL1	HTAL2
E100	0	0	0	0	0	0	0	0	0		0	0	0
E110	0	0	0	0	0	0	0	0	0		0	0	0
E120	0	0	0	0	0	0	0	0	0		0	0	0
E130	0	0	0	0	0	0	0	0	0		0	0	0
E140	0	0	0	0	0	0	0	0	0		0	0	0
E150	739	739	739	739	739	739	739	739	739	0.1%	739	739	739
E160	739	739	739	739	739	739	739	739	739	0.1%	739	739	739
E165	739	739	739	739	739	739	739	739	739	0.1%	739	739	739
E170	739	739	739	739	739	739	739	739	739	0.1%	739	739	739
E180	2957	2957	2957	2958	2957	2957	2957	2957	2958	0.0%	2957	2957	2957
E185	2957	2957	2957	2958	2957	2957	2957	2957	2958	0.0%	2957	2957	2957
E190	367	370	370	370	370	370	370	367	370	0.8%	370	370	370
E195	367	370	370	370	370	370	370	367	370	0.8%	370	370	370
E200	1221	1221	1221	1221	1221	1221	1221	1221	1221	0.0%	1221	1221	1221

results5-3.xls a:bt77..ch147; 10/15/02

Latent Coil - Zone Load, (Should be 0) (kWh,thermal)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) /Analytical	Analytical TUD	HTAL1	HTAL2
E100	0	0	0	0	0	0	0	0	0		0	0	0
E110	0	0	0	0	0	0	0	0	0		0	0	0
E120	0	0	0	0	0	0	0	0	0		0	0	0
E130	0	0	0	0	0	0	0	0	0		0	0	0
E140	0	0	0	0	0	0	0	0	0		0	0	0
E150	0	0	0	2	-7	0	0	-7	2		0	0	0
E160	1	0	0	0	-7	0	0	-7	1		0	0	0
E165	1	0	0	1	-6	0	0	-6	1		0	0	0
E170	1	0	0	-1	-6	0	0	-6	1		0	0	0
E180	1	0	0	-30	-13	0	0	-30	1		1	0	-1
E185	2	0	0	-28	-11	0	0	-28	2		1	0	-1
E190	3	0	0	-3	-2	0	0	-3	3		0	0	0
E195	3	0	0	-3	-1	0	0	-3	3		0	0	0
E200	1	0	0	-2	-11	0	0	-11	1		0	0	0

Sensitivities for Space Cooling Electricity Consumption

Delta Qtot (kWh,e)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		Abs(Max-	Analytical		
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	Min)/Analy.	TUD	HTAL1	HTAL2
E110-E100	-454	-441	-460	-454	-451	-455	-450	-460	-441	4.1%	-454	-454	-453
E120-E110	-65	-77	-50	-62	-63	-60	-60	-77	-50	42.3%	-64	-66	-66
E120-E100	-519	-518	-510	-516	-514	-515	-510	-519	-510	1.8%	-518	-520	-520
E130-E100	-1421	-1421	-1415	-1413	-1411	-1414	-1402	-1421	-1402	1.4%	-1420	-1421	-1421
E140-E130	-42	-40	-40	-40	-41	-41	-41	-42	-40	4.8%	-42	-41	-41
E140-E110	-1009	-1020	-996	-999	-1001	-999	-993	-1020	-993	2.6%	-1007	-1009	-1009
E150-E110	131	118	141	118	128	132	130	118	141	17.8%	130	129	129
E160-E150	-68	-68	-65	-76	-65	-62	-59	-76	-59	26.1%	-66	-67	-68
E165-E160	362	362	362	363	359	363	357	357	363	1.7%	357	360	361
E170-E150	-570	-569	-573	-563	-562	-563	-556	-573	-556	3.1%	-565	-569	-569
E180-E150	-125	-125	-125	-103	-115	-118	-112	-125	-103	18.0%	-124	-124	-125
E180-E170	445	444	448	460	447	445	444	444	460	3.6%	442	445	444
E185-E180	461	461	464	467	458	460	458	458	467	1.9%	462	461	461
E190-E180	-919	-918	-917	-920	-918	-917	-915	-920	-915	0.6%	-917	-918	-918
E190-E140	96	95	95	94	96	96	96	94	96	2.6%	96	96	96
E195-E190	86	86	85	86	86	86	86	85	86	2.0%	87	86	86
E195-E185	-1294	-1293	-1296	-1301	-1290	-1292	-1287	-1301	-1287	1.1%	-1292	-1293	-1293
E195-E130	140	141	140	140	142	141	141	140	142	1.5%	142	141	141
E200-E100	-54	-66	-53	-79	-55	-42	-32	-79	-32	86.0%	-55	-53	-54

Del Qcomp (kWh,e)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		Abs(Max-	Analytical		
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	Min)/Analy.	TUD	HTAL1	HTAL2
E110-E100	-430	-419	-442	-428		-432	-427	-442	-419	5.2%	-431	-430	-430
E120-E110	-49	-59	-16	-45		-43	-44	-59	-16	91.8%	-47	-50	-50
E120-E100	-479	-478	-457	-473		-475	-471	-479	-457	4.5%	-478	-480	-480
E130-E100	-1224	-1224	-1214	-1218		-1218	-1208	-1224	-1208	1.3%	-1224	-1225	-1225
E140-E130	-38	-37	-38	-37		-38	-38	-38	-37	3.6%	-38	-38	-38
E140-E110	-832	-842	-811	-827		-823	-819	-842	-811	3.7%	-831	-833	-833
E150-E110	111	100	141	99		113	111	99	141	38.0%	111	110	110
E160-E150	-50	-50	-44	-56		-45	-42	-56	-42	28.0%	-49	-50	-50
E165-E160	333	332	329	330		333	328	328	333	1.6%	328	331	331
E170-E150	-469	-469	-468	-459		-464	-458	-469	-458	2.3%	-466	-469	-469
E180-E150	-91	-91	-93	-70		-85	-80	-93	-70	25.1%	-91	-91	-92
E180-E170	378	378	375	389		379	378	375	389	3.7%	375	378	378
E185-E180	431	431	428	432		430	428	428	432	0.9%	432	431	431
E190-E180	-771	-770	-775	-774		-770	-768	-775	-768	0.9%	-770	-770	-770
E190-E140	81	81	85	82		82	82	81	85	4.4%	82	81	81
E195-E190	79	79	79	79		79	80	79	80	0.8%	80	79	79
E195-E185	-1123	-1122	-1124	-1127		-1120	-1116	-1127	-1116	1.0%	-1121	-1122	-1121
E195-E130	122	123	126	124		123	123	122	126	3.0%	123	122	123
E200-E100	-69	-79	-58	-93		-58	-50	-93	-50	61.6%	-70	-69	-69

Del Q IDfan (kWh,e)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		Abs(Max-	Analytical		
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	Min)/Analy.	TUD	HTAL1	HTAL2
E110-E100	-16	-15	-12	-19	-16	-16	-16	-19	-12	42.3%	-16	-16	-16
E120-E110	-11	-12	-23	-12	-11	-11	-11	-23	-11	110.0%	-11	-11	-11
E120-E100	-27	-27	-36	-31	-27	-27	-27	-36	-27	32.2%	-27	-27	-27
E130-E100	-134	-134	-137	-133	-133	-133	-132	-137	-132	3.7%	-134	-134	-134
E140-E130	-2	-2	-1	-2	-2	-2	-2	-2	-1	36.8%	-2	-2	-2
E140-E110	-120	-121	-126	-116	-119	-120	-118	-126	-116	8.3%	-120	-120	-120
E150-E110	13	12	0	14	13	13	13	0	14	107.0%	13	13	13
E160-E150	-12	-12	-14	-15	-12	-12	-11	-15	-11	32.6%	-12	-12	-12
E165-E160	20	21	23	24	20	20	20	20	24	21.8%	20	20	20
E170-E150	-68	-68	-72	-73	-67	-68	-66	-73	-66	9.7%	-68	-68	-68
E180-E150	-23	-22	-22	-24	-22	-22	-21	-24	-21	12.1%	-22	-23	-23
E180-E170	45	46	49	49	45	45	45	45	49	9.9%	45	45	45
E185-E180	21	20	24	25	21	21	21	20	25	24.3%	21	21	21
E190-E180	-100	-101	-97	-98	-100	-100	-100	-101	-97	4.3%	-101	-101	-101
E190-E140	10	10	7	8	10	10	10	7	10	28.1%	10	10	10
E195-E190	5	5	4	4	5	5	5	4	5	30.6%	5	5	5
E195-E185	-116	-116	-117	-119	-116	-117	-116	-119	-116	2.6%	-117	-117	-117
E195-E130	13	13	9	10	12	12	12	9	13	28.9%	12	12	12
E200-E100	10	9	4	10	10	11	12	4	12	79.1%	10	11	11

Del Q ODfan (kWh,e)	CA-SIS	CLM2000	DOE21E	DOE21E	Energy+	TRN-id	TRN-re	Statistics, All Results		Abs(Max-	Analytical		
	EDF	EDF	CIEMAT	NREL	GARD	TUD	TUD	Min	Max	Min)/Analy.	TUD	HTAL1	HTAL2
E110-E100	-8	-7	-6	-7		-7	-7	-8	-6	29.9%	-7	-7	-7
E120-E110	-5	-6	-11	-5		-5	-5	-11	-5	113.1%	-5	-5	-5
E120-E100	-13	-13	-17	-12		-13	-13	-17	-12	37.0%	-13	-13	-13
E130-E100	-63	-63	-64	-62		-63	-62	-64	-62	3.7%	-63	-63	-63
E140-E130	-1	-1	-1	-1		-1	-1	-1	-1	36.8%	-1	-1	-1
E140-E110	-56	-57	-59	-56		-56	-56	-59	-56	6.3%	-56	-56	-56
E150-E110	6	5	0	5		6	6	0	6	100.8%	6	6	6
E160-E150	-5	-5	-7	-5		-6	-5	-7	-5	27.0%	-6	-6	-6
E165-E160	9	9	11	9		10	9	9	11	17.5%	9	9	9
E170-E150	-32	-32	-34	-31		-32	-31	-34	-31	8.2%	-32	-32	-32
E180-E150	-10	-10	-10	-9		-11	-10	-11	-9	14.3%	-11	-11	-11
E180-E170	22	22	23	22		21	21	21	23	9.6%	21	21	21
E185-E180	9	9	11	10		10	10	9	11	24.6%	10	10	10
E190-E180	-48	-47	-45	-48		-47	-47	-48	-45	5.5%	-47	-47	-47
E190-E140	4	5	3	4		5	5	3	5	34.6%	5	5	5
E195-E190	3	2	2	3		2	2	2	3	60.5%	2	2	2
E195-E185	-54	-54	-55	-55		-55	-54	-55	-54	2.0%	-55	-55	-55
E195-E130	6	6	4	6		6	6	4	6	27.1%	6	6	6
E200-E100	5	4	2	4		5	6	2	6	79.1%	5	5	5

results5-3.xls q:ck491..cz580; 10/15/02

Sensitivities for COP and Coil Loads

Delta COP (kWh,t)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	Abs(Max-Min)/Analy.	Analytical TUD	HTAL1	HTAL2
E110-E100	0.99	0.95	1.03	1.01	1.00	1.01	1.01	0.95	1.03	7.6%	0.99	0.99	0.99
E120-E110	0.21	0.25	0.16	0.21	0.21	0.20	0.20	0.16	0.25	44.9%	0.21	0.21	0.21
E120-E100	1.20	1.20	1.18	1.22	1.20	1.20	1.21	1.18	1.22	2.8%	1.20	1.20	1.20
E130-E100	-0.48	-0.48	-0.46	-0.45	-0.50	-0.48	-0.50	-0.50	-0.45	9.8%	-0.50	-0.48	-0.48
E140-E130	0.86	0.83	0.94	0.90	0.87	0.88	0.88	0.83	0.94	13.3%	0.86	0.86	0.86
E140-E110	-0.61	-0.61	-0.54	-0.56	-0.63	-0.61	-0.63	-0.63	-0.54	13.6%	-0.63	-0.61	-0.61
E150-E110	0.24	0.29	0.21	0.29	0.25	0.24	0.25	0.21	0.29	32.0%	0.25	0.25	0.25
E160-E150	0.22	0.21	0.20	0.25	0.21	0.20	0.19	0.19	0.25	30.9%	0.21	0.21	0.21
E165-E160	-0.92	-0.92	-0.91	-0.96	-0.92	-0.92	-0.92	-0.96	-0.91	5.6%	-0.90	-0.91	-0.91
E170-E150	-0.24	-0.24	-0.23	-0.22	-0.26	-0.26	-0.27	-0.27	-0.22	18.1%	-0.26	-0.24	-0.24
E180-E150	0.42	0.41	0.42	0.33	0.39	0.40	0.38	0.33	0.42	22.6%	0.42	0.41	0.41
E180-E170	0.66	0.65	0.64	0.55	0.65	0.65	0.65	0.55	0.66	16.4%	0.68	0.65	0.65
E185-E180	-1.19	-1.19	-1.21	-1.20	-1.19	-1.20	-1.20	-1.21	-1.19	1.7%	-1.20	-1.19	-1.19
E190-E180	-0.63	-0.63	-0.60	-0.57	-0.65	-0.64	-0.65	-0.65	-0.57	12.4%	-0.66	-0.63	-0.63
E190-E140	0.64	0.68	0.57	0.60	0.62	0.61	0.61	0.57	0.68	16.4%	0.64	0.64	0.64
E195-E190	-1.10	-1.10	-1.13	-1.12	-1.09	-1.09	-1.10	-1.13	-1.09	3.3%	-1.09	-1.10	-1.10
E195-E185	-0.54	-0.54	-0.51	-0.49	-0.55	-0.54	-0.55	-0.55	-0.49	12.0%	-0.55	-0.54	-0.54
E195-E130	0.40	0.40	0.38	0.38	0.40	0.40	0.39	0.38	0.40	4.2%	0.40	0.40	0.40
E200-E100	1.23	1.22	1.24	1.30	1.24	1.21	1.19	1.19	1.30	8.9%	1.23	1.23	1.23

Del Q coil,t (kWh,t)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	Abs(Max-Min)/Analy.	Analytical TUD	HTAL1	HTAL2
E110-E100	-35	-34	-38	-38	-35	-35	-35	-38	-34	12.5%	-35	-35	-35
E120-E110	-16	-17	-40	-16	-16	-16	-16	-40	-16	147.5%	-16	-16	-17
E120-E100	-51	-51	-78	-55	-51	-51	-51	-78	-51	52.9%	-51	-52	-52
E130-E100	-3581	-3581	-3626	-3579	-3581	-3581	-3578	-3626	-3578	1.3%	-3581	-3581	-3581
E140-E130	-21	-21	-20	-21	-21	-21	-21	-21	-20	5.0%	-21	-21	-22
E140-E110	-3567	-3568	-3608	-3561	-3567	-3567	-3565	-3608	-3561	1.3%	-3567	-3567	-3568
E150-E110	752	751	739	772	746	752	752	739	772	4.4%	752	752	753
E160-E150	-16	-17	-26	-19	-18	-17	-16	-26	-16	61.3%	-17	-17	-18
E165-E160	37	38	51	40	38	37	36	36	51	40.8%	36	37	38
E170-E150	-2284	-2285	-2317	-2291	-2284	-2285	-2283	-2317	-2283	1.5%	-2285	-2286	-2286
E180-E150	-22	-22	-33	7	-28	-22	-21	-33	7	178.9%	-22	-23	-25
E180-E170	2262	2263	2284	2298	2256	2263	2262	2256	2298	1.8%	2263	2263	2261
E185-E180	12	40	55	48	41	40	40	12	55	107.7%	40	40	40
E190-E180	-3917	-3918	-3937	-3956	-3907	-3917	-3916	-3956	-3907	1.3%	-3918	-3918	-3916
E190-E140	380	379	377	384	378	380	379	377	384	1.8%	380	379	380
E195-E190	24	24	23	23	23	24	24	23	24	5.7%	24	24	24
E195-E185	-3905	-3934	-3970	-3981	-3925	-3934	-3933	-3981	-3905	1.9%	-3934	-3934	-3933
E195-E130	383	382	379	387	381	382	382	379	387	1.9%	382	382	382
E200-E100	1698	1636	1693	1728	1687	1698	1700	1636	1728	5.4%	1697	1697	1697

Del Q coil,s (kWh,t)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	Abs(Max-Min)/Analy.	Analytical TUD	HTAL1	HTAL2
E110-E100	-35	-34	-38	-38	-35	-35	-35	-38	-34	12.5%	-35	-35	-35
E120-E110	-16	-17	-40	-16	-16	-16	-16	-40	-16	147.5%	-16	-16	-17
E120-E100	-51	-51	-78	-55	-51	-51	-51	-78	-51	52.9%	-51	-52	-52
E130-E100	-3581	-3581	-3626	-3579	-3581	-3581	-3578	-3626	-3578	1.3%	-3581	-3581	-3581
E140-E130	-21	-21	-20	-21	-21	-21	-21	-21	-20	5.0%	-21	-21	-22
E140-E110	-3567	-3568	-3608	-3561	-3567	-3567	-3565	-3608	-3561	1.3%	-3567	-3567	-3568
E150-E110	13	12	0	30	13	13	13	0	30	232.9%	13	13	14
E160-E150	-17	-17	-26	-17	-17	-17	-16	-26	-16	60.3%	-17	-17	-18
E165-E160	37	37	51	40	36	37	36	36	51	40.8%	36	37	38
E170-E150	-2285	-2285	-2317	-2288	-2285	-2285	-2283	-2317	-2283	1.5%	-2285	-2286	-2286
E180-E150	-2241	-2240	-2250	-2179	-2239	-2240	-2239	-2250	-2179	3.2%	-2241	-2240	-2241
E180-E170	44	45	66	109	46	45	45	44	109	145.3%	45	45	45
E185-E180	11	40	55	46	39	40	40	11	55	110.3%	40	40	40
E190-E180	-1329	-1330	-1350	-1394	-1331	-1330	-1329	-1394	-1329	4.9%	-1330	-1330	-1330
E190-E140	10	10	7	18	10	10	9	7	18	102.7%	10	10	11
E195-E190	24	24	23	23	23	24	24	23	24	5.7%	24	24	24
E195-E185	-1316	-1346	-1382	-1418	-1347	-1346	-1345	-1418	-1316	7.6%	-1346	-1347	-1346
E195-E130	13	13	10	20	13	12	12	10	20	81.9%	12	12	12
E200-E100	476	415	472	509	477	477	479	415	509	19.7%	476	476	476

Del Qcoil,lat (kWh,t)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	Abs(Max-Min)/Analy.	Analytical TUD	HTAL1	HTAL2
E110-E100	0	0	0	0	0	0	0	0	0		0	0	0
E120-E110	0	0	0	0	0	0	0	0	0		0	0	0
E120-E100	0	0	0	0	0	0	0	0	0		0	0	0
E130-E100	0	0	0	0	0	0	0	0	0		0	0	0
E140-E130	0	0	0	0	0	0	0	0	0		0	0	0
E140-E110	0	0	0	0	0	0	0	0	0		0	0	0
E150-E110	739	739	739	742	733	739	739	733	742	1.2%	739	739	739
E160-E150	1	0	0	-2	-1	0	0	-2	1		0	0	0
E165-E160	0	0	0	1	1	0	0	0	1		0	0	0
E170-E150	1	0	0	-3	1	0	0	-3	1		0	0	0
E180-E150	2219	2218	2218	2186	2211	2218	2218	2186	2219	1.5%	2218	2218	2217
E180-E170	2218	2218	2218	2189	2210	2218	2218	2189	2218	1.3%	2218	2218	2217
E185-E180	1	0	0	2	2	0	0	0	2		0	0	0
E190-E180	-2588	-2587	-2587	-2562	-2576	-2587	-2587	-2588	-2562	1.0%	-2588	-2587	-2586
E190-E140	370	370	370	366	368	370	370	366	370	1.0%	370	370	370
E195-E190	0	0	0	0	0	0	0	0	0		0	0	0
E195-E185	-2589	-2587	-2587	-2563	-2578	-2587	-2587	-2589	-2563	1.0%	-2588	-2587	-2587
E195-E130	370	370	370	367	368	370	370	367	370	0.9%	370	370	370
E200-E100	1222	1221	1221	1219	1210	1221	1221	1210	1222	1.0%	1221	1221	1221

results5-3.xls q:db491..dq580; 10/15/02

Indoor Drybulb Temperature: Mean and (Max-Min)/Mean

Mean IDB (°C)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	22.2	22.2	22.3	22.3	22.2	22.2	22.6	22.2	22.6	2.0%	22.2	22.2	22.2
E110	22.2	22.2	22.3	22.3	22.2	22.2	22.5	22.2	22.5	1.5%	22.2	22.2	22.2
E120	26.7	26.7	26.8	26.7	26.7	26.7	27.1	26.7	27.1	1.4%	26.7	26.7	26.7
E130	22.2	22.2	22.1	22.1	22.2	22.2	21.6	21.6	22.2	2.5%	22.2	22.2	22.2
E140	22.2	22.2	22.1	22.1	22.2	22.2	21.5	21.5	22.2	3.1%	22.2	22.2	22.2
E150	22.2	22.2	22.3	22.3	22.2	22.2	22.7	22.2	22.7	2.1%	22.2	22.2	22.2
E160	26.7	26.7	26.8	26.7	26.7	26.7	27.0	26.7	27.0	1.1%	26.7	26.7	26.7
E165	23.3	23.3	23.4	23.4	23.3	23.3	23.8	23.3	23.8	2.1%	23.3	23.3	23.3
E170	22.2	22.2	22.2	22.2	22.2	22.2	22.1	22.1	22.2	0.5%	22.2	22.2	22.2
E180	22.2	22.2	22.3	22.3	22.2	22.2	22.3	22.2	22.3	0.6%	22.2	22.2	22.2
E185	22.2	22.2	22.3	22.3	22.2	22.2	22.4	22.2	22.4	0.8%	22.2	22.2	22.2
E190	22.2	22.2	22.1	22.1	22.2	22.2	21.9	21.9	22.2	1.1%	22.2	22.2	22.2
E195	22.2	22.2	22.1	22.1	22.2	22.2	22.0	22.0	22.2	0.9%	22.2	22.2	22.2
E200	26.7	26.7	26.8	26.8	26.7	26.7	26.7	26.7	26.8	0.4%	26.7	26.7	26.7

(Max - Min)/Mean IDB (°C)	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.000	0.049		0.000	0.000	0.002
E110	0.000	0.000	0.000	0.000	0.000	0.000	0.048	0.000	0.048		0.000	0.000	0.002
E120	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.000	0.077		0.000	0.000	0.002
E130	0.000	0.000	0.000	0.000	0.000	0.000	0.056	0.000	0.056		0.000	0.000	0.001
E140	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.000	0.069		0.000	0.000	0.002
E150	0.000	0.000	0.000	0.000	0.000	0.000	0.054	0.000	0.054		0.000	0.000	0.002
E160	0.000	0.000	0.000	0.000	0.000	0.000	0.045	0.000	0.045		0.000	0.000	0.002
E165	0.000	0.000	0.000	0.000	0.000	0.000	0.051	0.000	0.051		0.000	0.000	0.002
E170	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.050		0.000	0.000	0.001
E180	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.035		0.000	0.000	0.001
E185	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.021		0.000	0.000	0.001
E190	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.000	0.028		0.000	0.000	0.001
E195	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.023		0.000	0.000	0.001
E200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000

Humidity Ratio: Mean and (Max-Min)/Mean

Mean Humidity Ratio	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	0.0075	0.0069	0.0076	0.0074	0.0075	0.0075	0.0075	0.0069	0.0076	9.3%	0.0074	0.0073	0.0073
E110	0.0066	0.0069	0.0070	0.0064	0.0066	0.0066	0.0066	0.0064	0.0070	9.7%	0.0065	0.0064	0.0064
E120	0.0080	0.0070	0.0078	0.0078	0.0080	0.0080	0.0080	0.0070	0.0080	13.2%	0.0079	0.0079	0.0079
E130	0.0075	0.0069	0.0076	0.0073	0.0075	0.0075	0.0075	0.0069	0.0076	9.3%	0.0074	0.0073	0.0073
E140	0.0065	0.0069	0.0071	0.0064	0.0066	0.0066	0.0066	0.0064	0.0071	10.1%	0.0065	0.0064	0.0064
E150	0.0083	0.0085	0.0082	0.0083	0.0084	0.0083	0.0085	0.0082	0.0085	4.0%	0.0082	0.0082	0.0082
E160	0.0102	0.0101	0.0097	0.0099	0.0103	0.0101	0.0102	0.0097	0.0103	5.8%	0.0100	0.0099	0.0099
E165	0.0093	0.0099	0.0090	0.0092	0.0094	0.0093	0.0095	0.0090	0.0099	9.1%	0.0093	0.0092	0.0092
E170	0.0106	0.0107	0.0105	0.0105	0.0106	0.0105	0.0105	0.0105	0.0107	2.2%	0.0104	0.0105	0.0105
E180	0.0164	0.0164	0.0166	0.0164	0.0162	0.0163	0.0164	0.0162	0.0166	2.6%	0.0162	0.0162	0.0162
E185	0.0162	0.0171	0.0164	0.0162	0.0161	0.0162	0.0163	0.0161	0.0171	6.4%	0.0161	0.0161	0.0161
E190	0.0160	0.0161	0.0163	0.0159	0.0159	0.0159	0.0157	0.0157	0.0163	3.5%	0.0158	0.0159	0.0159
E195	0.0156	0.0164	0.0158	0.0155	0.0154	0.0155	0.0153	0.0153	0.0164	7.0%	0.0154	0.0154	0.0154
E200	0.0114	0.0115	0.0109	0.0111	0.0115	0.0113	0.0113	0.0109	0.0115	5.1%	0.0111	0.0111	0.0111

(Max - Min)/Mean Humidity Ratio	CA-SIS EDF	CLM2000 EDF	DOE21E CIEMAT	DOE21E NREL	Energy+ GARD	TRN-id TUD	TRN-re TUD	Statistics, All Results Min	Max	(Max-Min) / Analytical	Analytical TUD	HTAL1	HTAL2
E100	0.000	0.022	0.000	0.000	0.001	0.000	0.000	0.0000	0.0217		0.000	0.000	0.000
E110	0.000	0.022	0.014	0.000	0.000	0.000	0.000	0.0000	0.0217		0.000	0.000	0.000
E120	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.0000	0.0005		0.000	0.000	0.000
E130	0.000	0.010	0.000	0.000	0.001	0.000	0.000	0.0000	0.0101		0.000	0.000	0.000
E140	0.000	0.012	0.014	0.000	0.001	0.000	0.000	0.0000	0.0142		0.000	0.000	0.000
E150	0.012	0.000	0.000	0.000	0.013	0.000	0.013	0.0000	0.0132		0.000	0.000	0.000
E160	0.020	0.000	0.010	0.010	0.013	0.000	0.011	0.0000	0.0196		0.000	0.000	0.000
E165	0.011	0.001	0.011	0.000	0.013	0.000	0.013	0.0000	0.0131		0.000	0.000	0.000
E170	0.000	0.000	0.010	0.000	0.011	0.000	0.024	0.0000	0.0238		0.000	0.000	0.001
E180	0.018	0.000	0.012	0.012	0.010	0.000	0.040	0.0000	0.0402		0.000	0.000	0.001
E185	0.012	0.006	0.018	0.012	0.011	0.000	0.025	0.0000	0.0246		0.000	0.000	0.001
E190	0.000	0.000	0.018	0.019	0.014	0.000	0.031	0.0000	0.0312		0.000	0.000	0.001
E195	0.000	0.006	0.019	0.019	0.014	0.000	0.024	0.0000	0.0241		0.000	0.000	0.001
E200	0.018	0.000	0.009	0.009	0.013	0.000	0.000	0.0000	0.0175		0.000	0.000	0.000

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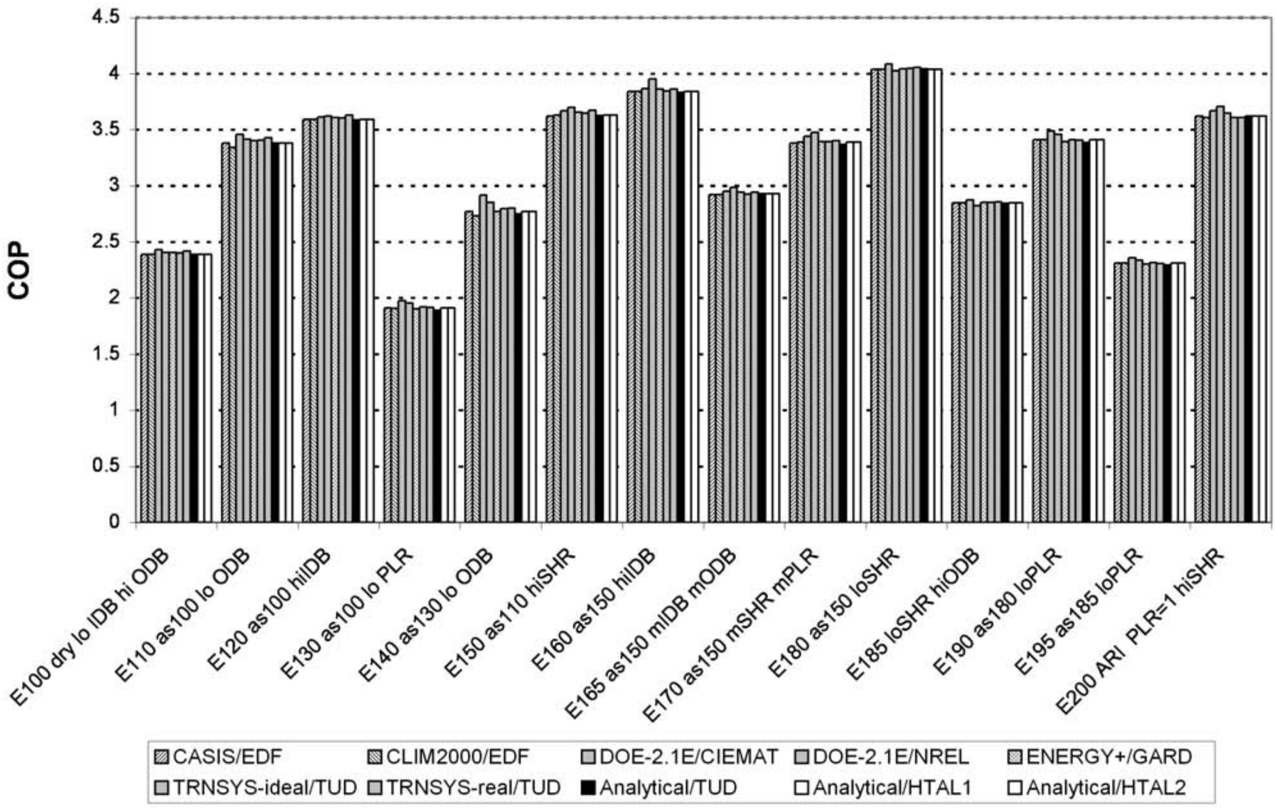
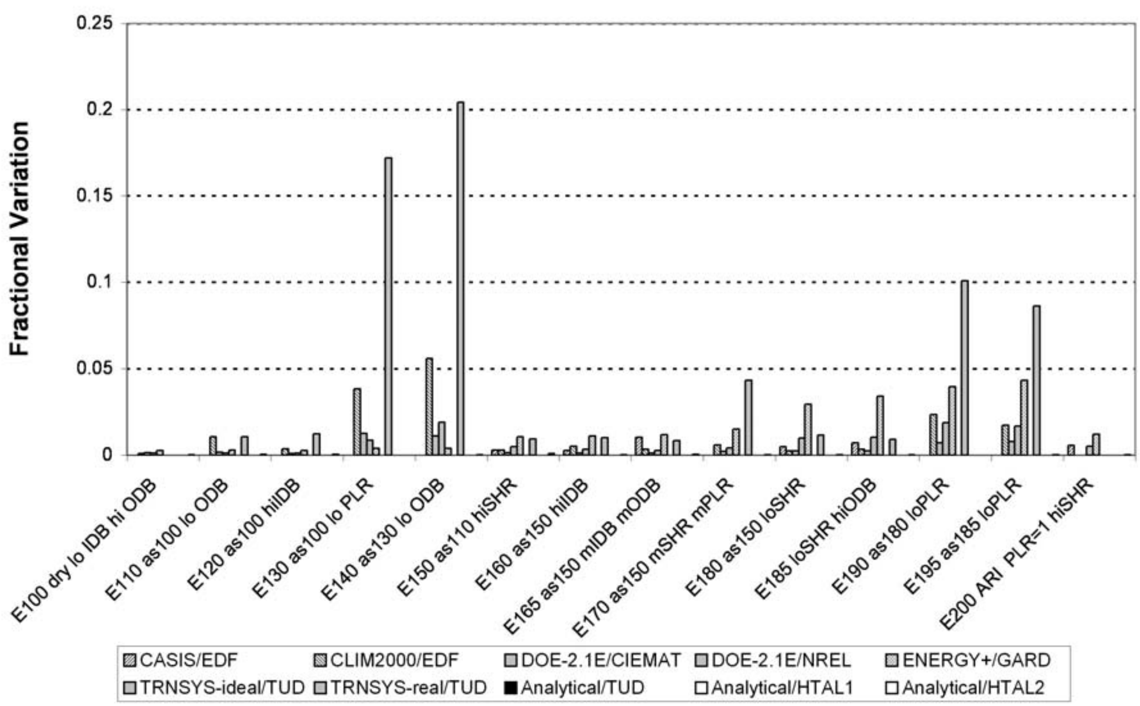
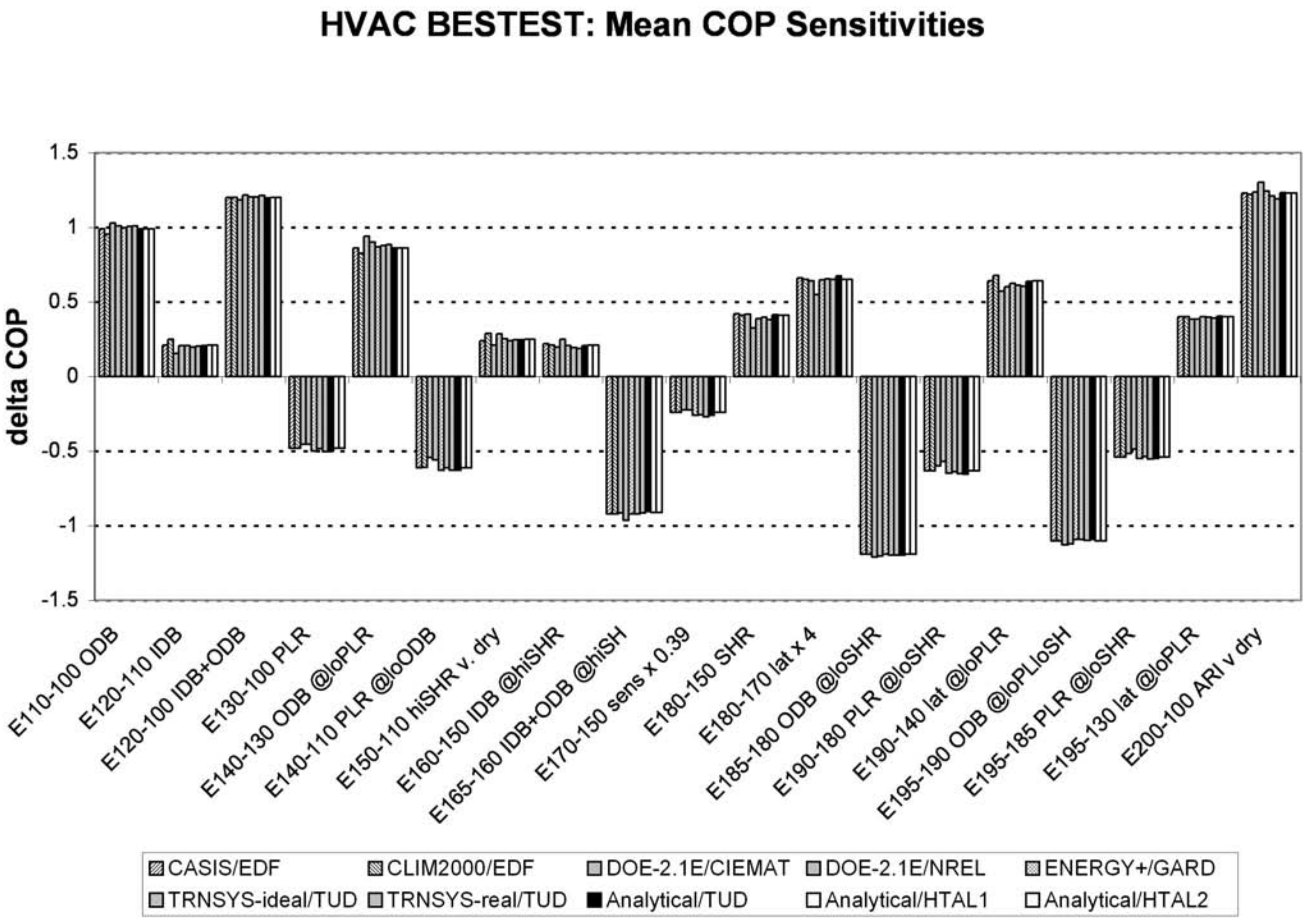
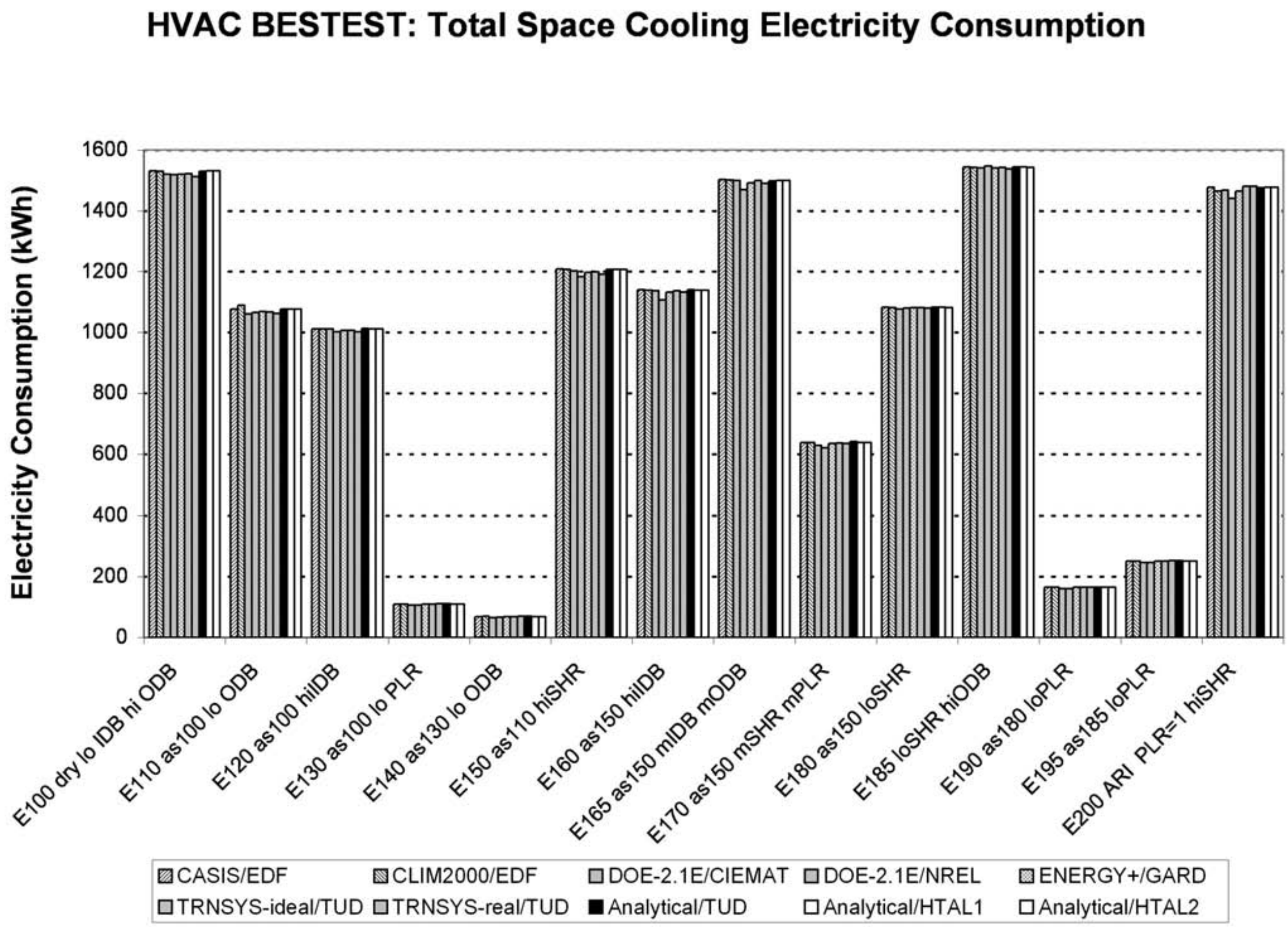
HVAC BESTEST: Mean COP

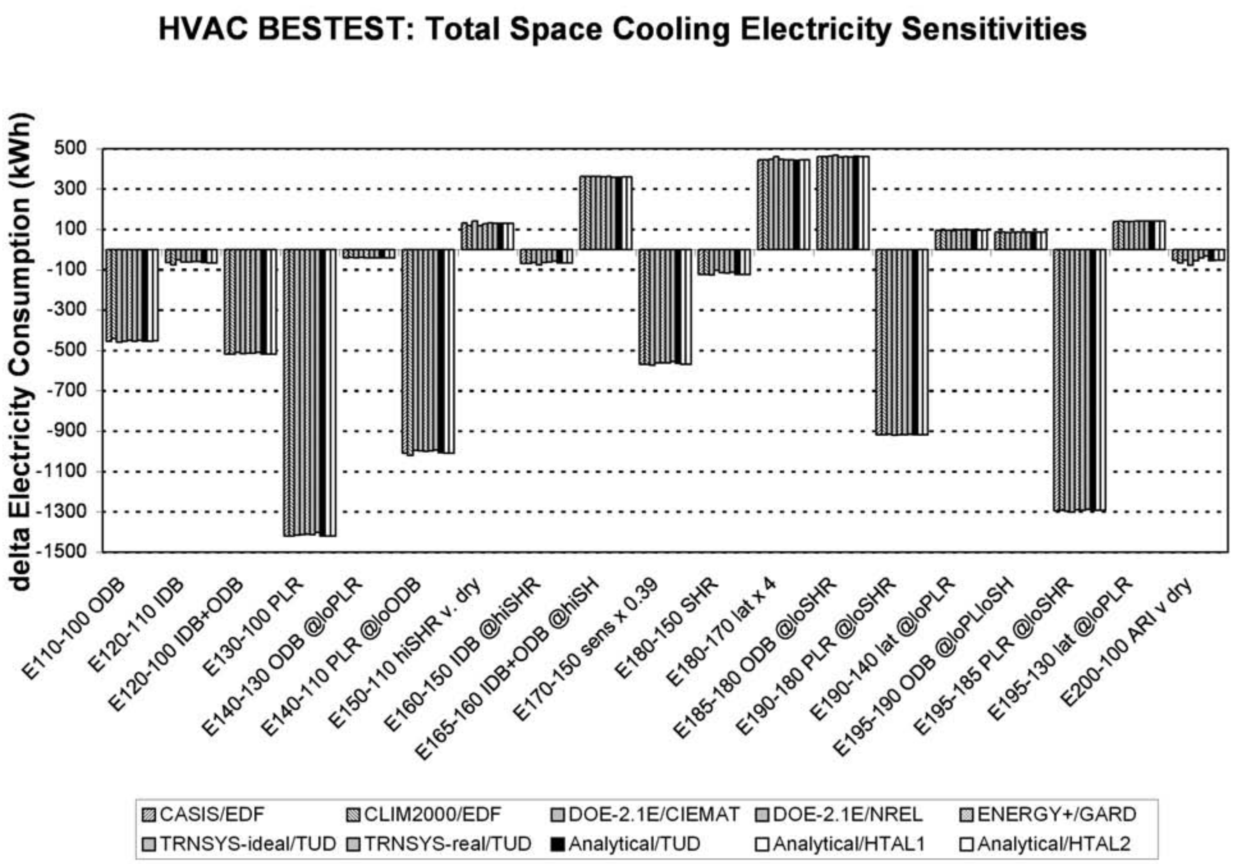


HVAC BESTEST: (Maximum - Minimum)/Mean COP

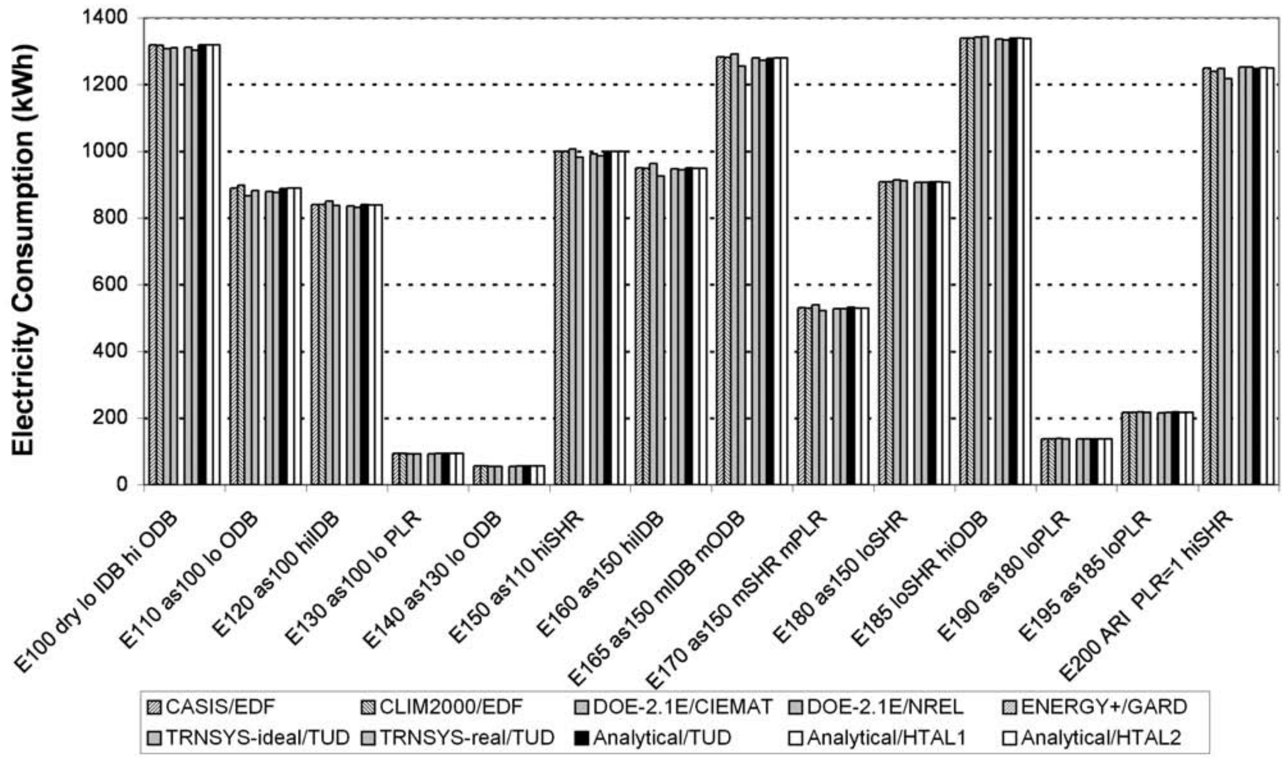



HVAC BESTEST: Mean COP Sensitivities
delta COP
1.5
1
0.5
0
-0.5
-1
-1.5
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPL loSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

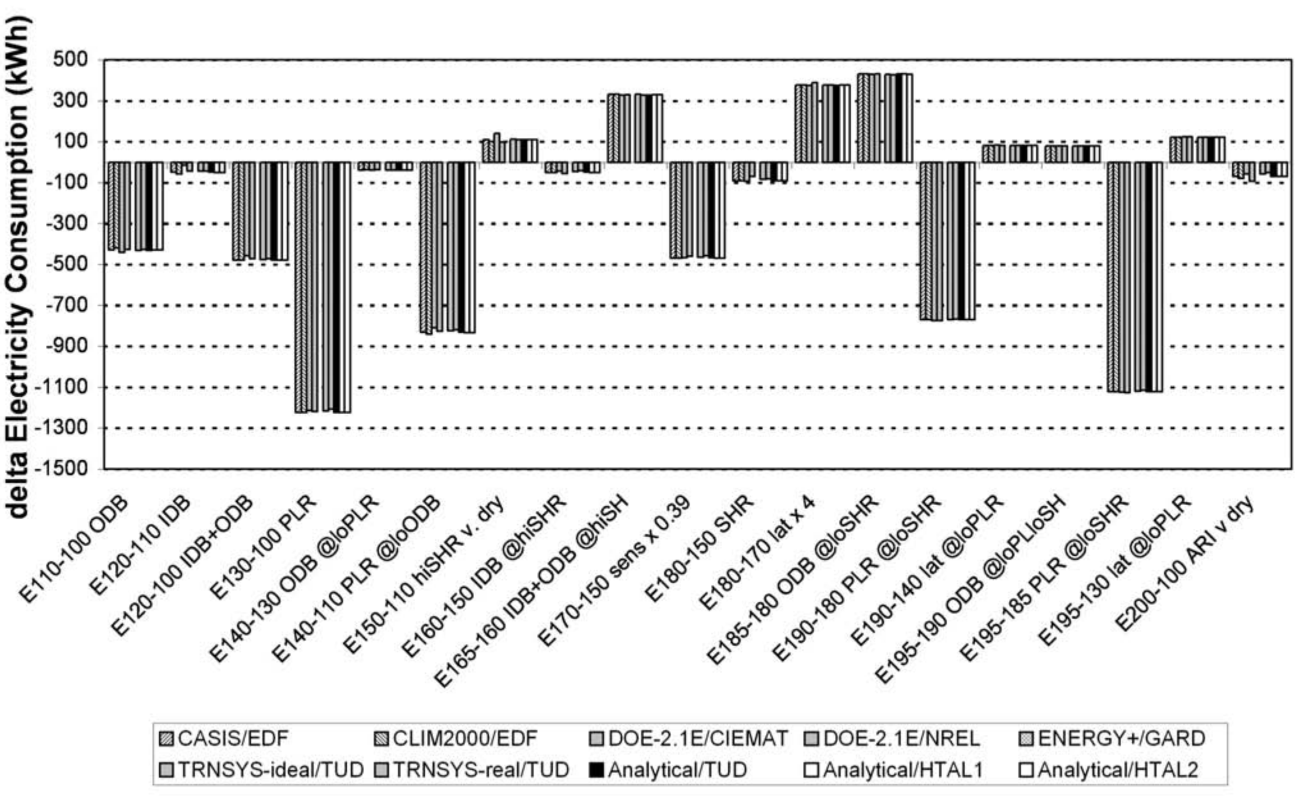

HVAC BESTEST: Total Space Cooling Electricity Consumption
Electricity Consumption (kWh)
1600
1400
1200
1000
800
600
400
200
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

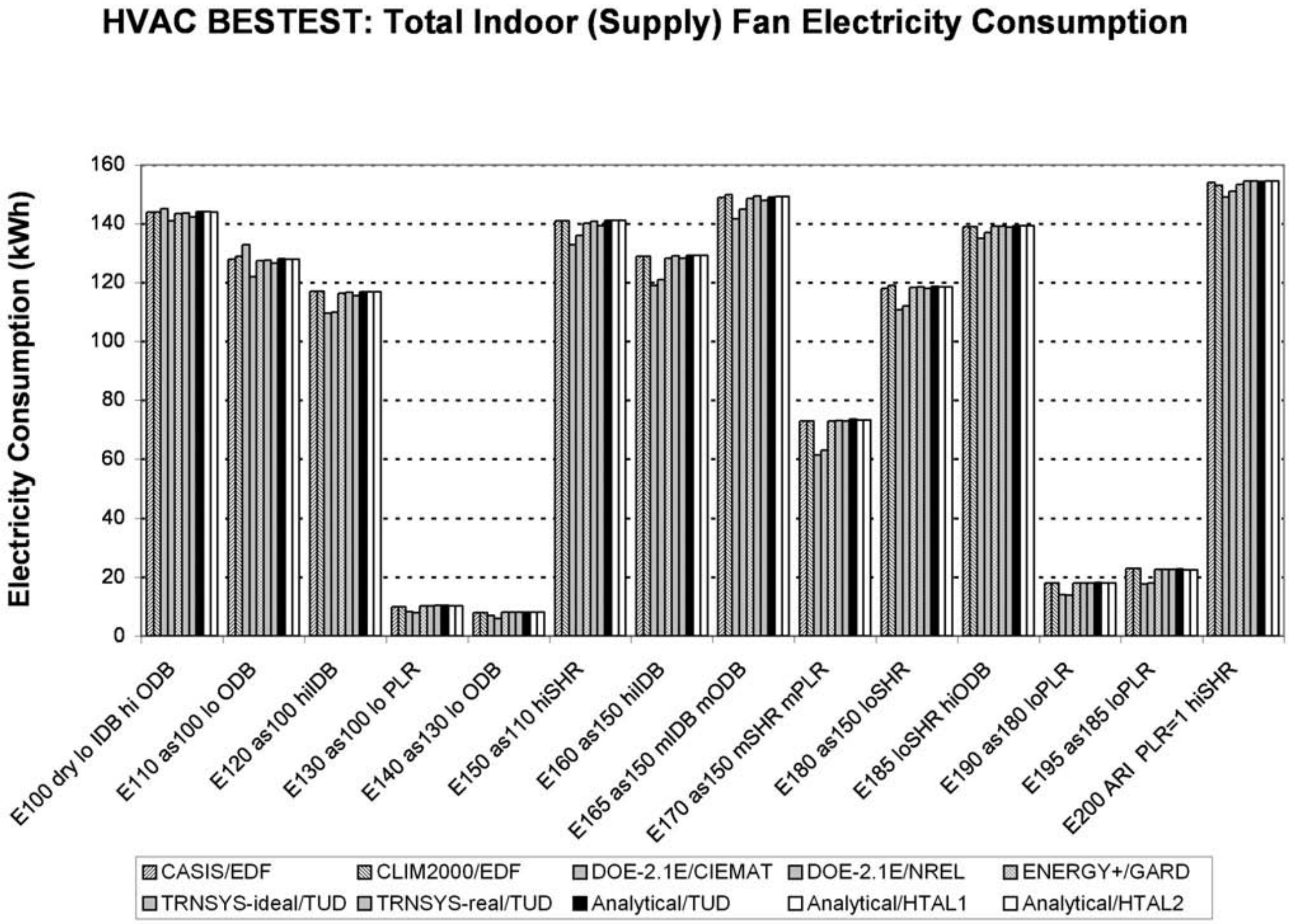

HVAC BESTEST: Total Space Cooling Electricity Sensitivities
delta Electricity Consumption (kWh)
500
300
100
-100
-300
-500
-700
-900
-1100
-1300
-1500
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPLloSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

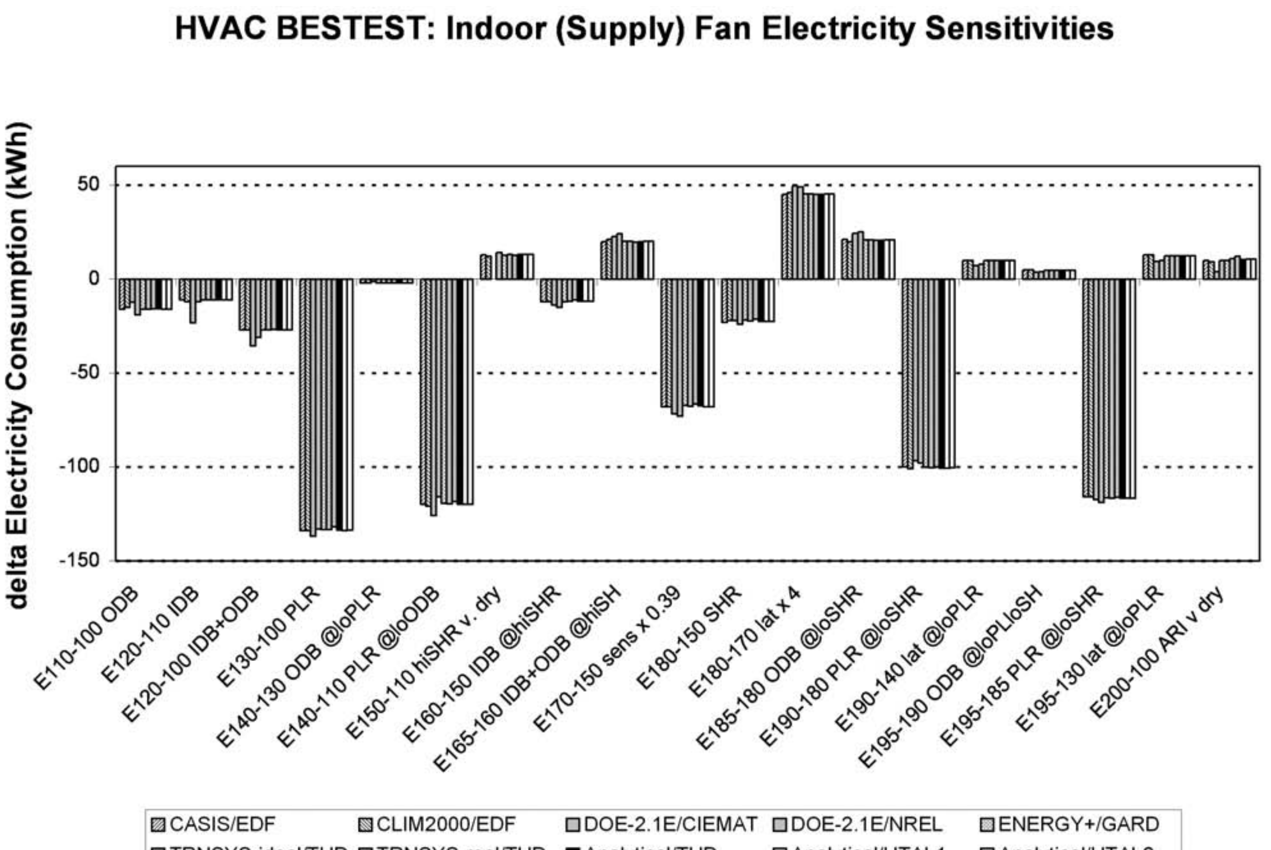
HVAC BESTEST: Compressor Electricity Consumption



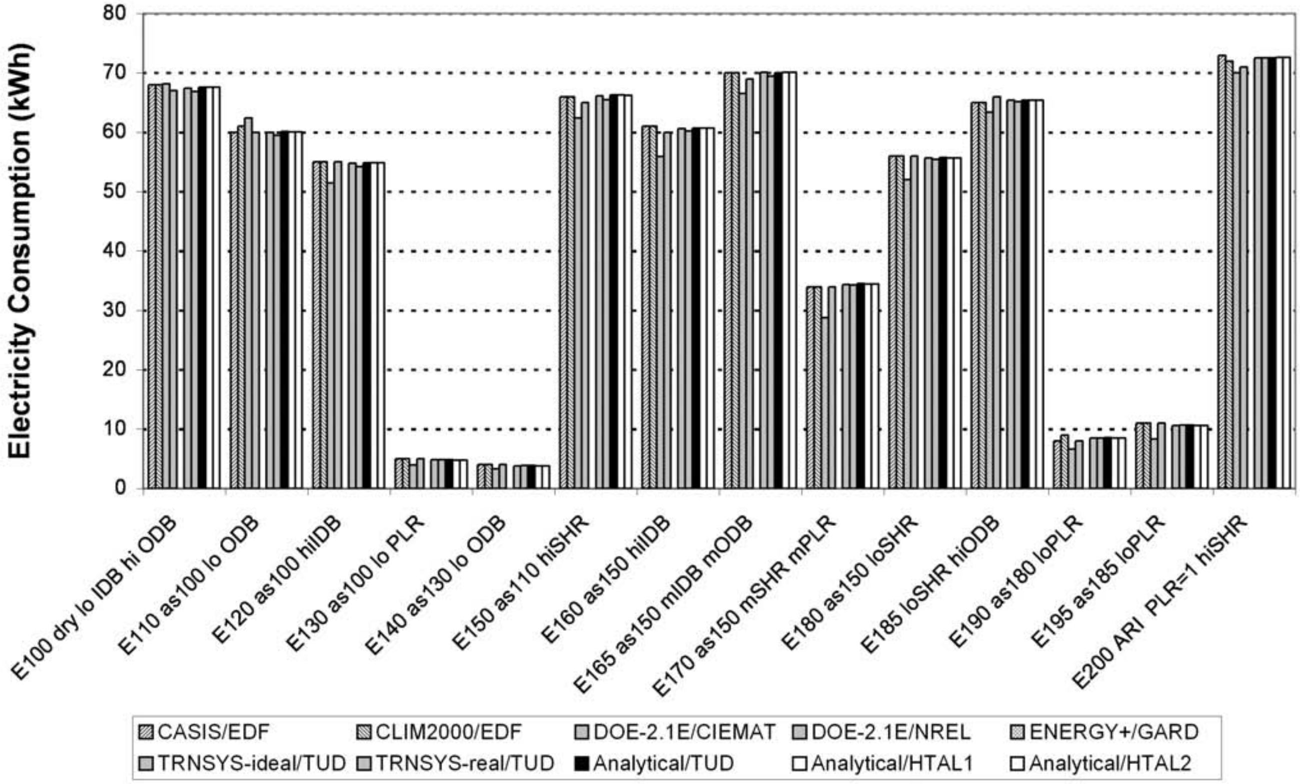
HVAC BESTEST: Total Compressor Electricity Sensitivities



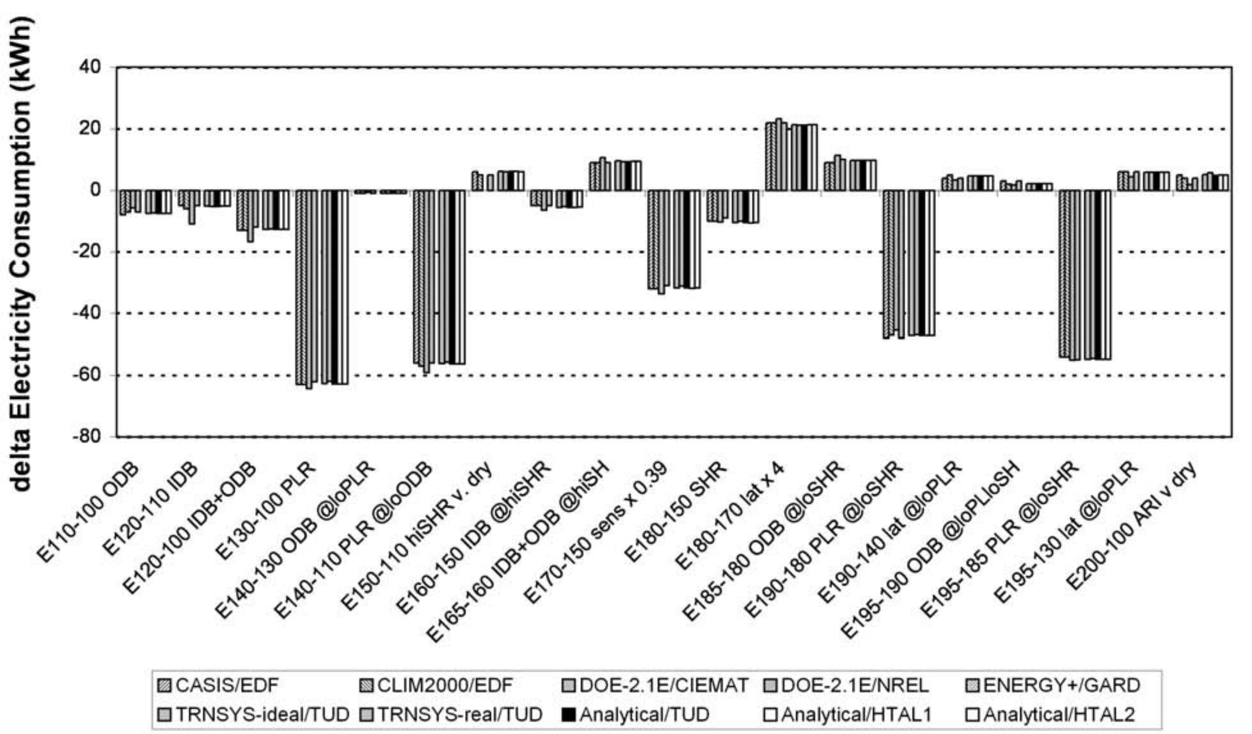

HVAC BESTEST: Total Indoor (Supply) Fan Electricity Consumption
Electricity Consumption (kWh)
160
140
120
100
80
60
40
20
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

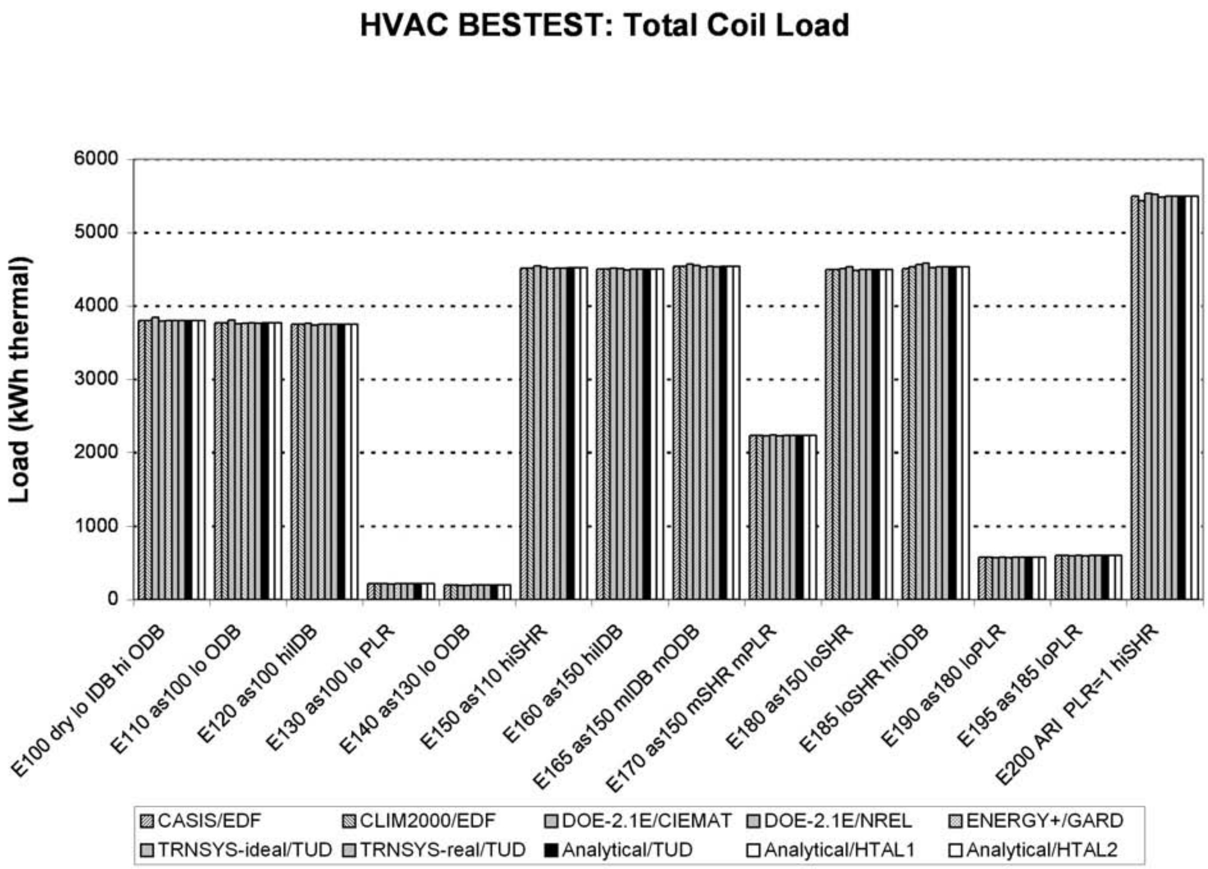

HVAC BESTEST: Indoor (Supply) Fan Electricity Sensitivities
delta Electricity Consumption (kWh)
50
0
-50
-100
-150
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPLloSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

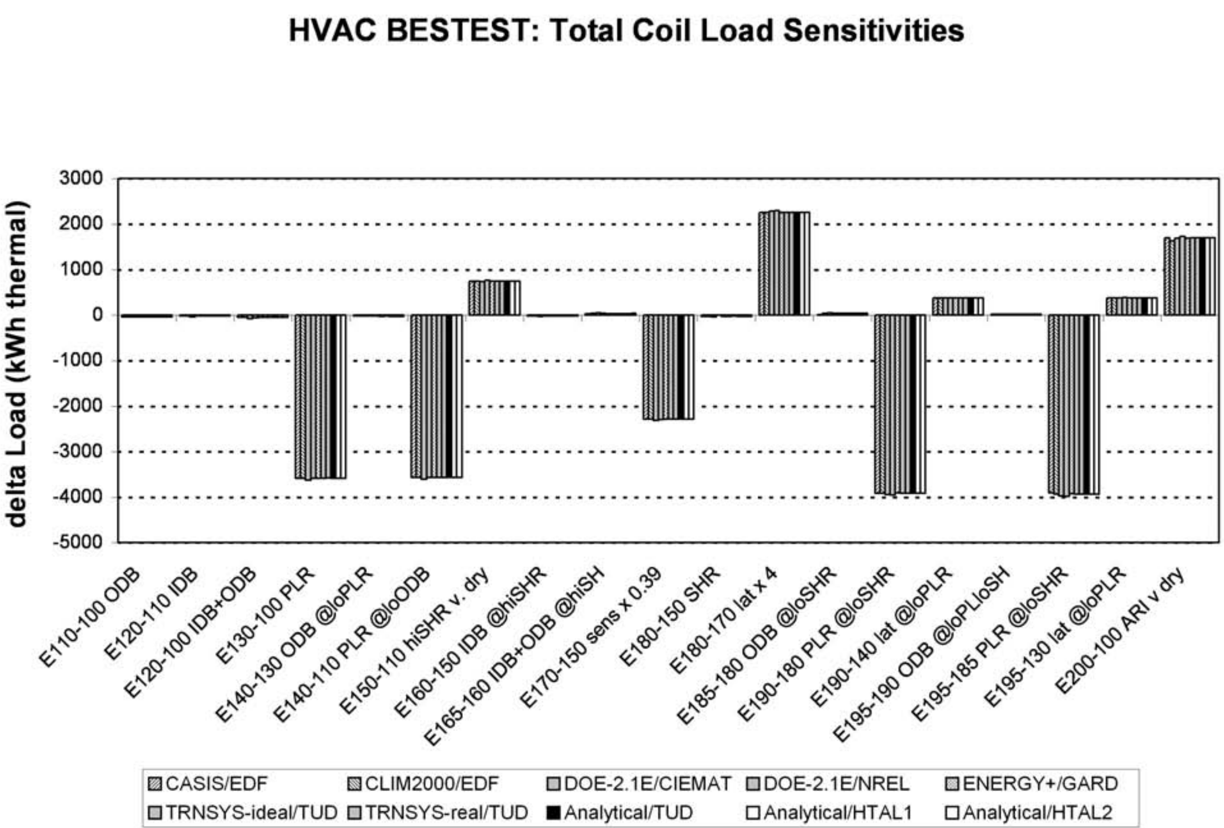
HVAC BESTEST: Outdoor (Condenser) Fan Electricity Consumption

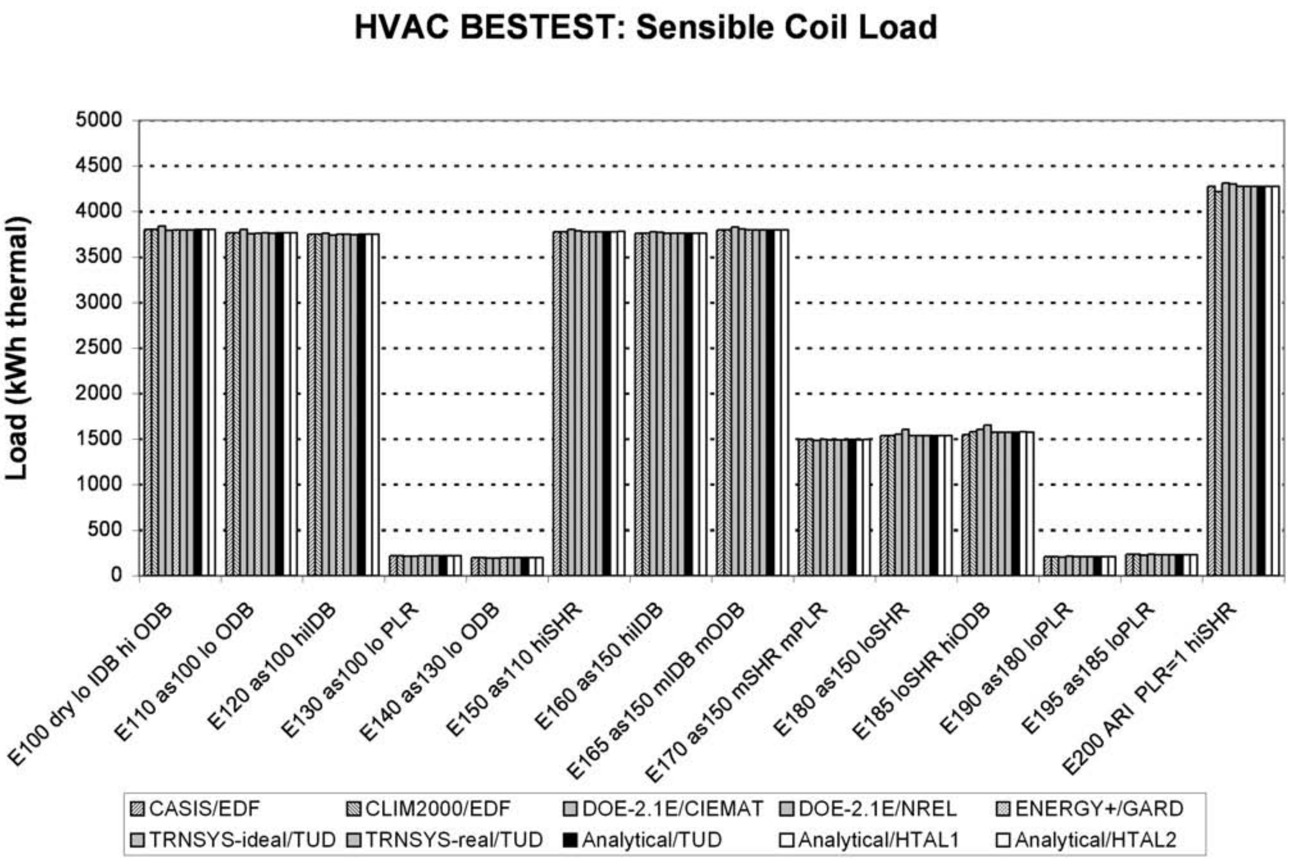


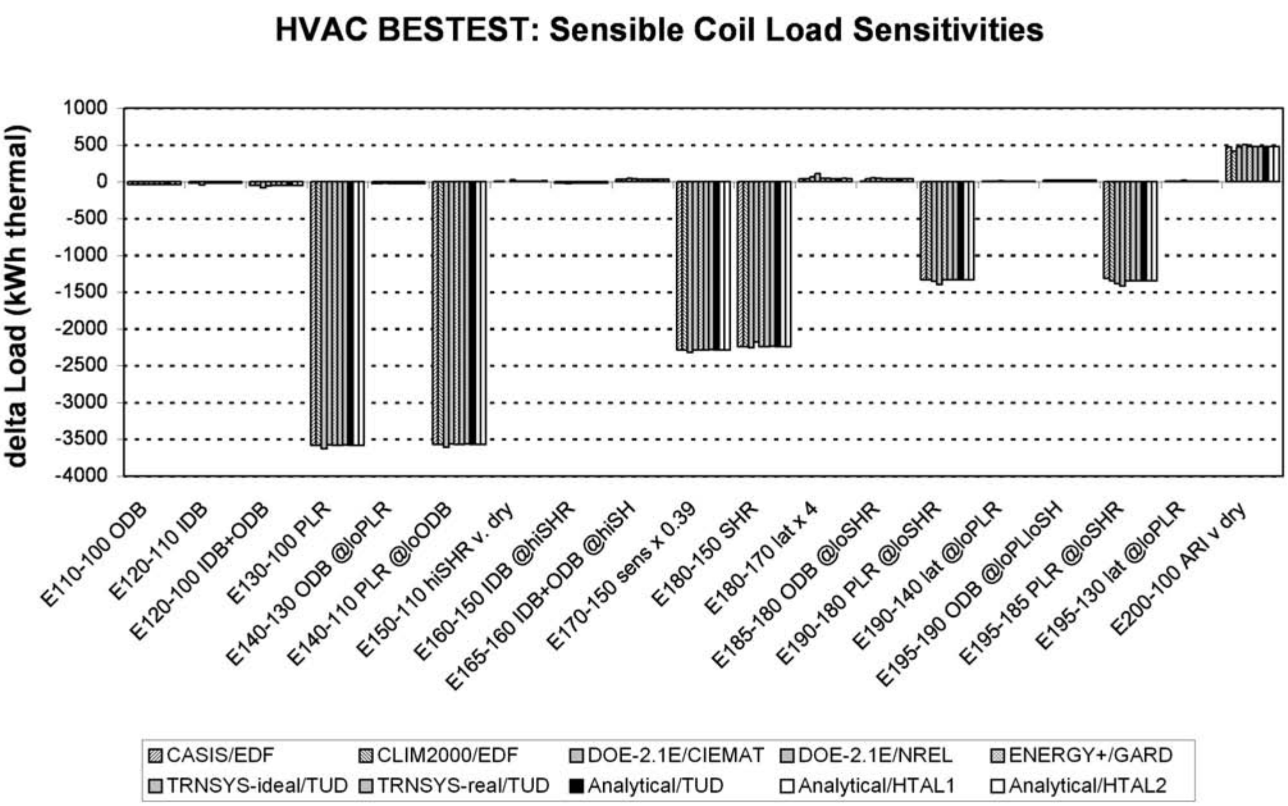
HVAC BESTEST: Outdoor (Condenser) Fan Electricity Sensitivities

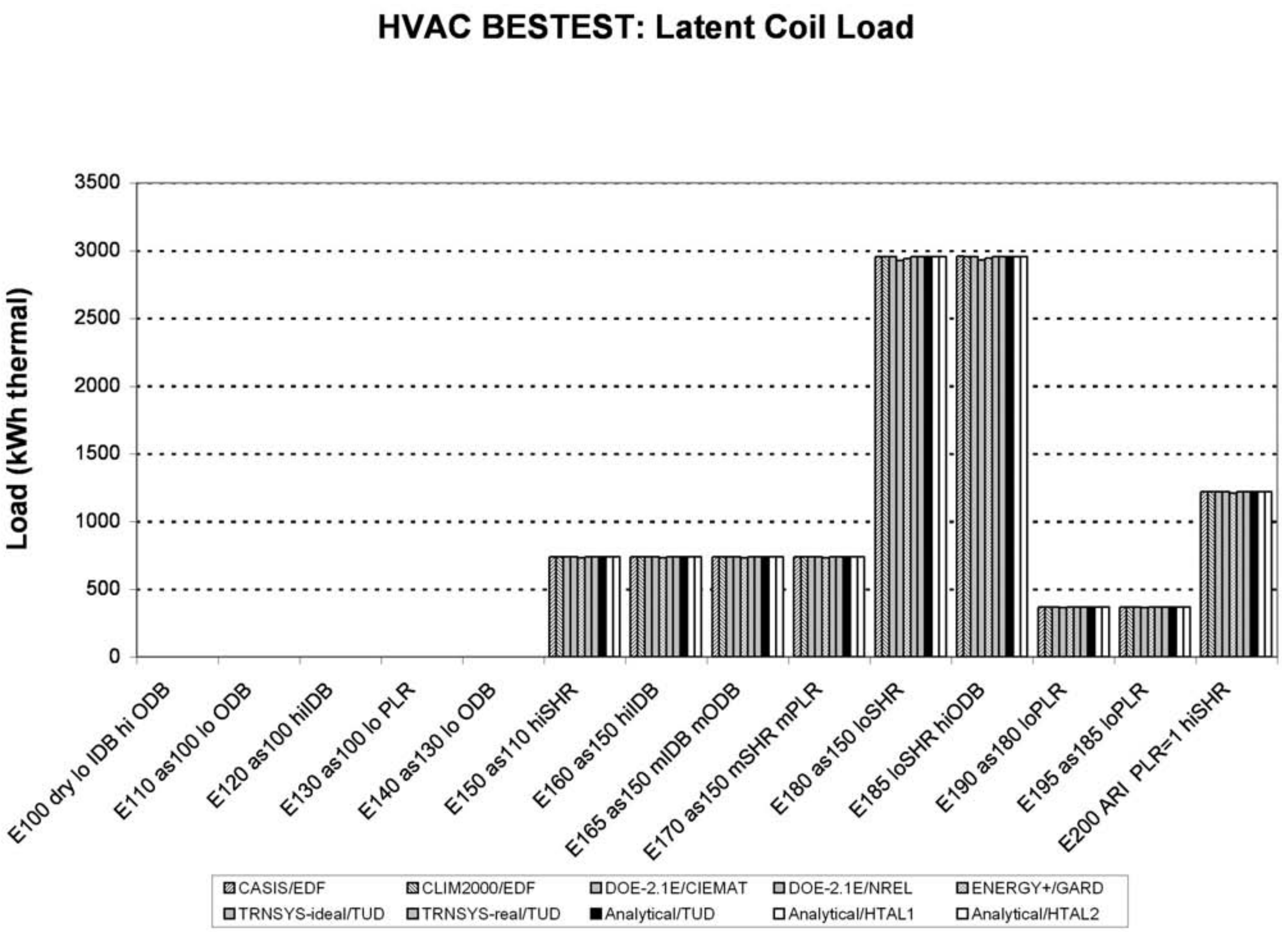


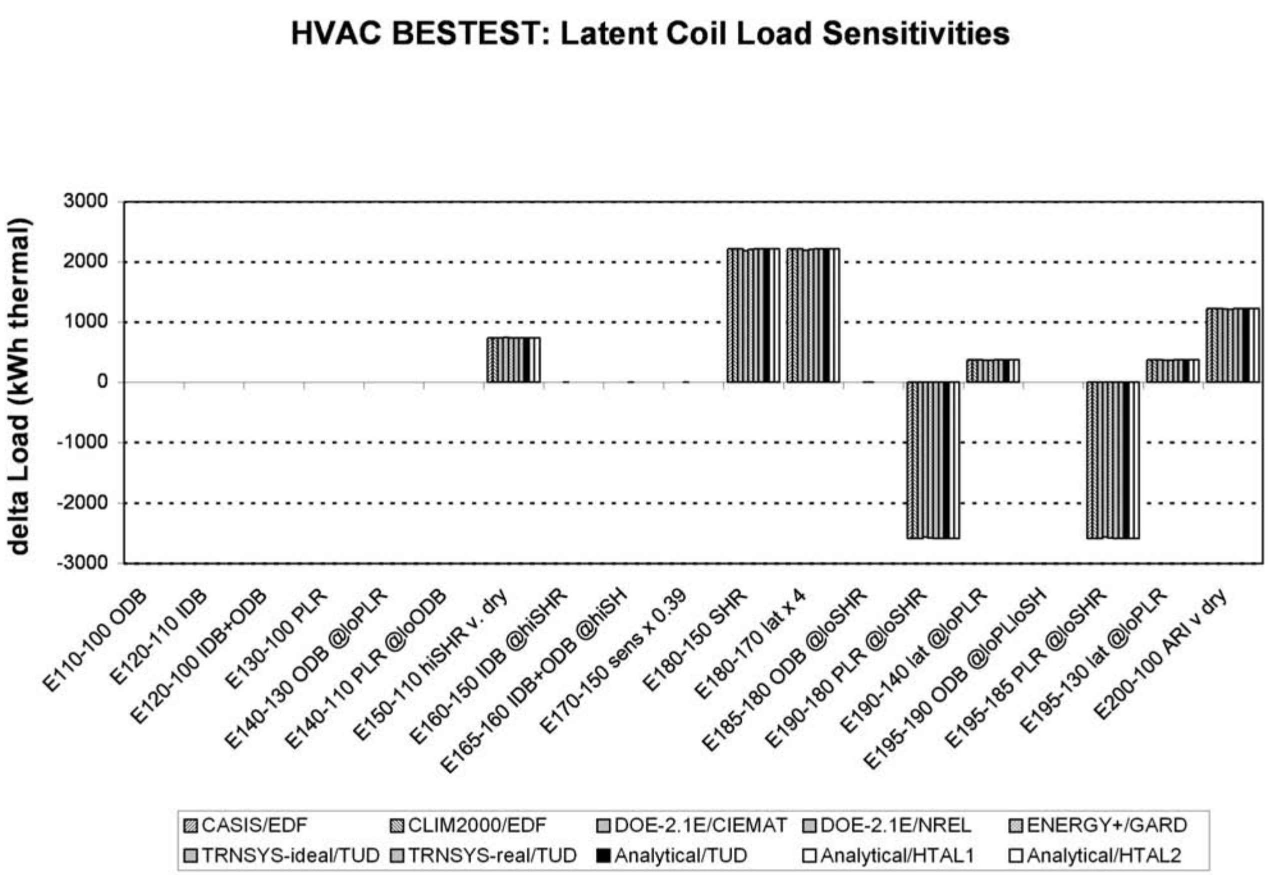

HVAC BESTEST: Total Coil Load
Load (kWh thermal)
6000
5000
4000
3000
2000
1000
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2


HVAC BESTEST: Total Coil Load Sensitivities
delta Load (kWh thermal)
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPLloSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

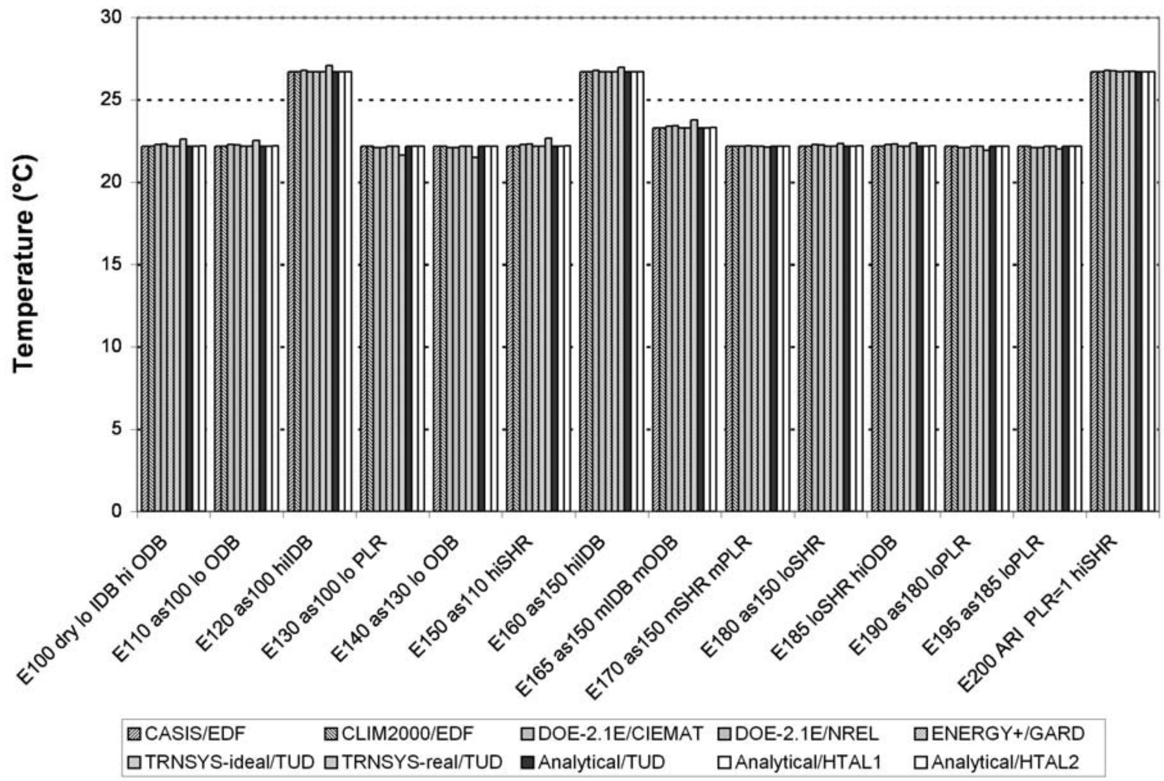

HVAC BESTEST: Sensible Coil Load
Load (kWh thermal)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2


HVAC BESTEST: Sensible Coil Load Sensitivities
delta Load (kWh thermal)
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPLloSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

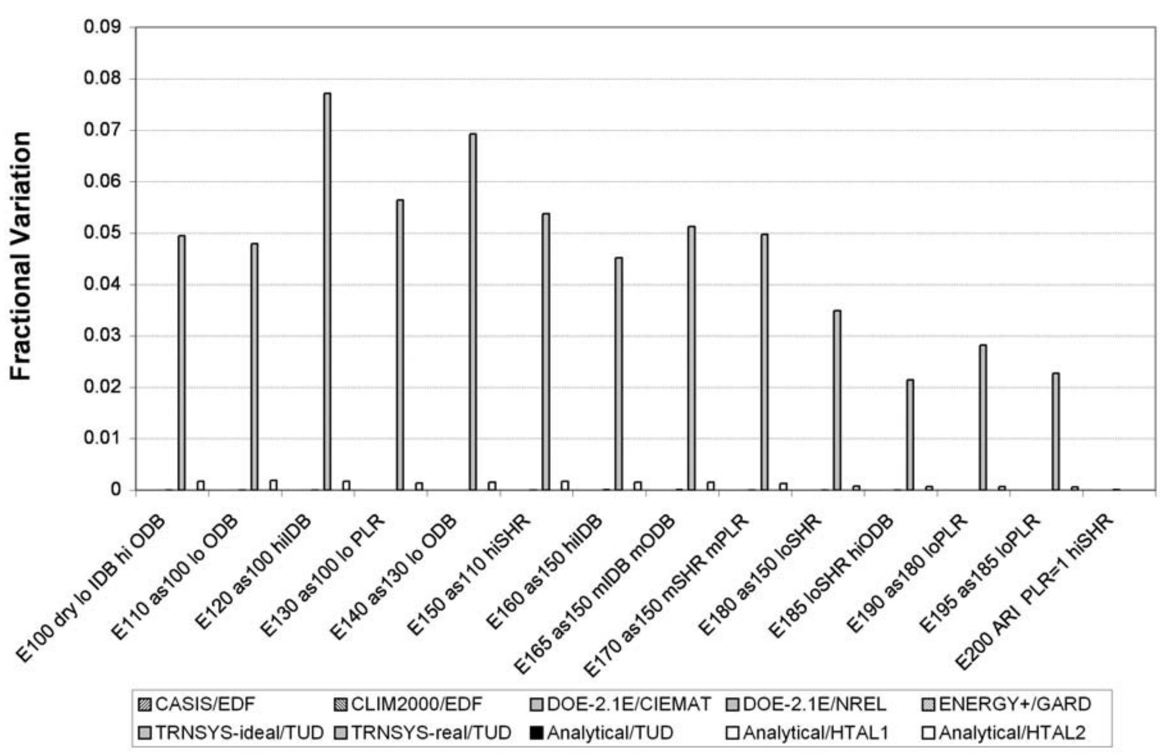

HVAC BESTEST: Latent Coil Load
Load (kWh thermal)
3500
3000
2500
2000
1500
1000
500
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

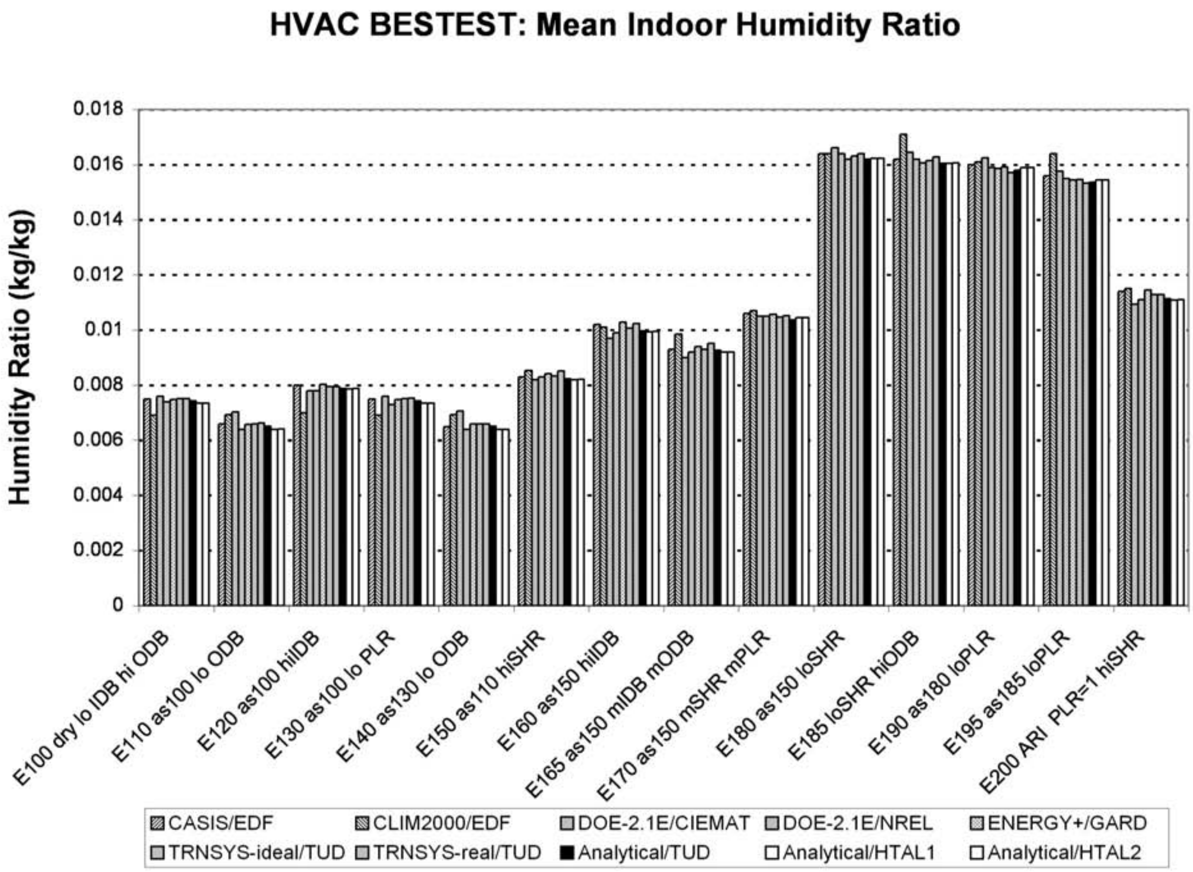

HVAC BESTEST: Latent Coil Load Sensitivities
delta Load (kWh thermal)
3000
2000
1000
0
-1000
-2000
-3000
E110-100 ODB
E120-110 IDB
E120-100 IDB+ODB
E130-100 PLR
E140-130 ODB @loPLR
E140-110 PLR @loODB
E150-110 hiSHR v. dry
E160-150 IDB @hiSHR
E165-160 IDB+ODB @hiSH
E170-150 sens x 0.39
E180-150 SHR
E180-170 lat x 4
E185-180 ODB @loSHR
E190-180 PLR @loSHR
E190-140 lat @loPLR
E195-190 ODB @loPLloSH
E195-185 PLR @loSHR
E195-130 lat @loPLR
E200-100 ARI v dry
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

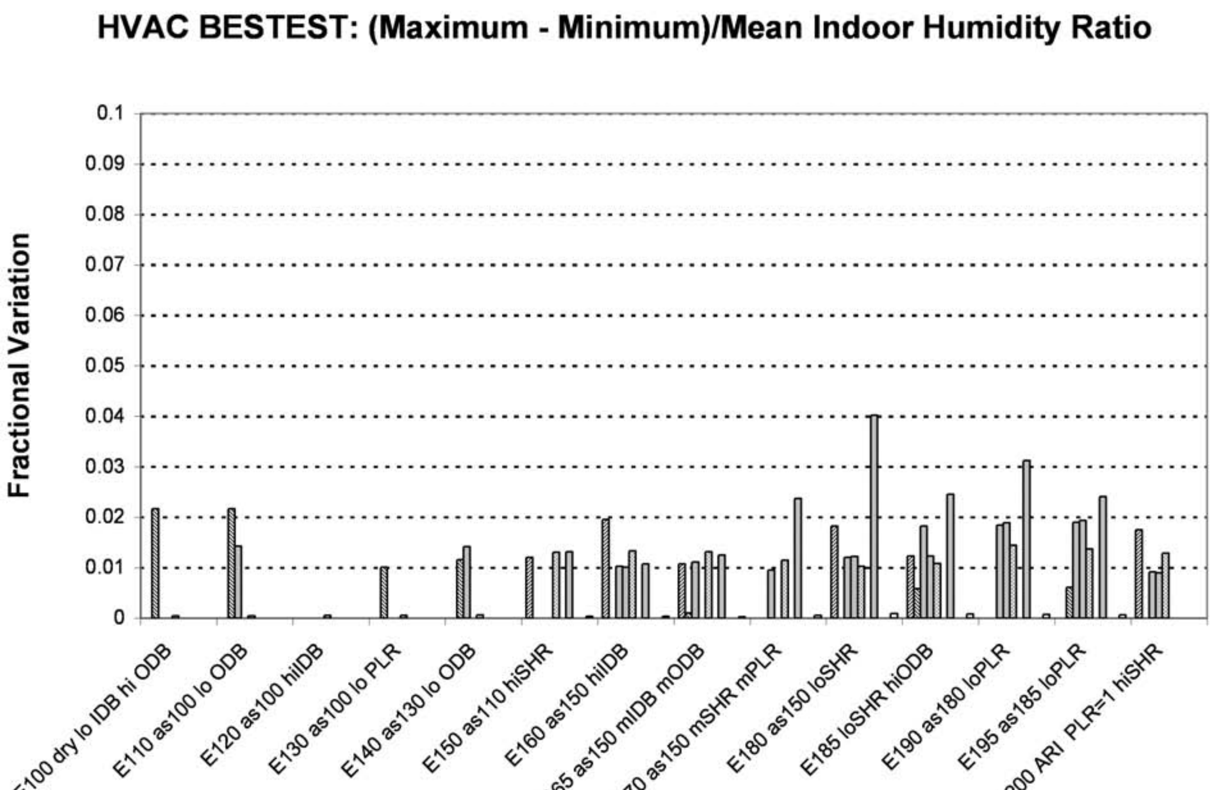
HVAC BESTEST: Mean Indoor Drybulb Temperature

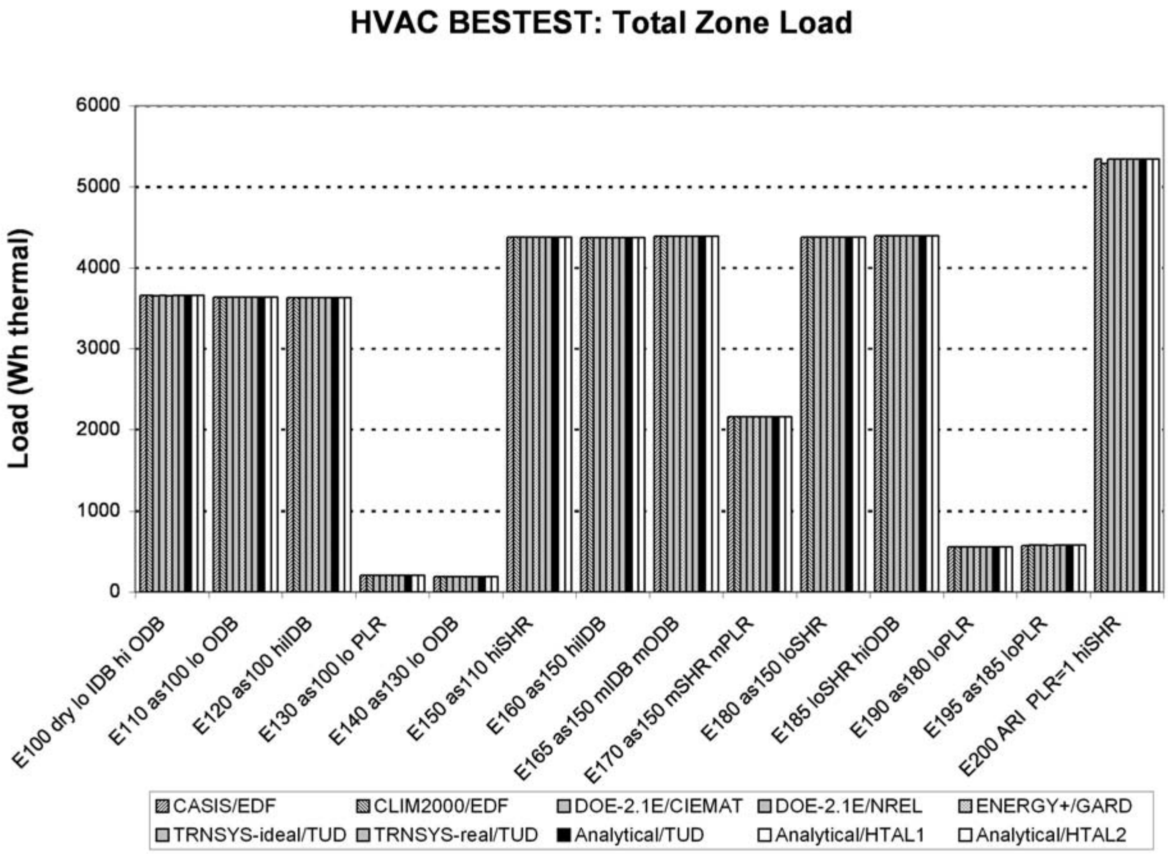


HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Drybulb Temperature

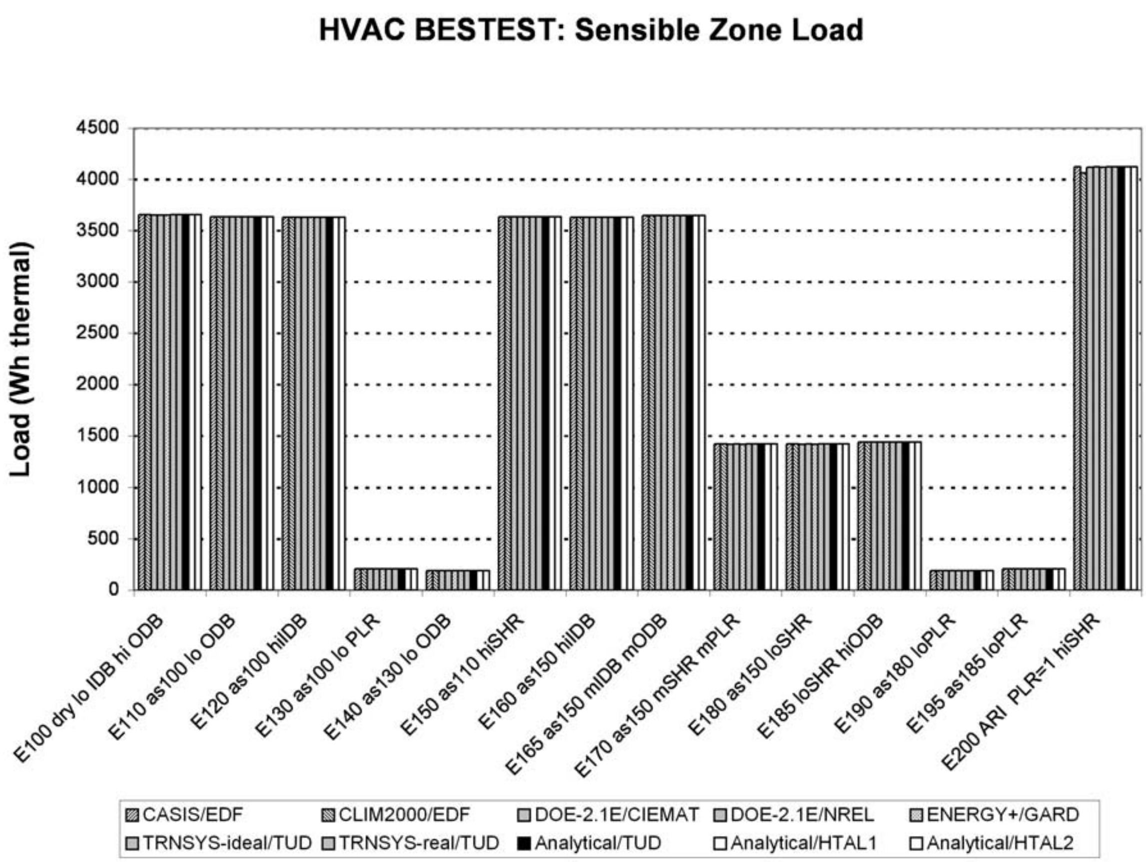



HVAC BESTEST: Mean Indoor Humidity Ratio
Humidity Ratio (kg/kg)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

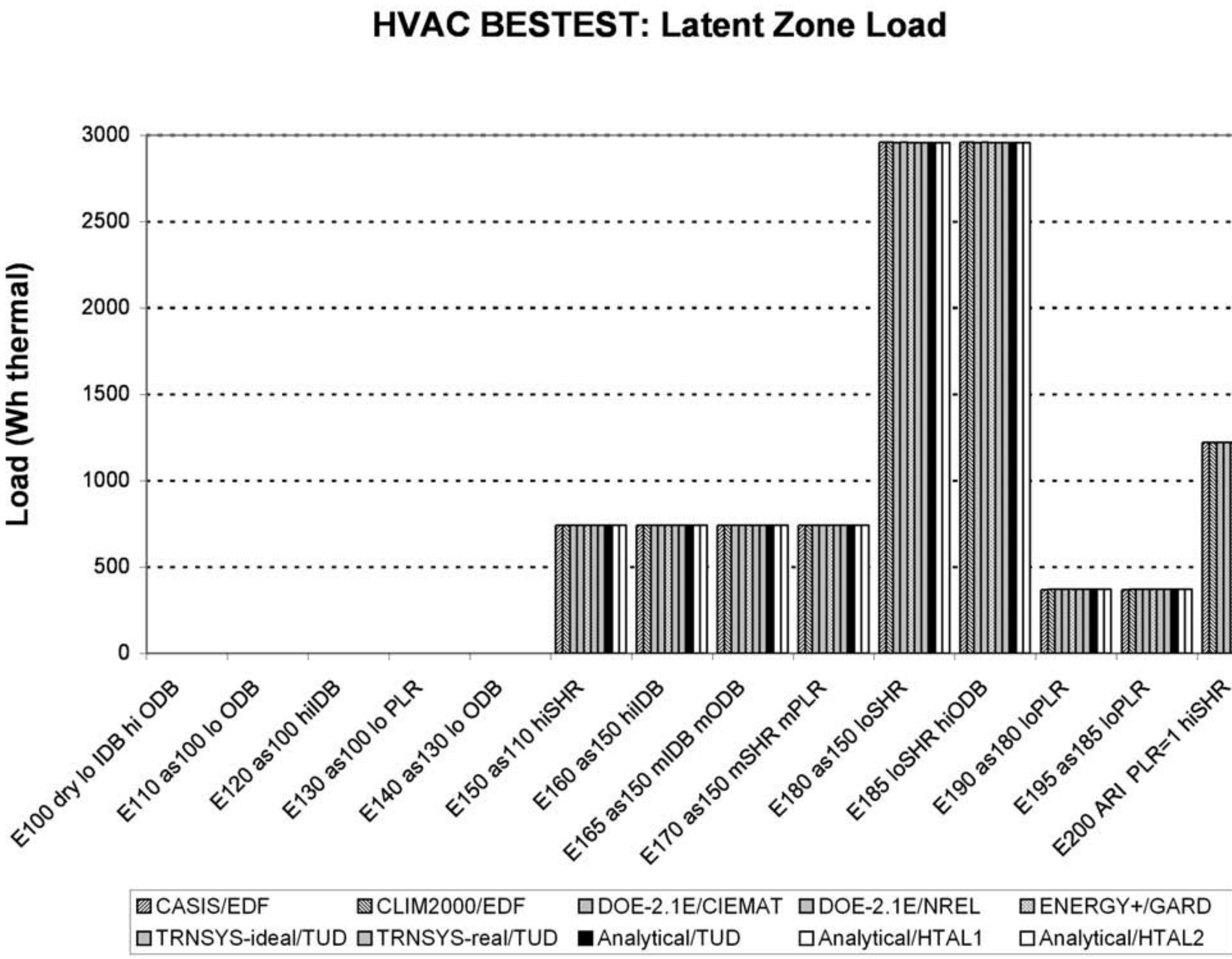

HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Humidity Ratio
Fractional Variation
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2



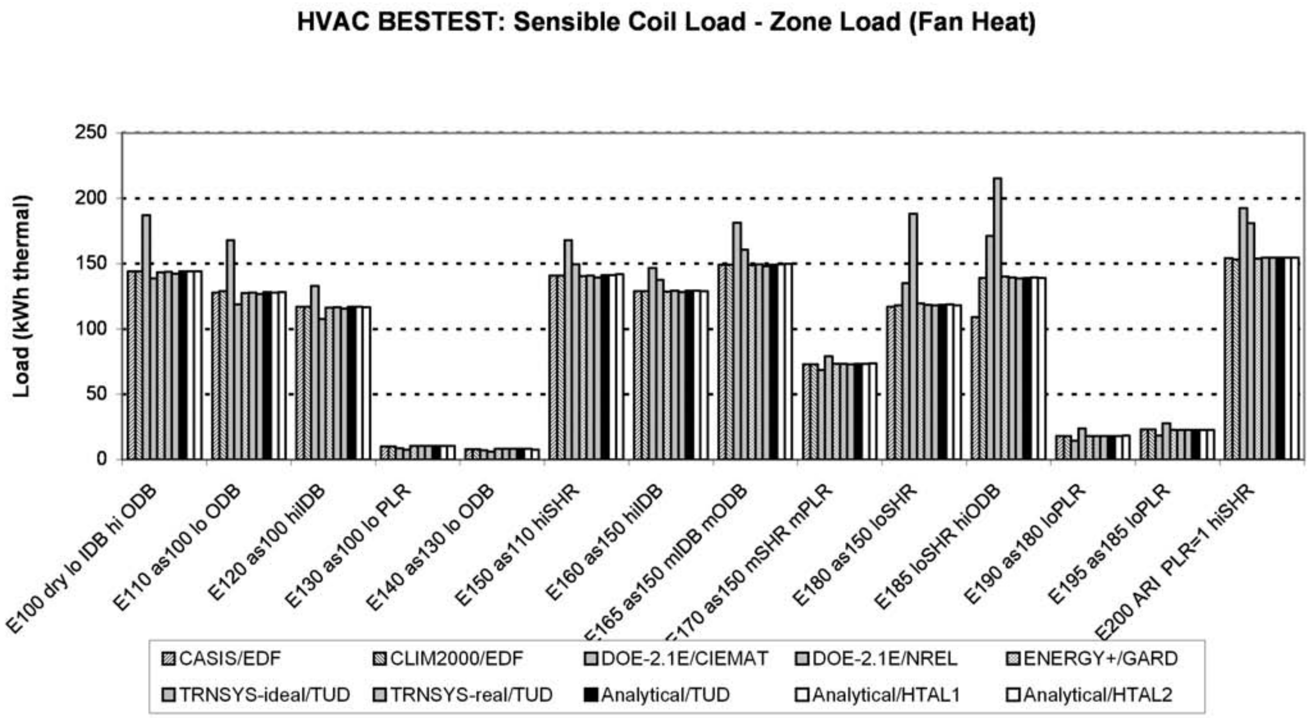
HVAC BESTEST: Total Zone Load
Load (Wh thermal)
6000
5000
4000
3000
2000
1000
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

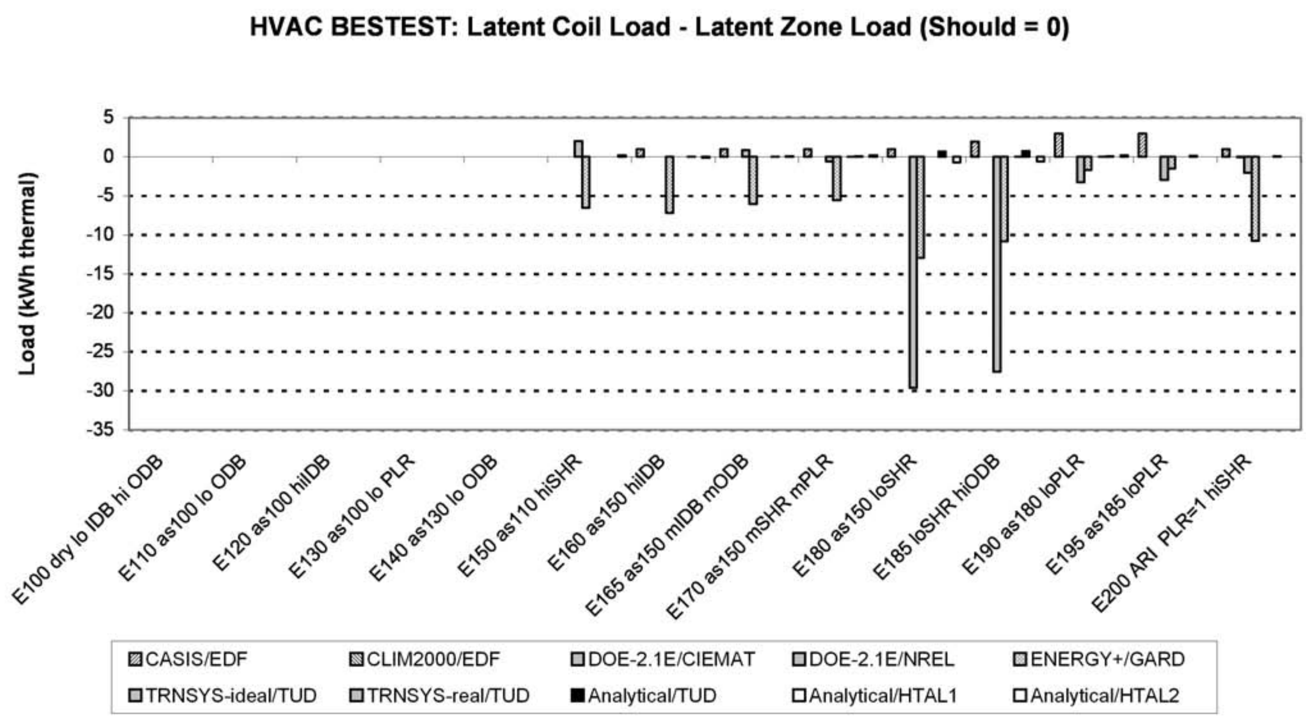


HVAC BESTEST: Sensible Zone Load
Load (Wh thermal)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2



HVAC BESTEST: Latent Zone Load
Load (Wh thermal)
3000
2500
2000
1500
1000
500
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2


HVAC BESTEST: Sensible Coil Load - Zone Load (Fan Heat)
Load (kWh thermal)
250
200
150
100
50
0
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2


HVAC BESTEST: Latent Coil Load - Latent Zone Load (Should = 0)
Load (kWh thermal)
5
0
-5
-10
-15
-20
-25
-30
-35
E100 dry lo IDB hi ODB
E110 as100 lo ODB
E120 as100 hiIDB
E130 as100 lo PLR
E140 as130 lo ODB
E150 as110 hiSHR
E160 as150 hiIDB
E165 as150 mIDB mODB
E170 as150 mSHR mPLR
E180 as150 loSHR
E185 loSHR hiODB
E190 as180 loPLR
E195 as185 loPLR
E200 ARI PLR=1 hiSHR
CASIS/EDF
CLIM2000/EDF
DOE-2.1E/CIEMAT
DOE-2.1E/NREL
ENERGY+/GARD
TRNSYS-ideal/TUD
TRNSYS-real/TUD
Analytical/TUD
Analytical/HTAL1
Analytical/HTAL2

(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.)

ANNEX B17

PRODUCTION OF QUASI-ANALYTICAL SOLUTION RESULTS AND EXAMPLE SIMULATION RESULTS

B17.1 Introduction

The full discussion regarding production of quasi-analytical solution results and example simulation results is included in *HVAC BESTEST*.[A-5] 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 B17.2) 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

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,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 Technology, State and Community Programs, Energy Efficiency and Renewable Energy

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.

Input decks used to generate the simulation results are provided in the files accompanying this standard (available at http://www.ashrae.org/template/PDFDetail?assetID=34505); 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.

B17.2 Quasi-Analytical Solution Results

The quasi-analytical solution results given in Annex B16 were developed as part of International Energy Agency (IEA) Solar Heating and Cooling Programme Task 22. The importance of having analytical or quasi-analytical solution results is discussed in Annex B16 (Section B16.2). Two of the IEA participating organizations independently developed quasi-analytical solutions that were submitted to a third party for review.[A-12, A-13, A-14] Comparing the results indicated some disagreements, which were then resolved by allowing the solvers to review the third-party reviewers' comments and to review and critique each others' solution techniques. This process resulted in both solvers making logical and non-arbitrary changes to their solutions such that their final results are mostly well within a <1% range of disagreement. Remaining differences in the quasi-analytical solutions are due in part to the difficulty of completely describing boundary conditions. In this case the boundary conditions are a compromise between full reality and some simplification of the real physical system that is mathematically solvable. Therefore, the quasi-analytical solutions have some element of interpretation of the exact nature of the boundary conditions that causes minor differences in the results. For example, in the modeling of the controller, one group derived a quasi-analytical solution for an "ideal" controller (that maintains zone temperature exactly at the thermostat setpoint) while another group developed a numerical solution for a "realistic" controller (that allows a small degree of zone temperature variation over very short simulation time steps). As another example, for the purpose of determining the "maximum EWB" dry-coil condition, one group used linear interpolation or extrapolation in conjunction with local intervals of given performance data, while another group used a similar but more generalized solution technique and incorporated the extremes of performance data. Each quasi-analytical solution yields slightly different results, but all are correct in the context of this exercise. This may be less than perfect from a mathematician's viewpoint but quite acceptable from an engineering perspective. A fully detailed presentation of the quasi-analytical solutions, including specific examples of remaining minor differences in the solutions, are discussed in Part II of *HVAC BESTEST.*[A-5]

B17.3 Selection of Programs for Producing Example Simulation Results

The criteria for selection of programs used for producing example results required that

(a) the program be a true simulation based on hourly weather data and calculational time increments of one hour or less and
(b) the program be representative of the state of the art in whole-building energy simulation as defined by the IEA country making the selection.

The programs used to generate example results have been subjected to extensive prior validation testing. Such testing includes the preliminary trials of *HVAC BESTEST*[A-5] that ran from 1997 through 2001. The programs (to various extents) were also subjected to other comparative, empirical validation and/or analytical verification tests such as those referenced in *HVAC BESTEST, IEA BESTEST,* and in International Building Performance Simulation Association (IBPSA) proceedings.[14,21,22, A-5]

(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.)

ANNEX B18

VALIDATION METHODOLOGIES AND OTHER RESEARCH RELEVANT TO STANDARD 140

[Informative Note: Delete Annex B13 and replace with new Annex B18 as follows.]

B18.1 Overall Validation Methodology

An overall validation methodology consists of three parts:

(a) Comparative Testing - in which a program is compared to itself or to other programs
(b) Analytical Verification - in which the output from a program, subroutine, algorithm, or software object is compared to the result from a known analytical or quasi-analytical solution for isolated heat transfer mechanisms under very simple and highly constrained boundary conditions
(c) Empirical Validation - in which calculated results from a program, subroutine, algorithm, or software object are compared to monitored data from a real building, test cell, or laboratory experiment

Table B18-1 shows the advantages and disadvantages of these three techniques.[A-15, A-5] Defining two terms is useful in interpreting Table 1. Here a "model" is the representation of reality for a given physical behavior. For example, one way to model heat transfer through a wall is by using a simplifying assumption of one-dimensional conduction. An alternative (more detailed) model for wall heat transfer could employ two-dimensional conduction. The "solution process" is a term that encompasses the mathematics and computer coding to solve a given model (e.g., a finite difference approximation to solve a differential equation) and the technique for integrating individual models and boundary conditions into an overall solution methodology—such as an iterative energy balance through layers of a single wall, over all the surfaces of a given zone, or between a zone(s) and its related mechanical system(s). The solution process for a model can be perfect, while the model

TABLE B18-1
Advantages and Disadvantages of Various Validation Techniques

Technique	Advantages	Disadvantages
Empirical Test of model and solution process	• Approximate truth standard within experimental accuracy • Any level of complexity	• Experimental uncertainties: - Instrument calibration, spatial/ temporal discretization - Imperfect knowledge/specification of the experimental object (building) being simulated • Detailed measurements of high quality are expensive and time consuming • Only a limited number of test conditions are practical
Analytical Test of solution process	• No input uncertainty • Exact mathematical truth standard for the given model • Inexpensive	• No test of model validity • Limited to highly constrained cases for which analytical solutions can be derived
Comparative Relative test of model and solution process	• No input uncertainty • Any level of complexity • Many diagnostic comparisons possible • Inexpensive and quick	• No truth standard

remains faulty or inappropriate for a given physical situation or purpose; for example, using a one-dimensional conduction model where two-dimensional conduction dominates.

The methodologies may be further subdivided within each category as building envelope tests and mechanical equipment tests, creating a matrix of six areas for testing including:

(a) Comparative Tests - Building Envelope
(b) Comparative Tests - Mechanical Equipment
(c) Analytical Verification - Building Envelope
(d) Analytical Verification - Mechanical Equipment
(e) Empirical Validation - Building Envelope
(f) Empirical Validation - Mechanical Equipment.

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"[A-16]
(b) "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)"[23]
(c) ASHRAE RP-865, "Development of Accuracy Tests for Mechanical System Simulation"[A-17]
(d) "Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Fuel-Fired Furnace Test Suite"[A-18]
(e) "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"
(f) "RADTEST Radiant Heating and Cooling Test Cases"[A-19]
(g) "Proposed IEA BESTEST Ground-Coupled Cases"
(h) ETNA BESTEST Empirical Validation Test Specification
(i) "Daylighting – HVAC Interaction Tests for the Empirical Validation of Building Energy Analysis Tools"[A-20]
(j) "Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools"
(k) 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 Task 34 and IEA Energy Conservation in Buildings and Community Systems Annex 43 (IEA SHC 34/ECBCS 43).[A-21]

(Note: Since items e, g, h, and j are works in progress, no references can yet be cited for them.)

B18.2.1 ASHRAE RP-1052[A-16] 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[23] 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[A-17] These tests are analytical verification tests that focus on the ability to model thermal physics related to the air-side of mechanical equipment. The tests were developed by Pennsylvania State University and Texas A&M University as an ASHRAE research project. Cases allow the comparison of quasi-analytical solutions to program results for the purpose of testing the ability of programs to model air-side mechanical equipment and systems. These tests are subdivided by system type, for example, constant-volume dual duct or variable-volume single duct with reheat.

B18.2.4 HVAC BESTEST Fuel-Fired Furnace Test Suite[A-18] 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.

B18.2.5 HVAC BESTEST Cases E300-E545 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.

B18.2.6 RADTEST[A-19] is a comparative test developed by Hochschule fur Technik + Architektur Luzern in conjunction with the IEA SHC 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.).

B18.2.7 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 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).

B18.2.8 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.

B18.2.9 Daylighting – HVAC Interaction Tests for the Empirical Validation of Building Energy Analysis Tools[A-20] 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.

B18.2.10 Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools 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.

Informative Note: Renumber Section B14, References, as Section B19 and divide it into two parts, Section B19.1, which contains the references in the current standard, and Section B19.2, which adds the new references for Addendum a.

(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.)

ANNEX B19~~4~~

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The following references are cited in this Addendum a to ANSI ASHRAE Standard 140-2001. Each reference begins with the letter "A," and all are informative. When Standard 140 is next republished, these references will be integrated with those in ANSI/ASHRAE Standard 140 and renumbered consecutively.

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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.