

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



# ASHRAE<sup>®</sup> STANDARD

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

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(Note: Additions are shown in this addendum by underlining and deletions are shown by ~~striking through~~ except when an informative note makes it clear that the entire material that follows is to be added or deleted as a whole.)

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**(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 capacity*.)

**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 ( $[\text{gross sensible capacity}]/[\text{gross total capacity}]$ ). (Also see *gross sensible capacity* and *gross total capacity*.)

**building thermal envelope and fabric:** includes the building thermal envelope as defined in ASHRAE Terminology, <sup>A-1</sup> 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<sub>SEER</sub>:** the seasonal energy efficiency ratio (dimensionless).

**COP degradation factor (CDF):** multiplier ( $\leq 1$ ) 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 effect* 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 heat* 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.<sup>A-2</sup> 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:

- Building Thermal Envelope and Fabric Load Base Case (see 4.2.1)
- 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)
- Building Thermal Envelope and Fabric Load In-Depth Tests (see 4.2.3)
- HVAC Equipment Performance Base Case (see 4.2.4)
- 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.XLSWK3` (for Annex B8) and `RESULTS5-3.XLS` (for Annex B16). Documentation regarding `RESULTS5-2.XLSWK3` 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 to 1 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 ( $6 \text{ m} \times 8 \text{ m} \times 2.7 \text{ m} = 129.6 \text{ m}^3$ ). 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.

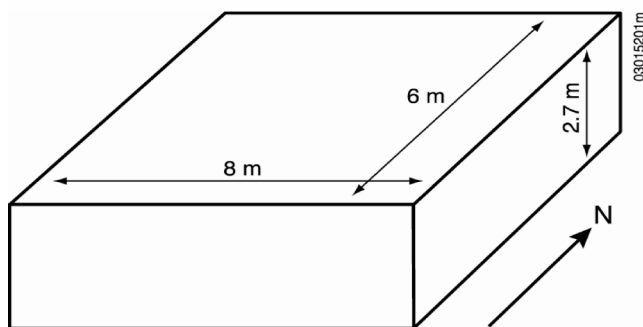
**5.2.1.6 Infiltration.** Infiltration rate = 0.5 ACH, continuously (24 hours per day for the full year).

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  $12 \text{ m}^2$  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  $21.0 \text{ W/m}^2\text{K}$ . 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 HVB461.TMY or HVB461A.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<sup>2</sup> floor area, single-story, low-mass building with rectangular-prism geometry as shown in Figure 8. Zone air volume is 129.6 m<sup>3</sup>.

**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<sup>3</sup>.

**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<sup>3</sup>.

**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 <sup>3</sup> |
| 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

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                        |                        |                              |                            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|------------------------|------------------------------|----------------------------|
| <b>EXTERIOR WALL (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                        |                        |                              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>k</b>               | <b>Thickness</b>       | <b>U</b>                     | <b>R</b>                   |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>(W/(m*K))</b>       | <b>(m)</b>             | <b>(W/(m<sup>2</sup>*K))</b> | <b>(m<sup>2</sup>*K/W)</b> |
| 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                    |
| <b>FLOOR (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                        |                        |                              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>k</b>               | <b>Thickness</b>       | <b>U</b>                     | <b>R</b>                   |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>(W/(m*K))</b>       | <b>(m)</b>             | <b>(W/(m<sup>2</sup>*K))</b> | <b>(m<sup>2</sup>*K/W)</b> |
| 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                    |
| <b>ROOF (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                        |                        |                              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>k</b>               | <b>Thickness</b>       | <b>U</b>                     | <b>R</b>                   |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>(W/(m*K))</b>       | <b>(m)</b>             | <b>(W/(m<sup>2</sup>*K))</b> | <b>(m<sup>2</sup>*K/W)</b> |
| 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                    |
| <b>SUMMARY</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                        |                        |                              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>AREA</b>            | <b>UA</b>              |                              |                            |
| <b>COMPONENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>(m<sup>2</sup>)</b> | <b>(W/K)</b>           |                              |                            |
| Wall                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 75.600                 | 0.755                  |                              |                            |
| Floor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 48.000                 | 0.479                  |                              |                            |
| Roof                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 48.000                 | 0.479                  |                              |                            |
| Infiltration (Note 3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                        | 0.000                  |                              |                            |
| Total UA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                        | 1.713                  |                              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>ACH</b>             | <b>VOLUME</b>          | <b>ALTITUDE</b>              |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                        | <b>(m<sup>3</sup>)</b> | <b>(m)</b>                   |                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0.00                   | 129.6                  | 2.0                          |                            |
| <p>Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are &lt; 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.</p> <p>Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.</p> <p>Note 3: Infiltration derived from:<br/>ACH*Volume*(specific heat of air)*(density of air at specified altitude)</p> |                        |                        |                              |                            |

**TABLE 23b**  
**Material Specifications Base Case (English Units)**

mspec4.xls; May 20, 2004

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |                    |                       |                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------|-----------------------|-----------------------|
| <b>EXTERIOR WALL (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                       |                    |                       |                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>k</b>              | <b>Thickness</b>   | <b>U</b>              | <b>R</b>              |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>(Btu/(h*ft²F))</b> | <b>(ft)</b>        | <b>(Btu/(h*ft²F))</b> | <b>(h*ft²F/Btu)</b>   |
| 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               |
| <b>FLOOR (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       |                    |                       |                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>k</b>              | <b>Thickness</b>   | <b>U</b>              | <b>R</b>              |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>(Btu/(h*ft²F))</b> | <b>(ft)</b>        | <b>(Btu/(h*ft²F))</b> | <b>(h*ft²F/Btu)</b>   |
| 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               |
| <b>ROOF (inside to outside)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |                    |                       |                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>k</b>              | <b>Thickness</b>   | <b>U</b>              | <b>R</b>              |
| <b>ELEMENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>(Btu/(h*ft²F))</b> | <b>(ft)</b>        | <b>(Btu/(h*ft²F))</b> | <b>(h*ft²F/Btu)</b>   |
| 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               |
| <b>SUMMARY</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                       |                    |                       |                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>AREA</b>           | <b>UA</b>          |                       |                       |
| <b>COMPONENT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>(ft²)</b>          | <b>(Btu/(h°F))</b> |                       |                       |
| Wall                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 813.752               | 1.432              |                       |                       |
| Floor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 516.668               | 0.909              |                       |                       |
| Roof                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 516.668               | 0.909              |                       |                       |
| Infiltration                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                       | 0.000              |                       |                       |
| Total UA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                       | 3.250              |                       |                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>ACH</b>            | <b>VOLUME</b>      | <b>ALTITUDE</b>       | <b>UAinf (Note 3)</b> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       | <b>(ft³)</b>       | <b>(ft)</b>           | <b>(Btu/(h°F))</b>    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 0.000                 | 4577               | 6.56                  | 0.000                 |
| <p>Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are &lt; 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.</p> <p>Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.</p> <p>Note 3: Infiltration derived from:<br/> ACH*Volume*(specific heat of air)*(density of air at specified altitude)</p> |                       |                    |                       |                       |

**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 <sup>2</sup> K (1.46 Btu/(hft <sup>2</sup> F)) |
| Upward heat transfer on horizontal surfaces   | 9.26 W/m <sup>2</sup> K (1.63 Btu/(hft <sup>2</sup> F)) |
| Downward heat transfer on horizontal surfaces | 6.13 W/m <sup>2</sup> K (1.08 Btu/(hft <sup>2</sup> 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<sup>2</sup>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<sup>2</sup>K [0.90 Btu/(hft<sup>2</sup>F)] for an interior infrared emissivity of 0.9.

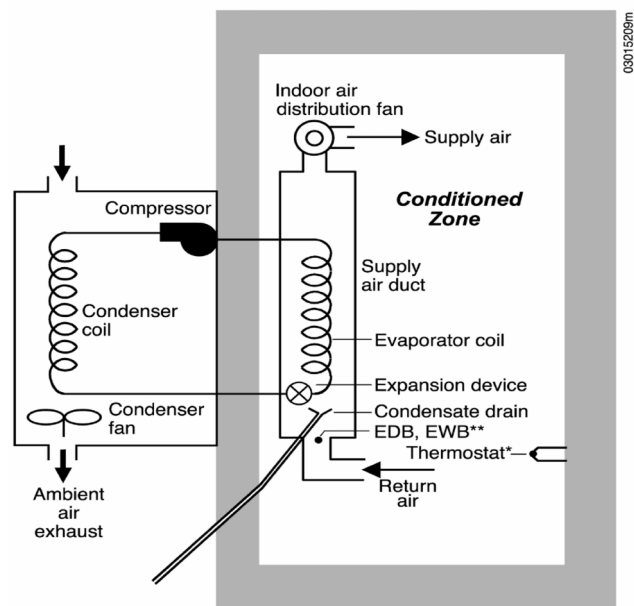
If the program being tested does not allow you to schedule these coefficients, then use 8.29 W/m<sup>2</sup>K [1.46 Btu/(hft<sup>2</sup>F)] for all horizontal surfaces. If different values can be justified, then use different values.

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



\* The thermostat senses only the zone air temperature (IDB)

\*\* Location of entering dry bulb and wet bulb temperatures

**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<sup>3</sup>/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 <sup>A-3</sup> 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, (net cap)<sub>adj</sub>, which is determined by

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

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

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

The technique for determining adjusted net sensible capacities (see Table 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<sup>1</sup> (SI Units)**

| ODB<br>(°C)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | EWB<br>(°C) | Net Total<br>Capacity <sup>2,3,4</sup><br>(kW) | Net Sensible Capacity <sup>2,3</sup> (kW) at<br>entering drybulb temperature (EDB, °C) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°C) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------------------|----------------------------------------------------------------------------------------|------|------|------|------|------------------------------------------|---------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                                                | 22.2                                                                                   | 23.3 | 24.4 | 25.6 | 26.7 |                                          |                                             |
| 29.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| 32.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| 35.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| 37.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| 40.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| 46.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
| <b>Values at ARI Rating Conditions (EDB = 26.7°C, EWB = 19.4°C, ODB = 35.0°C)</b><br>Net Total Capacity            7852 W<br>Airflow                         0.425 m <sup>3</sup> /s<br>Apparatus Dew Point        13.8 °C<br>Compressor Power           1858 W<br>Indoor Fan Power            230 W<br>Outdoor Fan Power          108 W<br>COP                              3.62<br>Seasonal Efficiency Rating<br>COP <sub>SEER</sub> 3.78                                                                                                                                                                                                                                        |             |                                                |                                                                                        |      |      |      |      |                                          |                                             |
| <b>Abbreviations:</b> ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature;<br>EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute;<br>COP = coefficient of performance;<br>COP <sub>SEER</sub> = dimensionless Seasonal Energy Efficiency Ratio.                                                                                                                                                                                                                                                                                                                                                                              |             |                                                |                                                                                        |      |      |      |      |                                          |                                             |
| <b>Notes:</b><br><sup>1</sup> 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.<br><sup>2</sup> Listed net total and net sensible capacities are gross total and gross sensible capacities respectively, with manufacturer default fan heat (329 W) deducted.<br><sup>3</sup> Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).<br><sup>4</sup> Compressor kW, Apparatus Dew Point, and Net Total Capacity valid only for wet coil. |             |                                                |                                                                                        |      |      |      |      |                                          |                                             |

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**TABLE 26b**  
**Equipment Full-Load Performance<sup>1</sup> (I-P Units)**

| ODB<br>(°F) | EWB<br>(°F) | Net Total<br>Capacity <sup>2,3,4</sup><br>(kBtu/h) | Net Sensible Capacity <sup>2,3</sup> (kBtu/h) at<br>entering drybulb temperature (EDB, °F) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°F) |
|-------------|-------------|----------------------------------------------------|--------------------------------------------------------------------------------------------|------|------|------|------|------------------------------------------|---------------------------------------------|
|             |             |                                                    | 72                                                                                         | 74   | 76   | 78   | 80   |                                          |                                             |
| 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 ratio; SEER = seasonal energy efficiency ratio.

Notes:

<sup>1</sup> 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.

<sup>2</sup> 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.

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

<sup>4</sup> 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<sup>1</sup> (SI Units)**

| ODB<br>(°C) | EWB<br>(°C) | Gross Total<br>Capacity <sup>2,3,4</sup><br>(kW) | Gross Sensible Capacity <sup>2,3</sup> (kW) at<br>entering drybulb temperature (EDB, °C) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°C) |
|-------------|-------------|--------------------------------------------------|------------------------------------------------------------------------------------------|------|------|------|------|------------------------------------------|---------------------------------------------|
|             |             |                                                  | 22.2                                                                                     | 23.3 | 24.4 | 25.6 | 26.7 |                                          |                                             |
| 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<sup>3</sup>/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<sub>SEER</sub>                    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<sub>SEER</sub> = dimensionless Seasonal Energy Efficiency Ratio.

Notes:

<sup>1</sup> 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.

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

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

<sup>4</sup> 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<sup>1</sup> (I-P Units)**

| ODB<br>(°F)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | EWB<br>(°F) | Gross Total<br>Capacity <sup>2,3,4</sup><br>(kBtu/h) | Gross Sensible Capacity <sup>2,3</sup> (kBtu/h) at<br>entering drybulb temperature (EDB, °F) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°F) |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------------------------|----------------------------------------------------------------------------------------------|------|------|------|------|------------------------------------------|---------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |             |                                                      | 72                                                                                           | 74   | 76   | 78   | 80   |                                          |                                             |
| 85                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| 90                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| 95                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| 100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| 105                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| 115                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 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                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 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                                        |
| <b>Values at ARI Rating Conditions (EDB = 80°F, EWB = 67°F, ODB = 95°F)</b><br>Gross Total Capacity    27920 Btu/h<br>Airflow                      900 CFM<br>Apparatus Dew Pt        56.8 °F<br>Compressor Power       1858 W<br>Indoor Fan Power        230 W<br>Outdoor Fan Power      108 W<br>EER                          12.36 (Btu/h)/W<br>Seasonal Efficiency Rating<br>SEER                    12.90 (Btu/h)/W                                                                                                                                                                                                               |             |                                                      |                                                                                              |      |      |      |      |                                          |                                             |
| <b>Abbreviations:</b> ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature;<br>EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute;<br>EER = energy efficiency ratio; SEER = seasonal energy efficiency ratio.                                                                                                                                                                                                                                                                                                                                                                     |             |                                                      |                                                                                              |      |      |      |      |                                          |                                             |
| <b>Notes:</b><br><sup>1</sup> 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.<br><sup>2</sup> Listed gross total and gross sensible capacities include manufacturer default fan heat of 1.12 kBtu/h.<br><sup>3</sup> Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).<br><sup>4</sup> 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<sup>1</sup> (SI Units)**

| ODB<br>(°C)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | EWB<br>(°C) | Adj Net Total<br>Capacity <sup>2,3,4</sup><br>(kW) | Adjusted Net Sensible Capacity <sup>2,3</sup> (kW) at<br>entering drybulb temperature (EDB, °C) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°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)<br>Adj Net Total Capacity            7951 W<br>Airflow                                0.4248 m <sup>3</sup> /s<br>Apparatus Dew Point                13.8 °C<br>Compressor Power                  1858 W<br>Indoor Fan Power                    230 W<br>Outdoor Fan Power                  108 W<br>COP                                    3.62<br>Seasonal Efficiency Rating<br>COP <sub>SEER</sub> 3.78                                                                                                                                                                        |             |                                                    |                                                                                                 |      |      |      |      |                                          |                                             |
| Abbreviations: ODB = outdoor drybulb temperature; EWB = entering wetbulb temperature;<br>EDB = entering drybulb temperature; ARI = Air-Conditioning and Refrigeration Institute;<br>COP = coefficient of performance;<br>COP <sub>SEER</sub> = dimensionless Seasonal Energy Efficiency Ratio.                                                                                                                                                                                                                                                                                                                                                               |             |                                                    |                                                                                                 |      |      |      |      |                                          |                                             |
| Notes:<br><sup>1</sup> 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.<br><sup>2</sup> Listed adjusted net total and adjusted net sensible capacities are gross capacities with actual fan heat (230 W) subtracted.<br><sup>3</sup> Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).<br><sup>4</sup> 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<sup>1</sup> (I-P Units)**

| ODB<br>(°F) | EWB<br>(°F) | Adj Net Total<br>Capacity <sup>2,3,4</sup><br>(kBtu/h) | Adjusted Net Sensible Capacity <sup>2,3</sup> (kBtu/h)<br>at entering drybulb temperature (EDB, °F) |      |      |      |      | Compressor<br>Power <sup>4</sup><br>(kW) | Apparatus<br>Dew Point <sup>4</sup><br>(°F) |
|-------------|-------------|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------|------|------|------|------|------------------------------------------|---------------------------------------------|
|             |             |                                                        | 72                                                                                                  | 74   | 76   | 78   | 80   |                                          |                                             |
| 85          | 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                                        |
|             | 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                                        |
| 90          | 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                                        |
|             | 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                                        |
| 95          | 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                                        |
|             | 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                                        |
| 100         | 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                                        |
|             | 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                                        |
| 105         | 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                                        |
|             | 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                                        |
| 115         | 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                                        |
|             | 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 ratio; SEER = seasonal energy efficiency ratio.

**Notes:**

- <sup>1</sup> 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.
- <sup>2</sup> Listed adjusted net total and adjusted net sensible capacities are gross capacities with actual fan heat (785 Btu/h) subtracted.
- <sup>3</sup> Where (Sensible Capacity) > (Total Capacity) indicates dry coil condition; in such case (Total Capacity) = (Sensible Capacity).
- <sup>4</sup> 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.<sup>A-4</sup>

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:

$$\text{Adjusted net total capacity} = \text{adjusted net sensible capacity} = 7.66 \text{ kW}$$

Linear interpolation based on adjusted net total capacity gives

$$\text{Maximum EWB for the dry-coil condition} = 16.75^\circ\text{C}$$

$$\text{Compressor power} = 1.652 \text{ kW}$$

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:

$$\text{Adjusted net total capacity} = \text{adjusted net sensible capacity} = 6.87 \text{ kW}$$

$$\text{Maximum dry-coil EWB} = 13.8^\circ\text{C}$$

$$\text{Resulting compressor power} = 1.598 \text{ kW.}$$

**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                  |
| <i>Maximum dry EWB</i><br><i>16.75*</i> | 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) |
|----------------------------------------|----------------------------------|-------------------------------------|-----------------------|
| <i>Maximum dry EWB</i><br><i>13.8*</i> | 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<sub>SEER</sub>” 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.

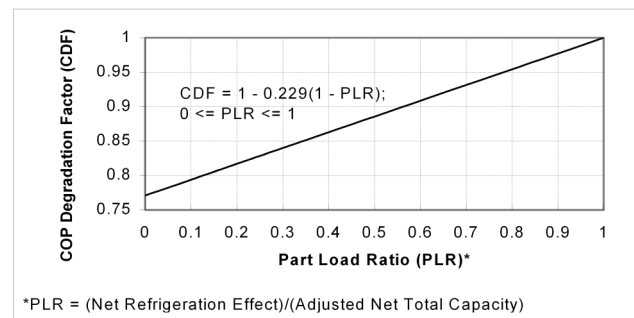
BF at ARI rating conditions is *approximately*  $0.049 \leq BF \leq 0.080$ .

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  $\leq 7.7^{\circ}\text{C}$  ( $45.9^{\circ}\text{F}$ ).



**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.<sup>A-5</sup>

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

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

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),

$$\text{Hourly fractional run time} = \text{PLR}/\text{CDF}.$$

In Figure 10, the PLR is calculated by

$$(\text{Net refrigeration effect}) / (\text{Adjusted net total capacity}),$$

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

PLR may be alternatively calculated as

$$(\text{Gross total coil load}) / (\text{Gross total capacity}),$$

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 m<sup>2</sup> (4.50 ft<sup>2</sup>)
- 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 m<sup>2</sup> (23.99 ft<sup>2</sup>).

**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 m<sup>2</sup> (345.36 ft<sup>2</sup>).

**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<sup>3</sup>/s = 1529 m<sup>3</sup>/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.

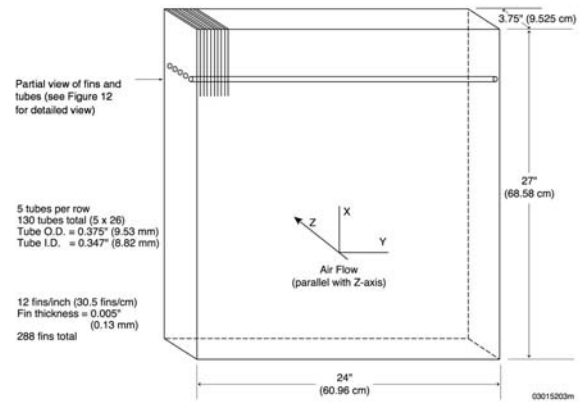
The draw-through indoor air distribution fan cycles on and off with the compressor. For calculating additional heating of the distribution air related to waste heat from the indoor distribution fan, assume that the distribution fan motor is mounted in the distribution airstream so that **100% of the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

**5.3.1.10.6.2 Outdoor Condenser Fan.**

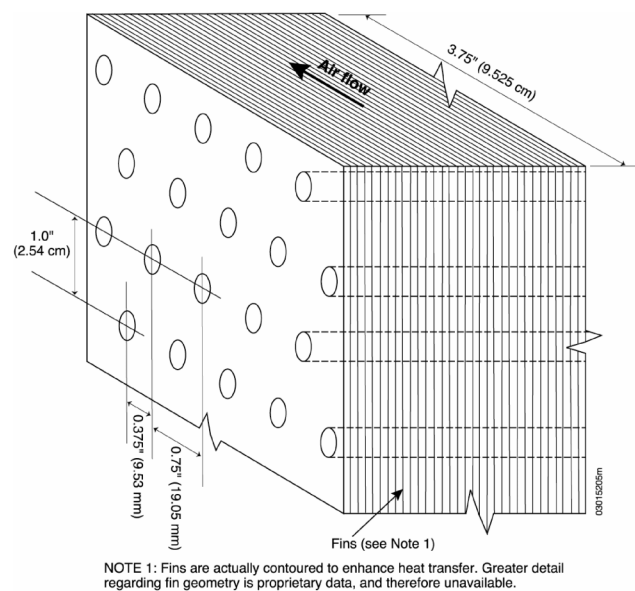
- Outdoor fan power = 108 W.

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  $> 26.7^{\circ}\text{C}$  ( $80.0^{\circ}\text{F}$ ); 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  $> 26.7^{\circ}\text{C}$  ( $80.0^{\circ}\text{F}$ ); 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  $> 23.3^{\circ}\text{C}$  ( $74.0^{\circ}\text{F}$ ); 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 ( $\geq 0$ ).

### 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 293.

**Table 293**

#### 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 ( $^{\circ}\text{C}$ )
- (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<br>(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/m <sup>2</sup> (119.2 kBtu/ft <sup>2</sup> )           |
| Direct Normal Solar Radiation 3-Month Total      |                                         | 1350 MJ/m <sup>2</sup> (118.8 kBtu/ft <sup>2</sup> )           |
| Direct Horizontal Solar Radiation 3-Month Total  |                                         | 817 MJ/m <sup>2</sup> (71.9 kBtu/ft <sup>2</sup> )             |
| Diffuse Horizontal Solar Radiation 3-Month Total |                                         | 536 MJ/m <sup>2</sup> (47.2 kBtu/ft <sup>2</sup> )             |
| 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<br>(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/m <sup>2</sup> (568 kBtu/ft <sup>2</sup> )             |                              |
| Direct Normal Solar Radiation Annual Total      | 5418 MJ/m <sup>2</sup> (477 kBtu/ft <sup>2</sup> )             |                              |
| Diffuse Horizontal Solar Radiation Annual Total | 2914 MJ/m <sup>2</sup> (257 kBtu/ft <sup>2</sup> )             |                              |
| Quantities That Vary Between Data Sets          | Ambient Dry Bulb<br>Temperature (constant)                     | Ambient<br>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 A1-42. 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<sup>8</sup> 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

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

and where

Lst ≡ standard meridian longitude (degrees)

Lloc ≡ local site longitude (degrees)

$$E = -9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B - 229.2(0.000075 + 0.001868 \cos(B) - 0.032077 \sin(B) - 0.014615 \cos(2B) - 0.04089 \sin(2B)) \text{ (minutes)}$$

where

$$B = 360(n - 81)/365 \text{ (degrees)}$$

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.<sup>4</sup>

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<sup>A-6</sup> 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.]***

[illegible]

**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]) <sup>A-6</sup>                                                                                                       |
| 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. |
| <b>038 - 044</b><br>038<br>040 - 041<br>043 - 044                                                                                                        | Latitude    | Latitude of the station<br>N = North of equator<br>Degrees<br>Minutes                                                                                                                                     |
| <b>046 - 053</b><br>046<br>048 - 050<br>052 - 053                                                                                                        | Longitude   | Longitude of the station<br>W = West, E = East<br>Degrees<br>Minutes                                                                                                                                      |
| 056 - 059                                                                                                                                                | Elevation   | Elevation of station in meters above sea level                                                                                                                                                            |
| FORTRAN Sample Format:<br>(1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4)<br>C Sample Format:<br>(%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                                                                                                                                                                                                                 |
|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>002 - 009</b><br>002 - 003<br>004 - 005<br>006 - 007<br>008 - 009 | Local Standard Time<br>Year<br>Month<br>Day<br>Hour                                             | 61 - 90<br>1 - 12<br>1 - 31<br>1 - 24 | Year, 1961-1990<br>Month<br>Day of month<br>Hour of day in local standard time                                                                                                                                             |
| 010 - 013                                                            | Extraterrestrial Horizontal Radiation                                                           | 0 - 1415                              | Amount of solar radiation in $\text{Wh/m}^2$ 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 $\text{Wh/m}^2$ received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated                                                       |
| <b>018 - 023</b><br>018 - 021<br>022<br>023                          | Global Horizontal Radiation<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty  | 0 - 1200<br>A - H, ?<br>0 - 9         | Total amount of direct and diffuse solar radiation in $\text{Wh/m}^2$ received on a horizontal surface during the 60 minutes preceding the hour indicated                                                                  |
| <b>024 - 029</b><br>024 - 027<br>028<br>029                          | Direct Normal Radiation<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty      | 0 - 1100<br>A - H, ?<br>0 - 9         | Amount of solar radiation in $\text{Wh/m}^2$ received within a $5.7^\circ$ field of view centered on the sun, during the 60 minutes preceding the hour indicated                                                           |
| <b>030 - 035</b><br>030 - 033<br>034<br>035                          | Diffuse Horizontal Radiation<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty | 0 - 700<br>A - H, ?<br>0 - 9          | Amount of solar radiation in $\text{Wh/m}^2$ received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated                                                   |
| <b>036 - 041</b><br>036 - 039<br>040<br>041                          | Global Horiz. Illuminance<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty    | 0 - 1,300<br>I, ?<br>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.<br>0 to 1,300 = 0 to 130,000 lux                            |
| <b>042 - 047</b><br>042 - 045<br>046<br>047                          | Direct Normal Illuminance<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty    | 0 - 1,100<br>I, ?<br>0 - 9            | Average amount of direct normal illuminance in hundreds of lux received within a $5.7^\circ$ degree field of view centered on the sun during the 60 minutes preceding the hour indicated.<br>0 to 1,100 = 0 to 110,000 lux |
| <b>048 - 053</b><br>048 - 051<br>052<br>053                          | Diffuse Horiz. Illuminance<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty   | 0 - 800<br>I, ?<br>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.<br>0 to 800 = 0 to 80,000 lux                |
| <b>054 - 059</b><br>054 - 057<br>058<br>059                          | Zenith Luminance<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty             | 0 - 7,000<br>I, ?<br>0 - 9            | Average amount of luminance at the sky's zenith in tens of $\text{Cd/m}^2$ during the 60 minutes preceding the hour indicated.<br>0 to 7,000 = 0 to 70,000 $\text{Cd/m}^2$                                                 |
| <b>060 - 063</b><br>060 - 061<br>062<br>063                          | Total Sky Cover<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty              | 0 - 10<br>A - F, ?<br>0 - 9           | Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated                                                                                                                                |
| <b>064 - 067</b><br>064 - 065<br>066<br>067                          | Opaque Sky Cover<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty             | 0 - 10<br>A - F<br>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                                                                          |
| <b>068 - 073</b><br>068 - 071<br>072<br>073                          | Dry Bulb Temperature<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty         | -500 to 500<br>A - F<br>0 - 9         | Dry bulb temperature in tenths of $^\circ\text{C}$ at the hour indicated.<br>-500 to 500 = -50.0 to 50.0 degrees C                                                                                                         |
| <b>074 - 079</b><br>074 - 077<br>078<br>079                          | Dew Point Temperature<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty        | -600 to 300<br>A - F<br>0 - 9         | Dew point temperature in tenths of $^\circ\text{C}$ at the hour indicated.<br>-600 to 300 = -60.0 to 30.0 $^\circ\text{C}$                                                                                                 |

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

| Field Position                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Element                                                                                     | Values                                                   | Definition                                                                                                                                                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>080 - 084</b><br>080 - 082<br>083<br>084                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Relative Humidity<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty        | 0 - 100<br>A - F<br>0 - 9                                | Relative humidity in percent at the hour indicated                                                                                                        |
| <b>085 - 090</b><br>085 - 088<br>089<br>090                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Atmospheric Pressure<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty     | 700 - 1100<br>A - F<br>0 - 9                             | Atmospheric pressure at station in millibars at the hour indicated                                                                                        |
| <b>091 - 095</b><br>091 - 093<br>094<br>095                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Wind Direction<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty           | 0 - 360<br>A - F<br>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.                    |
| <b>096 - 100</b><br>096 - 98<br>99<br>100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Wind Speed<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty               | 0 - 400<br>A - F<br>0 - 9                                | Wind speed in tenths of meters per second at the hour indicated.<br>0 to 400 = 0 to 40.0 m/s                                                              |
| <b>101 - 106</b><br>101 - 104<br>105<br>106                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Visibility<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty               | 0 - 1609<br>A - F, ?<br>0 - 9                            | Horizontal visibility in tenths of kilometers at the hour indicated.<br>7777 = unlimited visibility<br>0 to 1609 = 0.0 to 160.9 km<br>9999 = missing data |
| <b>107 - 113</b><br>107 - 111<br>112<br>113                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Ceiling Height<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty           | 0 - 30450<br>A - F, ?<br>0 - 9                           | Ceiling height in meters at the hour indicated.<br>77777 = unlimited ceiling height<br>88888 = cirroform<br>99999 = missing data                          |
| 114 - 123                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Present Weather                                                                             | See Appendix B of Marion and Urban (1995) <sup>A-6</sup> | Present weather conditions denoted by a 10-digit number. See Appendix B of Marion and Urban (1995) <sup>A-6</sup> for key to present weather elements.    |
| <b>124 - 128</b><br>124 - 126<br>127<br>128                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Precipitable Water<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty       | 0 - 100<br>A - F<br>0 - 9                                | Precipitable water in millimeters at the hour indicated                                                                                                   |
| <b>129 - 133</b><br>129 - 131<br>132<br>133                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Aerosol Optical Depth<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty    | 0 - 240<br>A - F<br>0 - 9                                | Broadband aerosol optical depth (broad-band turbidity) in thousandths on the day indicated.<br>0 to 240 = 0.0 to 0.240                                    |
| <b>134 - 138</b><br>134 - 136<br>137<br>138                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Snow Depth<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty               | 0 - 150<br>A - F, ?<br>0 - 9                             | Snow depth in centimeters on the day indicated.<br>999 = missing data                                                                                     |
| <b>139 - 142</b><br>139 - 140<br>141<br>142                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Days Since Last Snowfall<br>Data Value<br>Flag for Data Source<br>Flag for Data Uncertainty | 0 - 88<br>A - F, ?<br>0 - 9                              | Number of days since last snowfall<br>88 = 88 or greater days<br>99 = missing data                                                                        |
| <p>FORTRAN Sample Format:</p> <pre>(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))</pre> <p>C Sample Format:</p> <pre>(%2d%2d%2d%2d%4d%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%1d%3d%1s%1d%3d%1s%1d%3d%1s%1d%2d%1s%1d)</pre> <p>Note: For ceiling height data, integer variable should accept data values as large as 99999.</p> |                                                                                             |                                                          |                                                                                                                                                           |

(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 (~~S140OUT2Sec5-2out.XLSWK3~~, spreadsheet file)
- (b) Output Results for Section 5.3 Cases (Sec5-3out.XLS, spreadsheet file)
- (c) Modeling Notes (S140OUT2S140outNotes.TXT, text file reprinted as Attachment A2.3A2.4)

For entering output results into ~~S140OUT2Sec5-2out.XLSWK3~~ 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 ~~S140OUT2S140outNotes.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 ~~S140OUT2Sec5-2out.XLSWK3~~**

**[Informative Note: Revise results as follows.]**

STANDARD 140 OUTPUT FORM - RESULTS     ~~17-DEC~~  
~~1997; S140OUT2Sec5-2out.XLSWK3~~

**[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 "/ Worksheet Range Format Date 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<sup>3</sup>**

**[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<sup>5</sup>**

(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).**

| Case #                                                                                                                                                                                                         | Zone            |               |             | Weather     | Comments                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------|-------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                | Internal Gains* |               | Setpoint    | ODB<br>(°C) |                                                                                                                                                    |
|                                                                                                                                                                                                                | Sensible<br>(W) | Latent<br>(W) | EDB<br>(°C) |             |                                                                                                                                                    |
| 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.<br>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.<br>Tests PLR at low ODB vs E110.                                                                                     |
| humid zone series                                                                                                                                                                                              |                 |               |             |             |                                                                                                                                                    |
| E150                                                                                                                                                                                                           | 5400            | 1100          | 22.2        | 29.4        | High PLR. High SHR.<br>Tests latent load versus E110.                                                                                              |
| E160                                                                                                                                                                                                           | 5400            | 1100          | 26.7        | 29.4        | High PLR. High SHR.<br>Tests EDB versus E150.                                                                                                      |
| E165                                                                                                                                                                                                           | 5400            | 1100          | 23.3        | 40.6        | High PLR. High SHR. Tests ODB & EDB<br>interaction with latent load versus E160.                                                                   |
| E170                                                                                                                                                                                                           | 2100            | 1100          | 22.2        | 29.4        | Mid PLR. Mid SHR.<br>Tests low sensible load versus E150.                                                                                          |
| E180                                                                                                                                                                                                           | 2100            | 4400          | 22.2        | 29.4        | High PLR. Low SHR.<br>Tests SHR versus E150.<br>Tests high latent load versus E170.                                                                |
| E185                                                                                                                                                                                                           | 2100            | 4400          | 22.2        | 46.1        | High PLR. Low SHR.<br>Tests ODB versus E180.                                                                                                       |
| E190                                                                                                                                                                                                           | 270             | 550           | 22.2        | 29.4        | Low PLR. Low SHR<br>Tests low PLR at constant SHR vs E180.<br>Tests latent load at low PLR versus E140.                                            |
| E195                                                                                                                                                                                                           | 270             | 550           | 22.2        | 46.1        | Low PLR. Low SHR<br>Tests ODB at low PLR & SHR versus E190.<br>Tests low PLR at constant SHR vs E185.<br>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<br>at full sensible and latent loads.                                                                     |
| Abbreviations: PLR = Part Load Ratio; ODB = outdoor drybulb temperature;<br>EDB = entering drybulb temperature; vs = versus;<br>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<br>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).**

| Case #                                                                                                                                                                                                         | Zone                |                   |             | Weather     | Comments                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-------------------|-------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                | Internal Gains*     |                   | Setpoint    | ODB<br>(°F) |                                                                                                                                                    |
|                                                                                                                                                                                                                | Sensible<br>(Btu/h) | Latent<br>(Btu/h) | EDB<br>(°F) |             |                                                                                                                                                    |
| 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.<br>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.<br>Tests PLR at low ODB vs E110.                                                                                     |
| humid zone series                                                                                                                                                                                              |                     |                   |             |             |                                                                                                                                                    |
| E150                                                                                                                                                                                                           | 18430               | 3754              | 72.0        | 85.0        | High PLR. High SHR.<br>Tests latent load versus E110.                                                                                              |
| E160                                                                                                                                                                                                           | 18430               | 3754              | 80.0        | 85.0        | High PLR. High SHR.<br>Tests EDB versus E150.                                                                                                      |
| E165                                                                                                                                                                                                           | 18430               | 3754              | 74.0        | 105.0       | High PLR. High SHR. Tests ODB & EDB<br>interaction with latent load versus E160.                                                                   |
| E170                                                                                                                                                                                                           | 7166                | 3754              | 72.0        | 85.0        | Mid PLR. Mid SHR.<br>Tests low sensible load versus E150.                                                                                          |
| E180                                                                                                                                                                                                           | 7166                | 15018             | 72.0        | 85.0        | High PLR. Low SHR.<br>Tests SHR versus E150.<br>Tests high latent load versus E170.                                                                |
| E185                                                                                                                                                                                                           | 7166                | 15018             | 72.0        | 115.0       | High PLR. Low SHR.<br>Tests ODB versus E180.                                                                                                       |
| E190                                                                                                                                                                                                           | 922                 | 1877              | 72.0        | 85.0        | Low PLR. Low SHR<br>Tests low PLR at constant SHR vs E180.<br>Tests latent load at low PLR versus E140.                                            |
| E195                                                                                                                                                                                                           | 922                 | 1877              | 72.0        | 115.0       | Low PLR. Low SHR<br>Tests ODB at low PLR & SHR versus E190.<br>Tests low PLR at constant SHR vs E185.<br>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<br>at full sensible and latent loads.                                                                     |
| Abbreviations: PLR = Part Load Ratio; ODB = outdoor drybulb temperature;<br>EDB = entering drybulb temperature; vs = versus;<br>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<br>operation of the mechanical cooling system or its air distribution fan.                                       |                     |                   |             |             |                                                                                                                                                    |

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

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## 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.<sup>14</sup> ~~(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.

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## 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.XLSWK3 in the files accompanying this standard. Documentation regarding RESULTS5-2.XLSWK3 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*<sup>14</sup>.

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## 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 B9-5B9-4 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, 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).

**B9.5B9.4.2 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.

**B9.6B9.4.3 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 Examples**

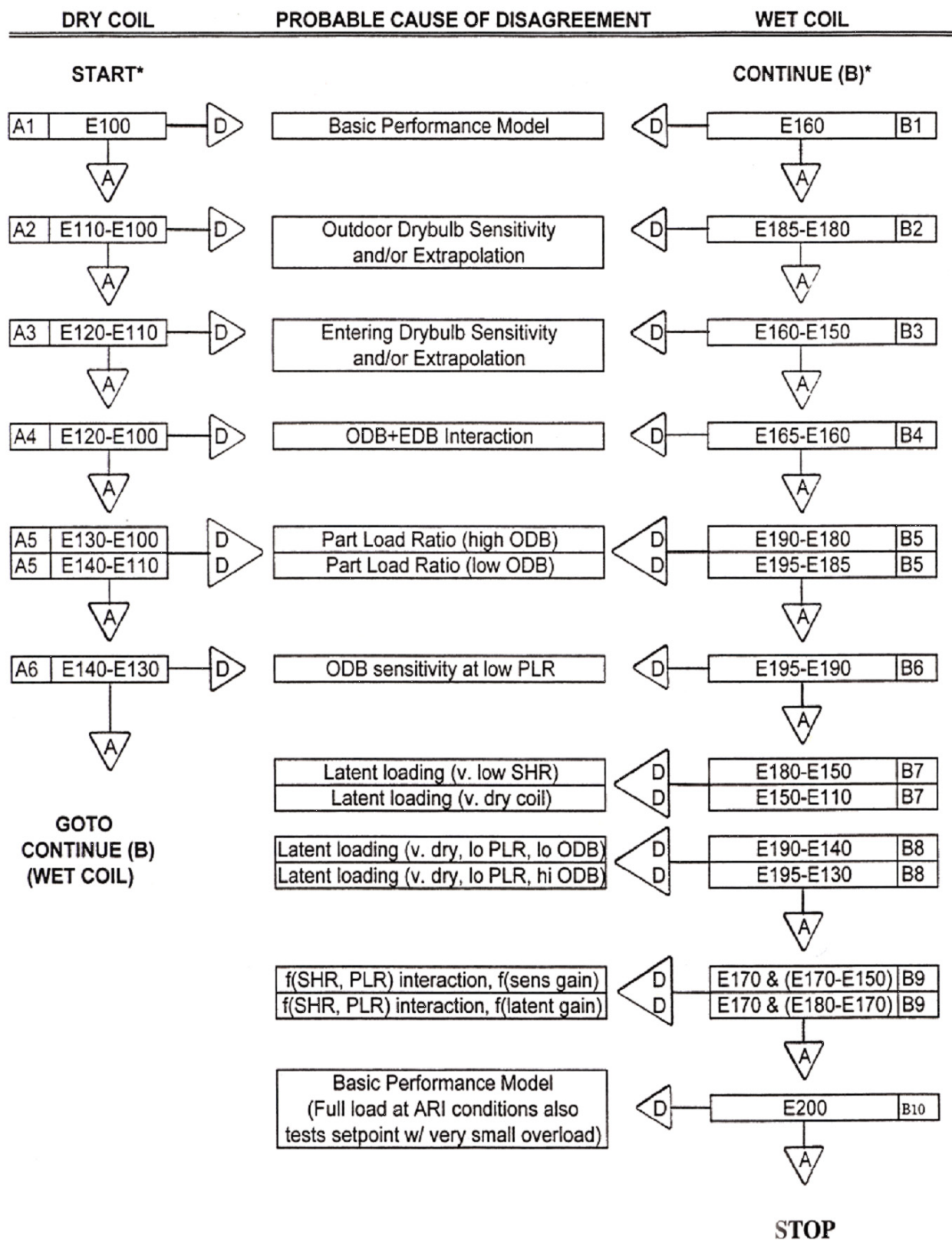
### **B9.6.1 Example Using Flow Diagrams for Building Thermal Envelope and Fabric Load Tests (Section 5.2).**

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<sup>14</sup> 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<sup>A-5</sup> 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.



**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.**

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## **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.XLSWK3 24 ~~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 (~~S140OUT2Sec5-2out.XLSWK3~~) has been designed such that values input to Column B of ~~S140OUT2Sec5-2out.XLSWK3~~ 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'<br>(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<br>(Total, Compressor, Supply Fan, Condenser Fan)     | A6 – P75      |
| COP including (Max-Min)/Mean                                                                | A185 – P220   |
| Coil Loads: Total, Sensible, Latent,<br>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.~~DOCTXT~~ 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*<sup>14</sup>. 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.

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## 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),

$$\begin{aligned} \text{CDF} &= 1 - \text{Cd}(1 - \text{PLR}), 0 \leq \text{PLR} \leq 1 \\ \text{CDF} &= 1, \text{PLR} \geq 1 \end{aligned} \quad (1)$$

where Cd is assumed constant for a given unit.

Cd can be determined from listed performance data using:

$$\text{SEER} = \text{EERb} (1 - 0.5\text{Cd}) \text{ which solves for Cd as,}$$

$$\text{Cd} = (1 - \text{SEER} / \text{EERb}) / 0.5 \quad (2)$$

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.

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#### Calculations to obtain EERb

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

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

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.<sup>A-7</sup> 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

$$PLR1 = Q_{net} / CAP_{net}$$

where

$Q_{net}$  = net refrigeration effect,

$CAP_{net}$  = adjusted net total capacity.

We wish to check the equivalence of defining PLR as

$$PLR2 = Q_{gtc} / CAP_{gtc}$$

where

$Q_{gtc}$  = gross total coil load,

$CAP_{gtc}$  = gross total capacity.

The net refrigeration effect =  $Q_{gtc} - Q_{fan}$   
where  $Q_{fan}$  is the air distribution fan heat.

The adjusted net capacity =  $CAP_{gtc} - P_{fan}$   
where  $P_{fan}$  = fan rated power.

Then, for  $PLR1 = PLR2$  to be true implies

$$Q_{gtc} / CAP_{gtc} = (Q_{gtc} - Q_{fan}) / (CAP_{gtc} - P_{fan}),$$

which is true if

$$Q_{fan} / P_{fan} = Q_{gtc} / CAP_{gtc},$$

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  $Q_{gtc}/CAP_{gtc}$  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

$$Q_{fan} / P_{fan} = PLR / CDF.$$

However, this relation implies

$$Q_{fan} / P_{fan} \neq Q_{gtc} / CAP_{gtc}$$

with the theoretical result that  $PLR1 \neq PLR2$ .

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<br>(Btu/h) | Qgtc<br>(Btu/h) | Pfan<br>(Btu/h) | CDF2   | Qfan<br>(Btu/h) | Qfan/<br>Pfan | Qnet<br>(Btu/h) | CAPnet<br>(Btu/h) | Qnet/<br>CAPnet | PLR1=  | PLR2/<br>PLR1 | PLR2 -<br>PLR1 | CDF1       | CDF2/<br>CDF1 |
|-------|-------------------|-----------------|-----------------|--------|-----------------|---------------|-----------------|-------------------|-----------------|--------|---------------|----------------|------------|---------------|
| 0.01  | 27920             | 2792            | 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         | 1.00021681 |               |
| 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             | 0.454         | 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         | 1.00049288 |               |
| 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         | 12150           | 27135             | 0.4481          | 1.0042 | 0.0019        | 0.8736         | 1.00049158 |               |
| 0.46  | 27920             | 12843           | 785             | 0.8763 | 412             | 0.525         | 12411           | 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         | 19954           | 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         | 1.00026558 |               |
| 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  $\pm 1\%$ .

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  $\pm 1\%$  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 <sup>3</sup> /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)                                       |
| $\rho_r$  | density of standard dry air at fan rating conditions (0.075 lb/ft <sup>3</sup> ) |

### B14.2.2 Known Information

Air-Conditioning and Refrigeration Institute (ARI) Conditions:

- $T_{db1} = 80^\circ\text{F}$
- $T_{wb1} = 67^\circ\text{F}$ .

From Table 26d at ARI conditions:

- $Q = 900 \text{ ft}^3/\text{min}$
- $q_s = 21700 \text{ Btu/h}$  (gross sensible capacity)
- $q_T = 27900 \text{ Btu/h}$  (gross total capacity)
- $ADP = 56.8^\circ\text{F}$ .

### B14.2.3 Governing Equations

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

The following equations and related properties are commonly used approximations for working with volumetric flow rates.<sup>A-9</sup>

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

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

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

$$cp_a = 0.24 \text{ Btu/lb}^\circ\text{F}$$

$$cp_w = 0.45 \text{ Btu/lb}^\circ\text{F}$$

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

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

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

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

### 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.<sup>A-10</sup> The condition line is the line going through coil entering conditions with slope determined by sensible heat ratio for the given operating conditions.<sup>A-8</sup> 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 ( $T_{db1} = 80.0^\circ\text{F}$ ,  $T_{wb1} = 67^\circ\text{F}$ ). 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  $q_T = 27,900 \text{ Btu/h}$  and  $Q = 900 \text{ ft}^3/\text{min}$ . From ideal gas equations commonly used for psychrometrics,<sup>1</sup> at ARI conditions  $h_1 = 31.45 \text{ Btu/lb dry air}$ . These values applied to Equation (B14-2) give:

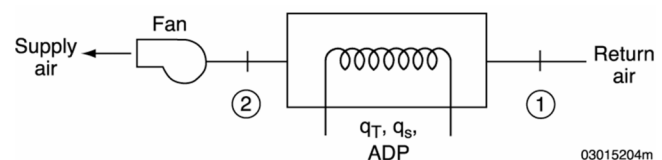


Figure B14-1 System schematic.

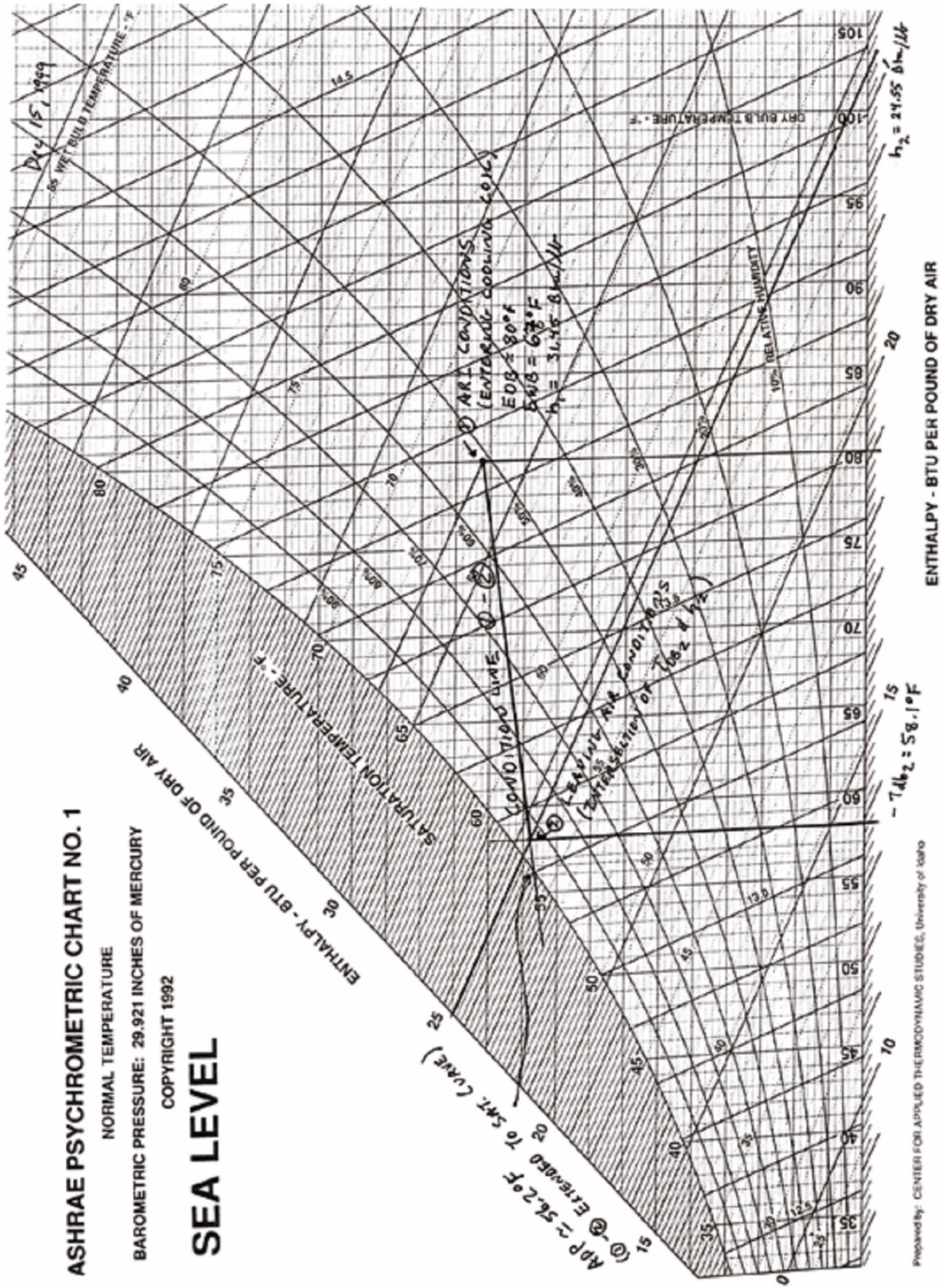


Figure B14-2 ADP calculation.

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

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

$$T_{db2} = 58.1^\circ\text{F.}$$

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

$$\text{ADP} = 56.2^\circ\text{F.}$$

Solving Equation (B14-1) using  $T_{db1} = 80^\circ\text{F}$ ,  $T_{db2} = 58.1^\circ\text{F}$ , and  $\text{ADP} = 56.2^\circ\text{F}$  gives:

$$\text{BF} = 0.080$$

#### B14.2.5 Solution Technique Using ADP Listed in Performance Data

Solving Equation (B14-1) using  $T_{db1} = 80^\circ\text{F}$ ,  $T_{db2} = 58.1^\circ\text{F}$ , and  $\text{ADP} = 56.8^\circ\text{F}$  gives:

$$\text{BF} = 0.055$$

#### B14.2.6 Solution by TUD

The TRNSYS-TUD modeler report in Part III of HVAC BESTEST<sup>A-5</sup> indicates that:

$$\text{BF} = 0.049$$

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:

$$0.049 \leq \text{BF} \leq 0.080$$

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  $\pm 1\%$ .
- Assuming a constant value of BF versus allowing BF to vary as a function of EWB and ODB adds an additional  $\pm 1\%$  uncertainty to the total energy consumption results for Case E185, and less for the other cases.

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## ANNEX B15

### INDOOR FAN DATA EQUIVALENCE

Fan performance data for indoor fan power (230 W) and airflow rate (900 CFM =  $0.425 \text{ m}^3/\text{s}$ ) 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  $68^\circ\text{F}$  ( $20^\circ\text{C}$ ) with a density of  $0.075 \text{ lb/ft}^3$  ( $1.204 \text{ kg/m}^3$ ).<sup>A-9</sup>

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

The **total fan pressure** is based on:<sup>A-11</sup>

$$\text{Eff} = Q * \Delta P / W$$

where

$Q$  = indoor fan airflow rate ( $\text{m}^3/\text{s}$ )

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

$W$  = fan electric power input (W)

$\text{Eff}$  = total fan plus motor and drive efficiency (motor/drive in air stream).

Solving for  $\Delta P$ ,

$$\Delta P = W * \text{Eff} / Q$$

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

The supply air temperature rise from fan heat is based on

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

where

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

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

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

$Q$  = indoor fan airflow rate ( $\text{ft}^3/\text{min}$  or  $\text{m}^3/\text{s}$ ),

$\Delta T$  = supply air temperature rise from fan heat ( $^\circ\text{F}$  or  $^\circ\text{C}$ ),

$C$  = units conversion constant.

Solving for  $\Delta T$ ,

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

where

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

$c_p = 0.24 \text{ Btu/lb F}$  for dry air, or

$c_p = 0.2445 \text{ Btu/lb F}$  when humidity ratio = 0.01.<sup>A-9</sup>

Then,  $\Delta T = 785 \text{ Btu/h} / \{0.075 \text{ lb/ft}^3 * 900 \text{ ft}^3/\text{min} * 60 \text{ min/h} * 0.2445 \text{ Btu/(lb°F)}\}$

$$\Delta T = 0.793^\circ\text{F} (0.441^\circ\text{C})$$

or

for  $c_p = 0.24 \text{ Btu/(lb°F)}$ ,  $\Delta T = 0.808^\circ\text{F} (0.449^\circ\text{C})$ .

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## 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*.<sup>A-5</sup>

#### 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.

|                   |                                                                         |
|-------------------|-------------------------------------------------------------------------|
| <b>Analytical</b> | quasi-analytical solution                                               |
| <b>ARI</b>        | Air-Conditioning & Refrigeration Institute                              |
| <b>CA-SIS</b>     | CA-SIS VI (see Table B17-1)                                             |
| <b>CIEMAT</b>     | Centro de Investigaciones Energeticas, Medioambientales y Technologicas |
| <b>CLM2000</b>    | CLIM2000 2.1.6 (see Table B17-1)                                        |
| <b>COP</b>        | coefficient of performance                                              |
| <b>Delta</b>      | sensitivity between listed cases                                        |

|                |                                                                                                      |                  |                                                        |
|----------------|------------------------------------------------------------------------------------------------------|------------------|--------------------------------------------------------|
| <b>DOE21E</b>  | DOE-2.1E-088 or DOE-2.1E-133 (see Table B17-1)                                                       | <b>ODB</b>       | outdoor dry-bulb temperature                           |
| <b>dry</b>     | dry coil                                                                                             | <b>PL</b>        | part-load ratio                                        |
| <b>EDF</b>     | Electricité de France                                                                                | <b>PLR</b>       | part-load ratio                                        |
| <b>Energy+</b> | EnergyPlus 1.0.0.023 (see Table B17-1)                                                               | <b>Qcoil,lat</b> | latent coil load                                       |
| <b>Hi</b>      | high                                                                                                 | <b>Qcoil,s</b>   | sensible coil load                                     |
| <b>HTAL1</b>   | quasi-analytical solution with ideal controller by Hochschule Technik & Architektur Luzern           | <b>Qcoil,t</b>   | total sensible + latent coil load                      |
| <b>HTAL2</b>   | quasi-analytical solution with realistic controller model by Hochschule Technik & Architektur Luzern | <b>Qcomp</b>     | compressor electric energy                             |
| <b>IDB</b>     | indoor dry-bulb temperature                                                                          | <b>Q ID fan</b>  | indoor fan electric energy                             |
| <b>kWh</b>     | kilowatt hours                                                                                       | <b>Q OD fan</b>  | outdoor fan electric energy                            |
| <b>kWh,e</b>   | kilowatt hours, electrical                                                                           | <b>Qtot</b>      | total electric energy of compressor + both fans        |
| <b>lat</b>     | latent internal gains                                                                                | <b>sens</b>      | sensible internal gains                                |
| <b>lo</b>      | low                                                                                                  | <b>SH</b>        | sensible heat ratio                                    |
| <b>m</b>       | mid-range                                                                                            | <b>SHR</b>       | sensible heat ratio                                    |
| <b>Max</b>     | maximum                                                                                              | <b>TRN-id</b>    | TRNSYS-TUD with ideal controller (see Table B17-1)     |
| <b>Min</b>     | minimum                                                                                              | <b>TRN-re</b>    | TRNSYS-TUD with realistic controller (see Table B17-1) |
| <b>GARD</b>    | GARD Analytics                                                                                       | <b>TUD</b>       | Technische Universität Dresden                         |
| <b>NREL</b>    | National Renewable Energy Laboratory                                                                 | <b>v.</b>        | versus                                                 |
|                |                                                                                                      | <b>x</b>         | multiplied by                                          |
|                |                                                                                                      | <b>@</b>         | at                                                     |

**Space Cooling Electricity Consumption**

| Energy Consumption, Total (kWh,e)         |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
|-------------------------------------------|---------|--------|--------|---------|--------|--------|------|-------------------------|------|--------------|------------|-------|-------|
| CA-SIS                                    | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              | TUD        | HTAL1 | HTAL2 |
| EDF                                       | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      | Min                     | Max  | / Analytical |            |       |       |
| 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)    |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
| CA-SIS                                    | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              | TUD        | HTAL1 | HTAL2 |
| EDF                                       | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      | Min                     | Max  | / Analytical |            |       |       |
| 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)    |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
| CA-SIS                                    | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              | TUD        | HTAL1 | HTAL2 |
| EDF                                       | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      | Min                     | Max  | / Analytical |            |       |       |
| 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) |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
| CA-SIS                                    | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              | TUD        | HTAL1 | HTAL2 |
| EDF                                       | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      | Min                     | Max  | / Analytical |            |       |       |
| 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              |        |         |        |        |         |        |        | Statistics, All Results |       |              | Analytical |       |       |
|-----------------------|--------|---------|--------|--------|---------|--------|--------|-------------------------|-------|--------------|------------|-------|-------|
|                       | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | (Max-Min)               |       |              | TUD        | HTAL1 | HTAL2 |
|                       | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    | Min                     | Max   | / Analytical |            |       |       |
| 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 |        |         |        |        |         |        |        | Statistics, All Results |       |              | Analytical |       |       |
|                       | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | (Max-Min)               |       |              | TUD        | HTAL1 | HTAL2 |
|                       | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    | Min                     | Max   | / Analytical |            |       |       |
| 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)    |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
|-----------------------------------|---------|--------|--------|---------|--------|--------|------|-------------------------|------|--------------|------------|-------|-------|
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              |            |       |       |
| 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) |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              |            |       |       |
| 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)   |         |        |        |         |        |        |      | Statistics, All Results |      |              | Analytical |       |       |
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |      | (Max-Min)               |      |              |            |       |       |
| 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  |

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| Sensible Coil - Zone Load, (Fan Heat) (kWh,thermal) |         |        |        |         |        |        |     | Statistics, All Results |     |              | Analytical |       |       |
|-----------------------------------------------------|---------|--------|--------|---------|--------|--------|-----|-------------------------|-----|--------------|------------|-------|-------|
| CA-SIS                                              | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |     | (Max-Min)               |     |              |            |       |       |
| 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)    |         |        |        |         |        |        |      |      | Statistics, All Results |      |             |      |       |       |
|-----------------------------------|---------|--------|--------|---------|--------|--------|------|------|-------------------------|------|-------------|------|-------|-------|
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | TUD  | TUD  | (Max-Min)               |      | Analytical  |      |       |       |
| EDF                               | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      |      | Min                     | Max  | /Analytical | TUD  | HTAL1 | HTAL2 |
| E100                              | 3656    | 3656   | 3654   | 3655    | 3654   | 3656   | 3656 | 3656 | 3654                    | 3656 | 0.1%        | 3656 | 3656  | 3656  |
| E110                              | 3637    | 3637   | 3636   | 3637    | 3636   | 3637   | 3637 | 3637 | 3636                    | 3637 | 0.0%        | 3637 | 3637  | 3637  |
| E120                              | 3632    | 3632   | 3630   | 3632    | 3631   | 3632   | 3631 | 3631 | 3630                    | 3632 | 0.0%        | 3632 | 3632  | 3632  |
| E130                              | 209     | 209    | 207    | 208     | 207    | 209    | 209  | 209  | 207                     | 209  | 1.3%        | 209  | 209   | 209   |
| E140                              | 190     | 190    | 189    | 188     | 188    | 190    | 190  | 190  | 188                     | 190  | 1.1%        | 190  | 190   | 190   |
| E150                              | 4376    | 4376   | 4375   | 4376    | 4375   | 4376   | 4376 | 4376 | 4375                    | 4376 | 0.0%        | 4376 | 4376  | 4376  |
| E160                              | 4371    | 4371   | 4370   | 4371    | 4370   | 4371   | 4371 | 4371 | 4370                    | 4371 | 0.0%        | 4371 | 4371  | 4371  |
| E165                              | 4388    | 4388   | 4386   | 4387    | 4386   | 4388   | 4387 | 4387 | 4386                    | 4388 | 0.0%        | 4388 | 4388  | 4388  |
| E170                              | 2159    | 2159   | 2157   | 2158    | 2157   | 2159   | 2159 | 2159 | 2157                    | 2159 | 0.1%        | 2159 | 2159  | 2159  |
| E180                              | 4376    | 4376   | 4375   | 4376    | 4375   | 4376   | 4376 | 4376 | 4375                    | 4376 | 0.0%        | 4376 | 4376  | 4376  |
| E185                              | 4396    | 4396   | 4394   | 4395    | 4393   | 4395   | 4395 | 4395 | 4393                    | 4396 | 0.1%        | 4396 | 4396  | 4396  |
| E190                              | 557     | 559    | 558    | 558     | 558    | 559    | 559  | 559  | 557                     | 559  | 0.4%        | 559  | 559   | 559   |
| E195                              | 576     | 579    | 577    | 577     | 576    | 578    | 579  | 579  | 576                     | 579  | 0.5%        | 579  | 579   | 579   |
| E200                              | 5343    | 5283   | 5342   | 5343    | 5342   | 5343   | 5343 | 5343 | 5283                    | 5343 | 1.1%        | 5343 | 5343  | 5343  |
| Zone Load, Sensible (kWh,thermal) |         |        |        |         |        |        |      |      | Statistics, All Results |      |             |      |       |       |
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | TUD  | TUD  | (Max-Min)               |      | Analytical  |      |       |       |
| EDF                               | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |      |      | Min                     | Max  | /Analytical | TUD  | HTAL1 | HTAL2 |
| E100                              | 3656    | 3656   | 3654   | 3655    | 3654   | 3656   | 3656 | 3656 | 3654                    | 3656 | 0.1%        | 3656 | 3656  | 3656  |
| E110                              | 3637    | 3637   | 3636   | 3637    | 3636   | 3637   | 3637 | 3637 | 3636                    | 3637 | 0.0%        | 3637 | 3637  | 3637  |
| E120                              | 3632    | 3632   | 3630   | 3632    | 3631   | 3632   | 3631 | 3631 | 3630                    | 3632 | 0.0%        | 3632 | 3632  | 3632  |
| E130                              | 209     | 209    | 207    | 208     | 207    | 209    | 209  | 209  | 207                     | 209  | 1.3%        | 209  | 209   | 209   |
| E140                              | 190     | 190    | 189    | 188     | 188    | 190    | 190  | 190  | 188                     | 190  | 1.1%        | 190  | 190   | 190   |
| E150                              | 3637    | 3637   | 3636   | 3637    | 3636   | 3637   | 3636 | 3636 | 3636                    | 3637 | 0.0%        | 3637 | 3637  | 3637  |
| E160                              | 3632    | 3632   | 3630   | 3632    | 3631   | 3632   | 3631 | 3631 | 3630                    | 3632 | 0.0%        | 3632 | 3632  | 3632  |
| E165                              | 3649    | 3649   | 3647   | 3648    | 3647   | 3649   | 3648 | 3648 | 3647                    | 3649 | 0.1%        | 3649 | 3649  | 3649  |
| E170                              | 1420    | 1420   | 1418   | 1419    | 1418   | 1419   | 1419 | 1419 | 1418                    | 1420 | 0.1%        | 1420 | 1420  | 1420  |
| E180                              | 1420    | 1420   | 1418   | 1419    | 1418   | 1419   | 1419 | 1419 | 1418                    | 1420 | 0.1%        | 1420 | 1420  | 1420  |
| E185                              | 1439    | 1439   | 1437   | 1437    | 1437   | 1438   | 1438 | 1438 | 1437                    | 1439 | 0.2%        | 1439 | 1439  | 1439  |
| E190                              | 190     | 190    | 188    | 188     | 188    | 190    | 190  | 190  | 188                     | 190  | 1.0%        | 190  | 190   | 190   |
| E195                              | 209     | 209    | 207    | 208     | 207    | 209    | 209  | 209  | 207                     | 209  | 1.1%        | 209  | 209   | 209   |
| E200                              | 4122    | 4062   | 4121   | 4122    | 4121   | 4122   | 4122 | 4122 | 4062                    | 4122 | 1.5%        | 4122 | 4122  | 4122  |
| Zone Load, Latent (kWh,thermal)   |         |        |        |         |        |        |      |      | Statistics, All Results |      |             |      |       |       |
| CA-SIS                            | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | TUD  | TUD  | (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     | 0     |
| E110                              | 0       | 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     | 0     |
| E130                              | 0       | 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     | 0     |
| E150                              | 739     | 739    | 739    | 739     | 739    | 739    | 739  | 739  | 739                     | 739  | 0.1%        | 739  | 739   | 739   |
| E160                              | 739     | 739    | 739    | 739     | 739    | 739    | 739  | 739  | 739                     | 739  | 0.1%        | 739  | 739   | 739   |
| E165                              | 739     | 739    | 739    | 739     | 739    | 739    | 739  | 739  | 739                     | 739  | 0.1%        | 739  | 739   | 739   |
| E170                              | 739     | 739    | 739    | 739     | 739    | 739    | 739  | 739  | 739                     | 739  | 0.1%        | 739  | 739   | 739   |
| E180                              | 2957    | 2957   | 2957   | 2958    | 2957   | 2957   | 2957 | 2957 | 2957                    | 2958 | 0.0%        | 2957 | 2957  | 2957  |
| E185                              | 2957    | 2957   | 2957   | 2958    | 2957   | 2957   | 2957 | 2957 | 2957                    | 2958 | 0.0%        | 2957 | 2957  | 2957  |
| E190                              | 367     | 370    | 370    | 370     | 370    | 370    | 370  | 370  | 367                     | 370  | 0.8%        | 370  | 370   | 370   |
| E195                              | 367     | 370    | 370    | 370     | 370    | 370    | 370  | 370  | 367                     | 370  | 0.8%        | 370  | 370   | 370   |
| E200                              | 1221    | 1221   | 1221   | 1221    | 1221   | 1221   | 1221 | 1221 | 1221                    | 1221 | 0.0%        | 1221 | 1221  | 1221  |

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| Latent Coil - Zone Load, (Should be 0) (kWh,thermal) |         |        |        |         |        |        |     |     | Statistics, All Results |     |             |     |       |       |
|------------------------------------------------------|---------|--------|--------|---------|--------|--------|-----|-----|-------------------------|-----|-------------|-----|-------|-------|
| CA-SIS                                               | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re | TUD | TUD | (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     | 0     |
| E110                                                 | 0       | 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     | 0     |
| E130                                                 | 0       | 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     | 0     |
| E150                                                 | 0       | 0      | 0      | 2       | -7     | 0      | 0   | 0   | -7                      | 2   |             | 0   | 0     | 0     |
| E160                                                 | 1       | 0      | 0      | 0       | -7     | 0      | 0   | 0   | -7                      | 1   |             | 0   | 0     | 0     |
| E165                                                 | 1       | 0      | 0      | 1       | -6     | 0      | 0   | 0   | -6                      | 1   |             | 0   | 0     | 0     |
| E170                                                 | 1       | 0      | 0      | -1      | -6     | 0      | 0   | 0   | -6                      | 1   |             | 0   | 0     | 0     |
| E180                                                 | 1       | 0      | 0      | -30     | -13    | 0      | 0   | 0   | -30                     | 1   |             | 1   | 0     | -1    |
| E185                                                 | 2       | 0      | 0      | -28     | -11    | 0      | 0   | 0   | -28                     | 2   |             | 1   | 0     | -1    |
| E190                                                 | 3       | 0      | 0      | -3      | -2     | 0      | 0   | 0   | -3                      | 3   |             | 0   | 0     | 0     |
| E195                                                 | 3       | 0      | 0      | -3      | -1     | 0      | 0   | 0   | -3                      | 3   |             | 0   | 0     | 0     |
| E200                                                 | 1       | 0      | 0      | -2      | -11    | 0      | 0   | 0   | -11                     | 1   |             | 0   | 0     | 0     |

# Sensitivities for Space Cooling Electricity Consumption

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

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

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# Sensitivities for COP and Coil Loads

| Delta COP (kWh,t)      |               |                |                  |                |                 |               |               | Statistics, All Results |                             |        | Analytical |       |       |
|------------------------|---------------|----------------|------------------|----------------|-----------------|---------------|---------------|-------------------------|-----------------------------|--------|------------|-------|-------|
|                        | CA-SIS<br>EDF | CLM2000<br>EDF | DOE21E<br>CIEMAT | DOE21E<br>NREL | Energy+<br>GARD | TRN-id<br>TUD | TRN-re<br>TUD | Min                     | Abs(Max-<br>Max fin)/Analy. |        | 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)   |               |                |                  |                |                 |               |               | Statistics, All Results |                             |        | Analytical |       |       |
|                        | CA-SIS<br>EDF | CLM2000<br>EDF | DOE21E<br>CIEMAT | DOE21E<br>NREL | Energy+<br>GARD | TRN-id<br>TUD | TRN-re<br>TUD | Min                     | Abs(Max-<br>Max fin)/Analy. |        | 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)   |               |                |                  |                |                 |               |               | Statistics, All Results |                             |        | Analytical |       |       |
|                        | CA-SIS<br>EDF | CLM2000<br>EDF | DOE21E<br>CIEMAT | DOE21E<br>NREL | Energy+<br>GARD | TRN-id<br>TUD | TRN-re<br>TUD | Min                     | Abs(Max-<br>Max fin)/Analy. |        | 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 Q coil,lat (kWh,t) |               |                |                  |                |                 |               |               | Statistics, All Results |                             |        | Analytical |       |       |
|                        | CA-SIS<br>EDF | CLM2000<br>EDF | DOE21E<br>CIEMAT | DOE21E<br>NREL | Energy+<br>GARD | TRN-id<br>TUD | TRN-re<br>TUD | Min                     | Abs(Max-<br>Max fin)/Analy. |        | TUD        | HTAL1 | HTAL2 |
| E110-E100              | 0             | 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     | 0     |
| E120-E100              | 0             | 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     | 0     |
| E140-E130              | 0             | 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     | 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     | 0     |
| E165-E160              | 0             | 0              | 0                | 1              | 1               | 0             | 0             | 0                       | 1                           | 0      | 0          | 0     | 0     |
| E170-E150              | 1             | 0              | 0                | -3             | 1               | 0             | 0             | -3                      | 1                           | 0      | 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     | 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     | 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  |

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

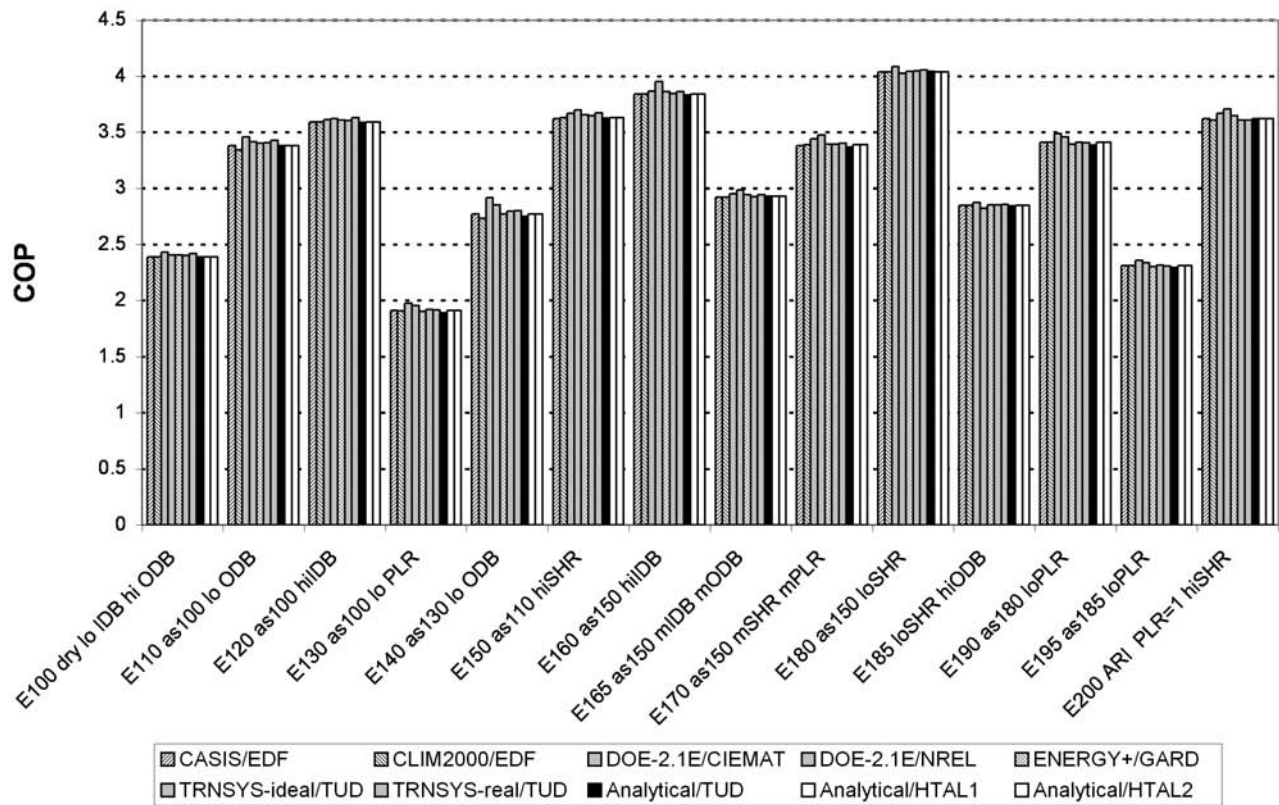
| Mean IDB (°C)              |        |         |        |        |         |        |        |  | Statistics, All Results |       |              | Analytical |       |       |
|----------------------------|--------|---------|--------|--------|---------|--------|--------|--|-------------------------|-------|--------------|------------|-------|-------|
|                            | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |  | (Max-Min)               |       |              | TUD        | HTAL1 | HTAL2 |
|                            | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |  | Min                     | Max   | / Analytical |            |       |       |
| 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) |        |         |        |        |         |        |        |  | Statistics, All Results |       |              | Analytical |       |       |
|                            | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |  | (Max-Min)               |       |              | TUD        | HTAL1 | HTAL2 |
|                            | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |  | Min                     | Max   | / Analytical |            |       |       |
| 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

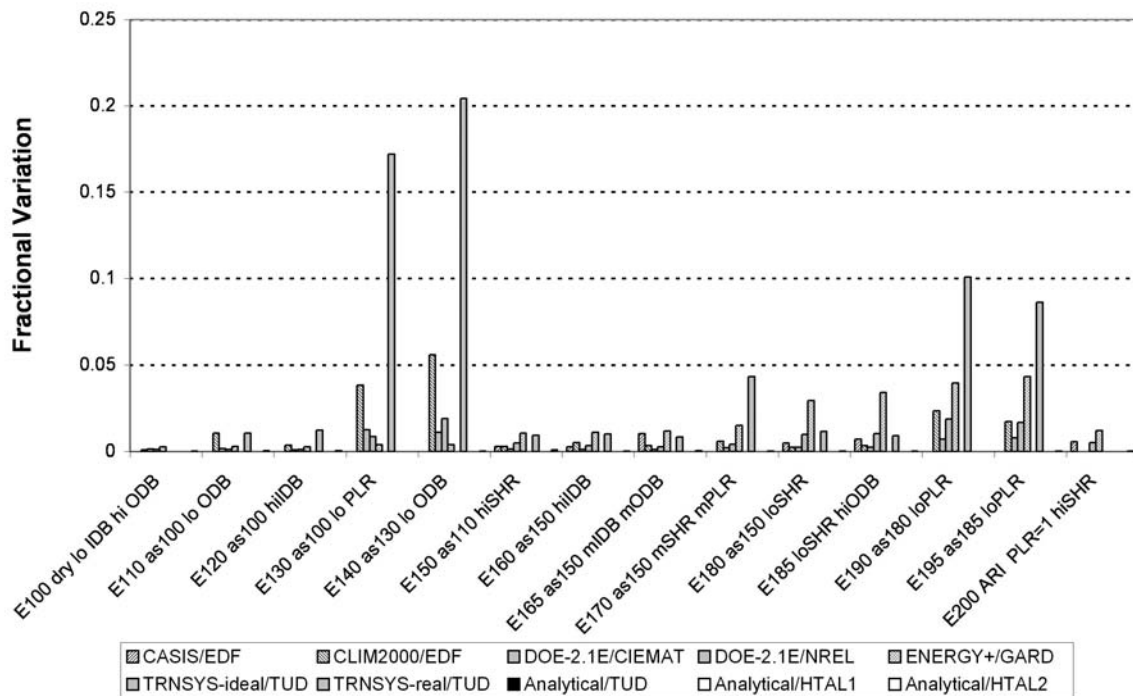
| Mean Humidity Ratio              |        |         |        |        |         |        |        |  | Statistics, All Results |        |              | Analytical |        |        |
|----------------------------------|--------|---------|--------|--------|---------|--------|--------|--|-------------------------|--------|--------------|------------|--------|--------|
|                                  | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |  | (Max-Min)               |        |              | TUD        | HTAL1  | HTAL2  |
|                                  | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |  | Min                     | Max    | / Analytical |            |        |        |
| 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 |        |         |        |        |         |        |        |  | Statistics, All Results |        |              | Analytical |        |        |
|                                  | CA-SIS | CLM2000 | DOE21E | DOE21E | Energy+ | TRN-id | TRN-re |  | (Max-Min)               |        |              | TUD        | HTAL1  | HTAL2  |
|                                  | EDF    | EDF     | CIEMAT | NREL   | GARD    | TUD    | TUD    |  | Min                     | Max    | / Analytical |            |        |        |
| 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  |

results5-3.xls q:bc233..br304; 10/15/02

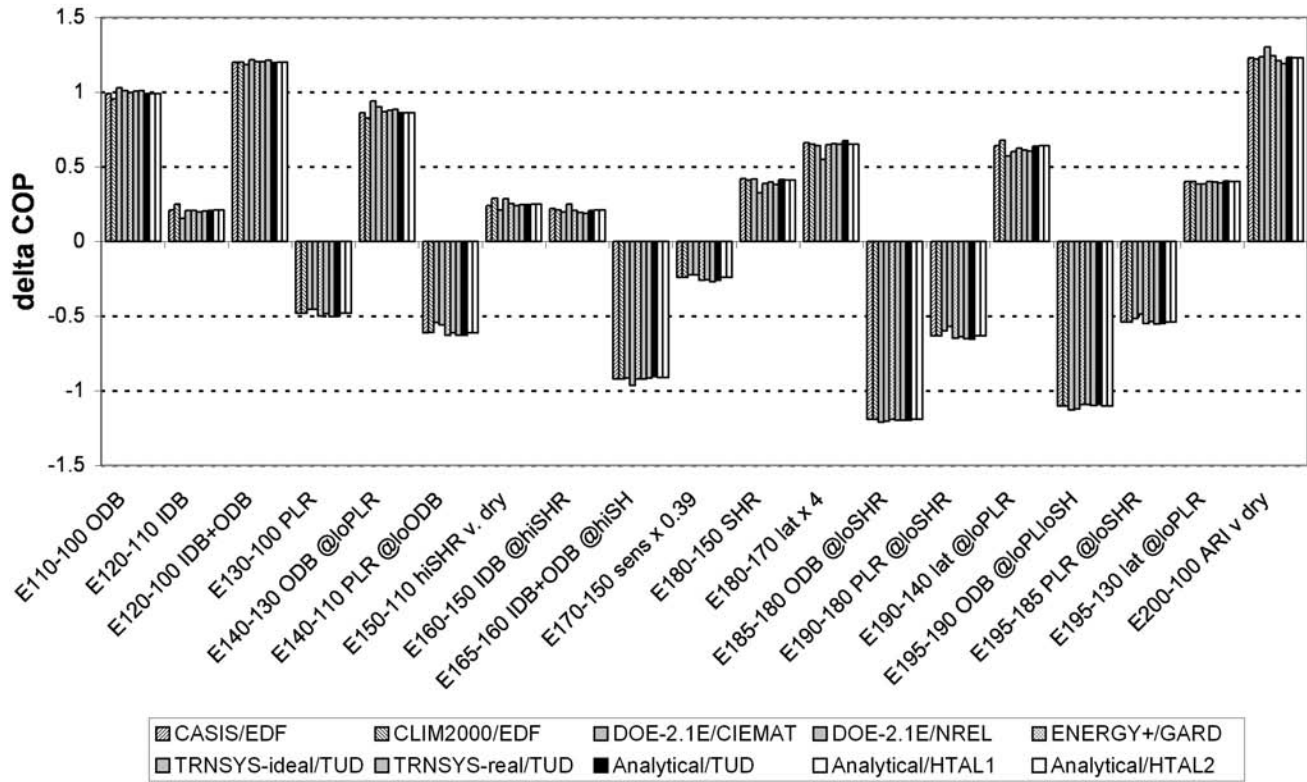
## HVAC BESTEST: Mean COP



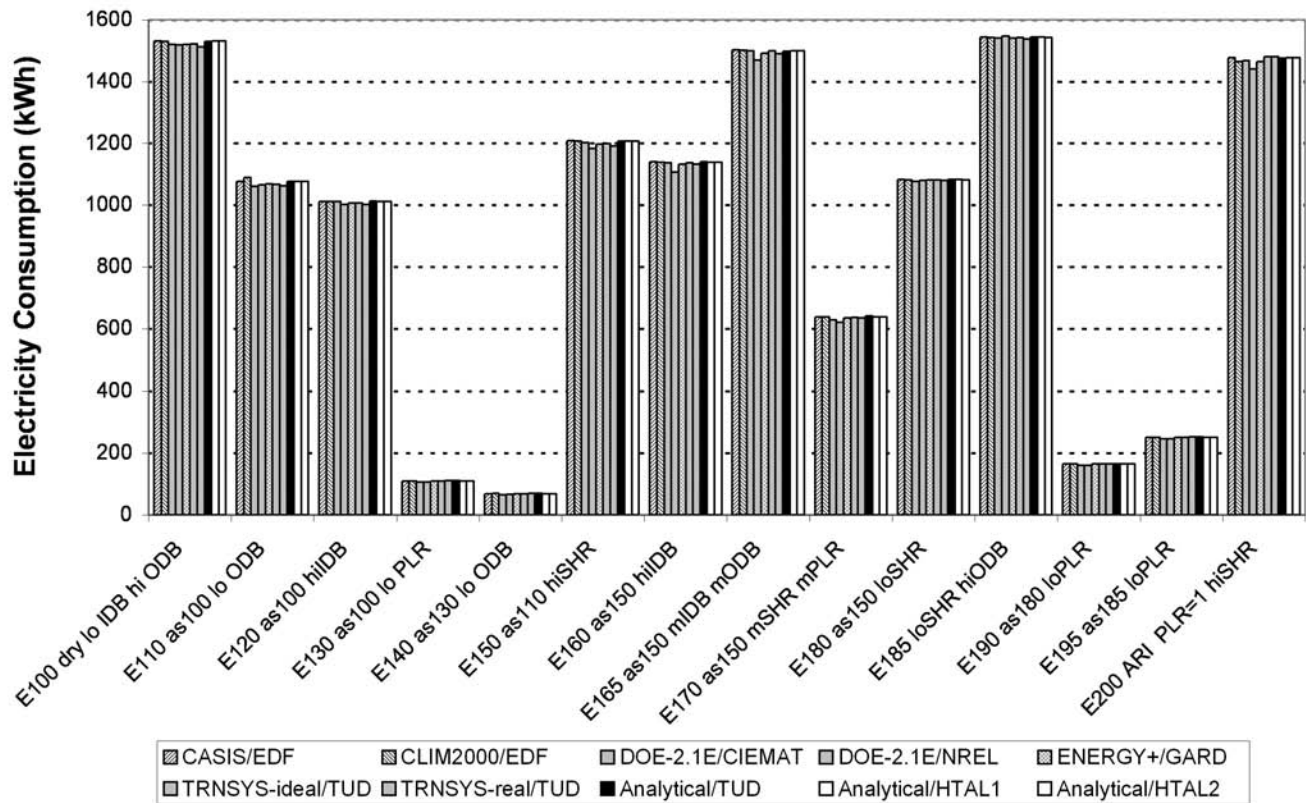
## HVAC BESTEST: (Maximum - Minimum)/Mean COP



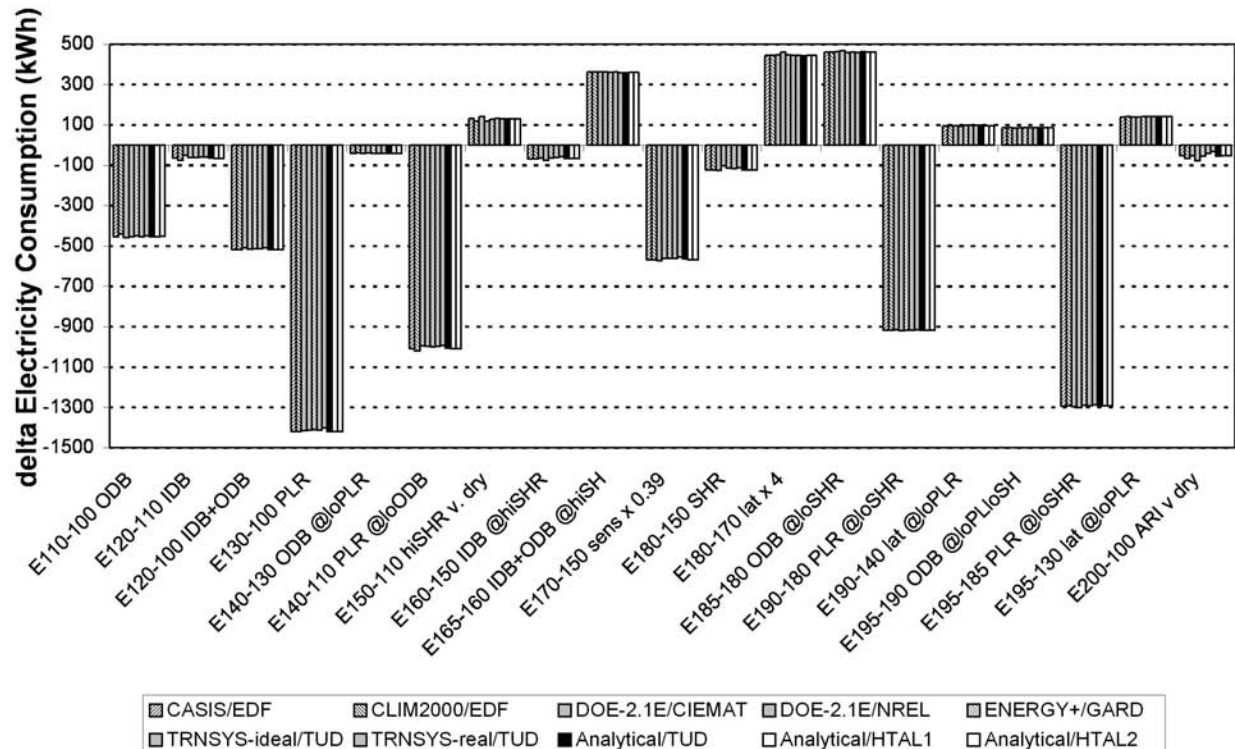
## HVAC BESTEST: Mean COP Sensitivities



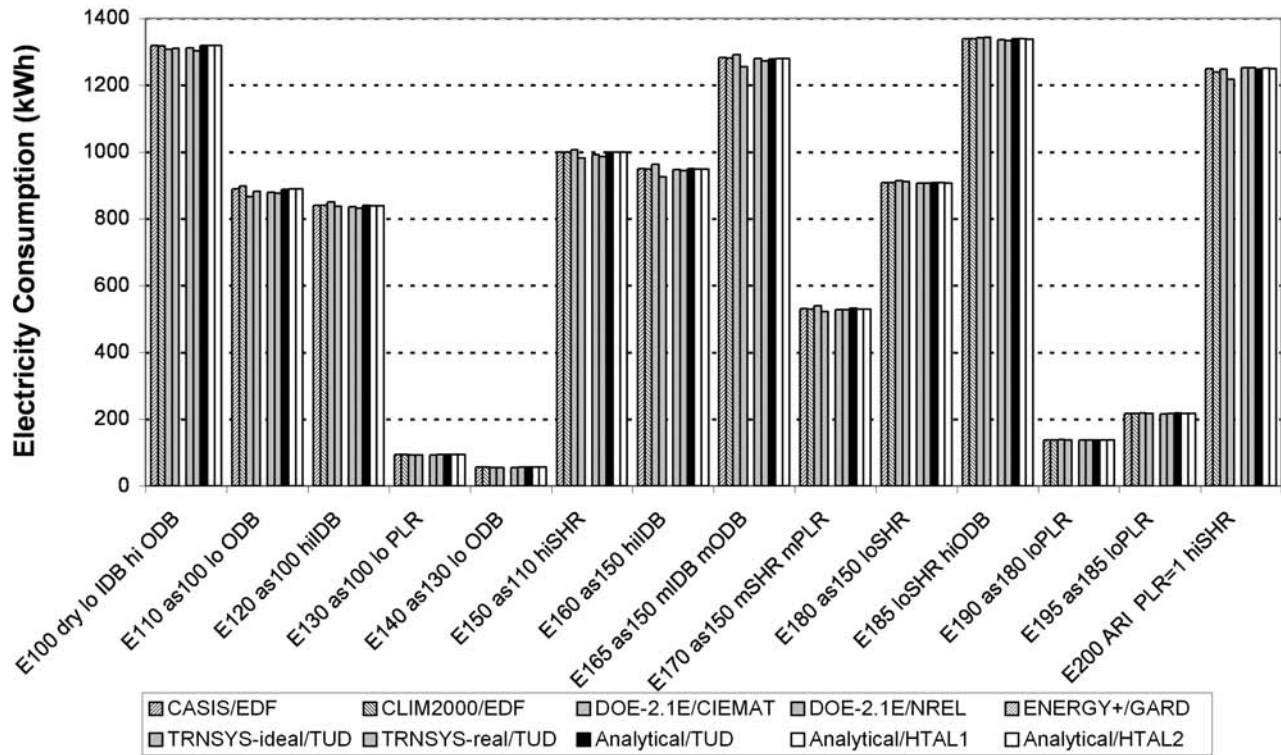
## HVAC BESTEST: Total Space Cooling Electricity Consumption



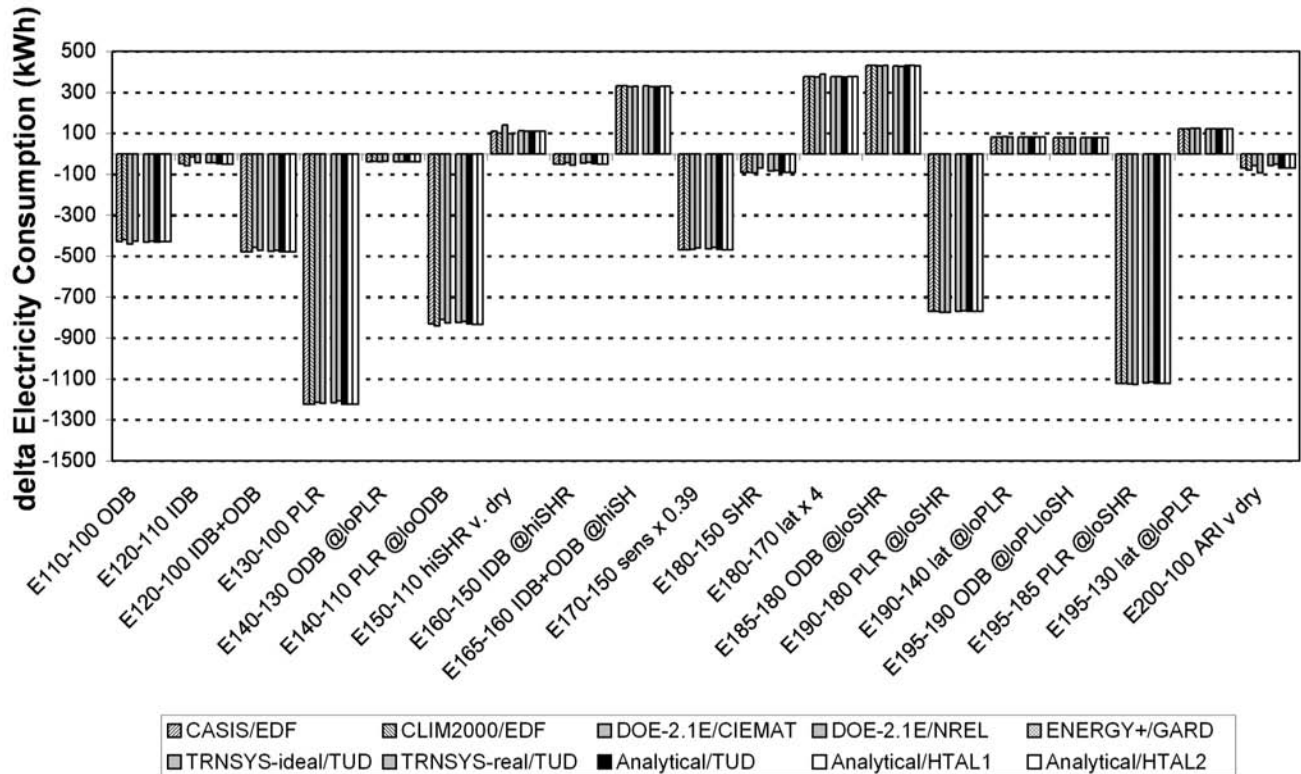
## HVAC BESTEST: Total Space Cooling Electricity Sensitivities



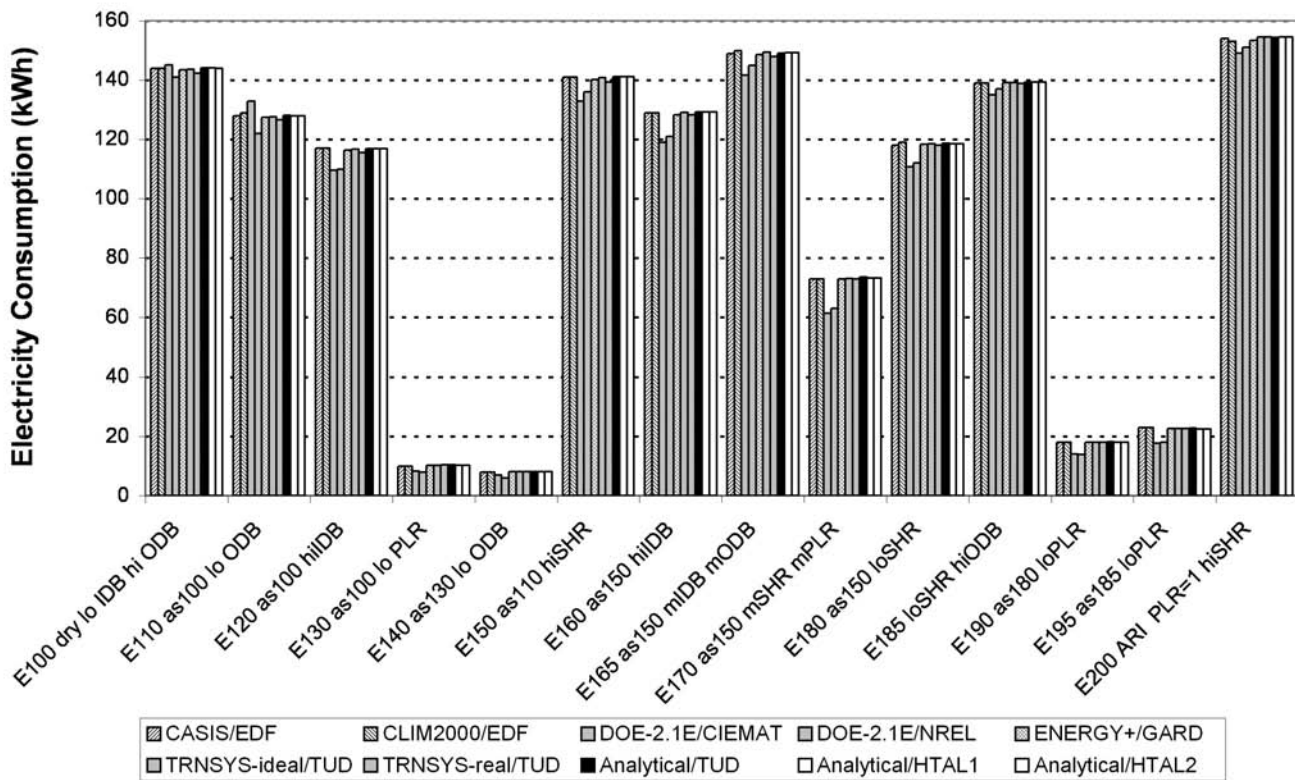
## HVAC BESTEST: Compressor Electricity Consumption



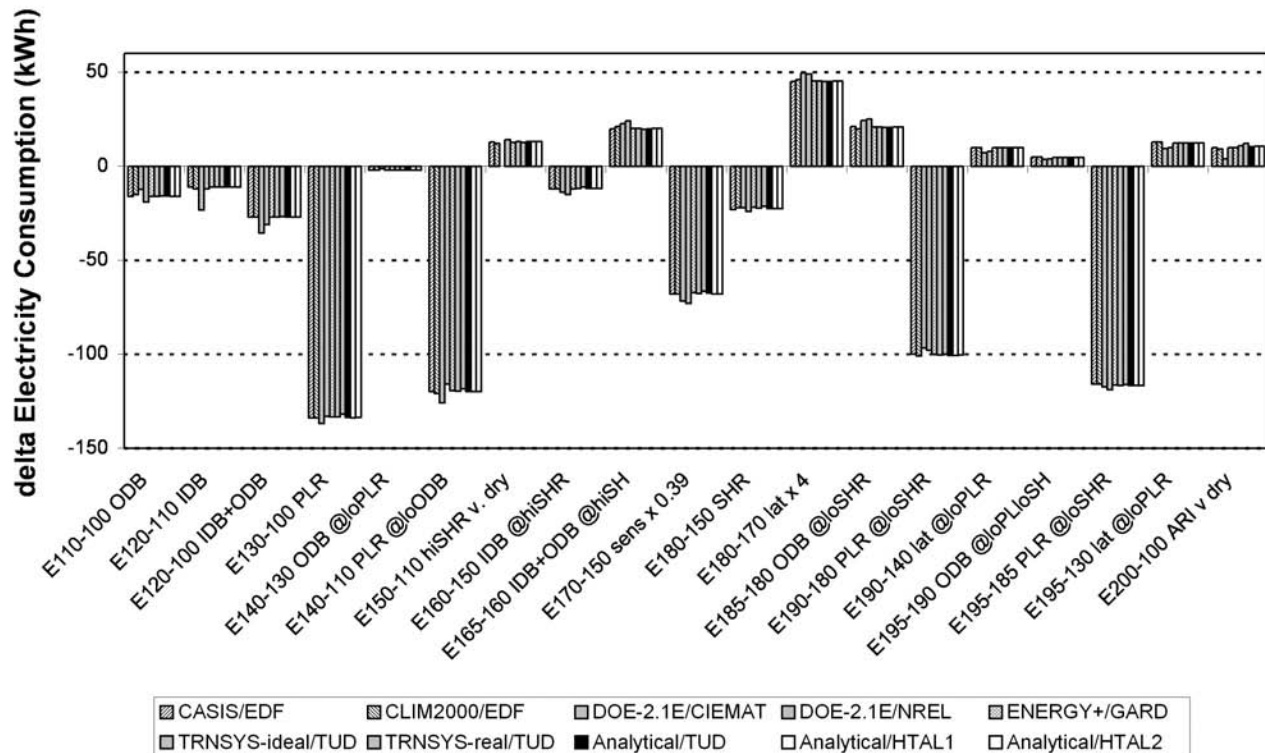
## HVAC BESTEST: Total Compressor Electricity Sensitivities



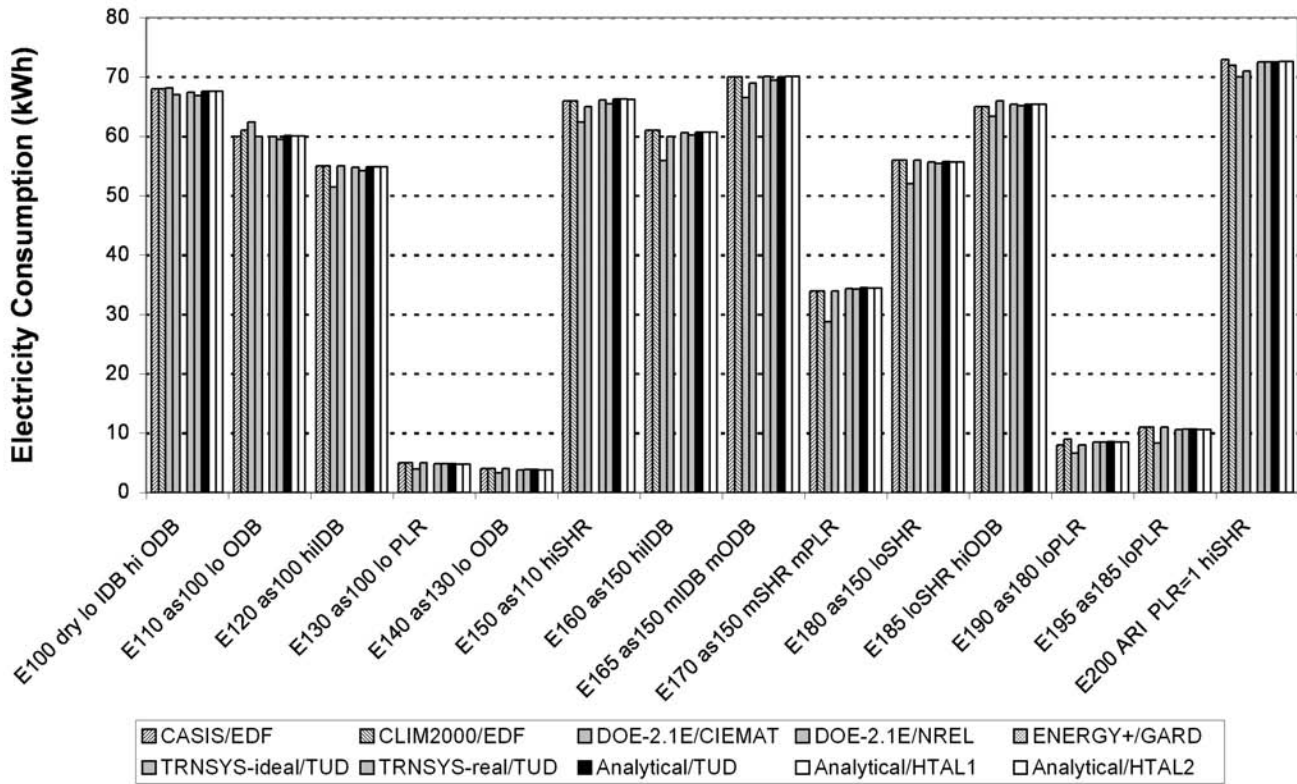
## HVAC BESTEST: Total Indoor (Supply) Fan Electricity Consumption



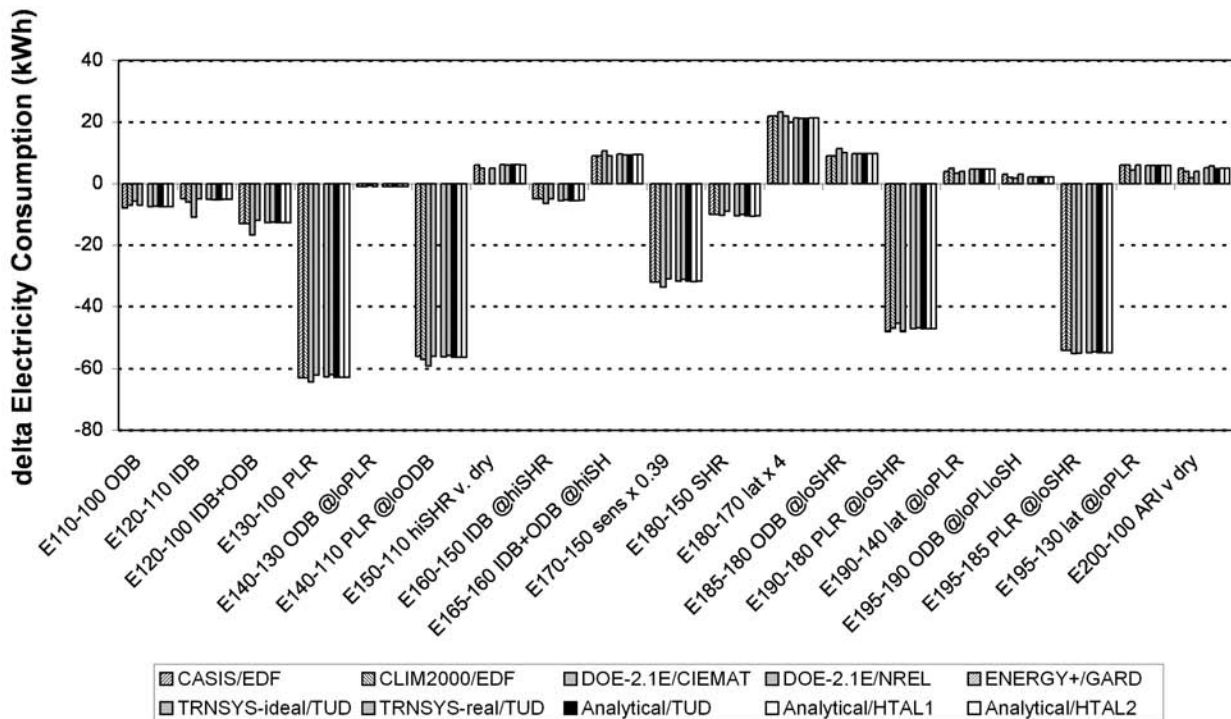
## HVAC BESTEST: Indoor (Supply) Fan Electricity Sensitivities



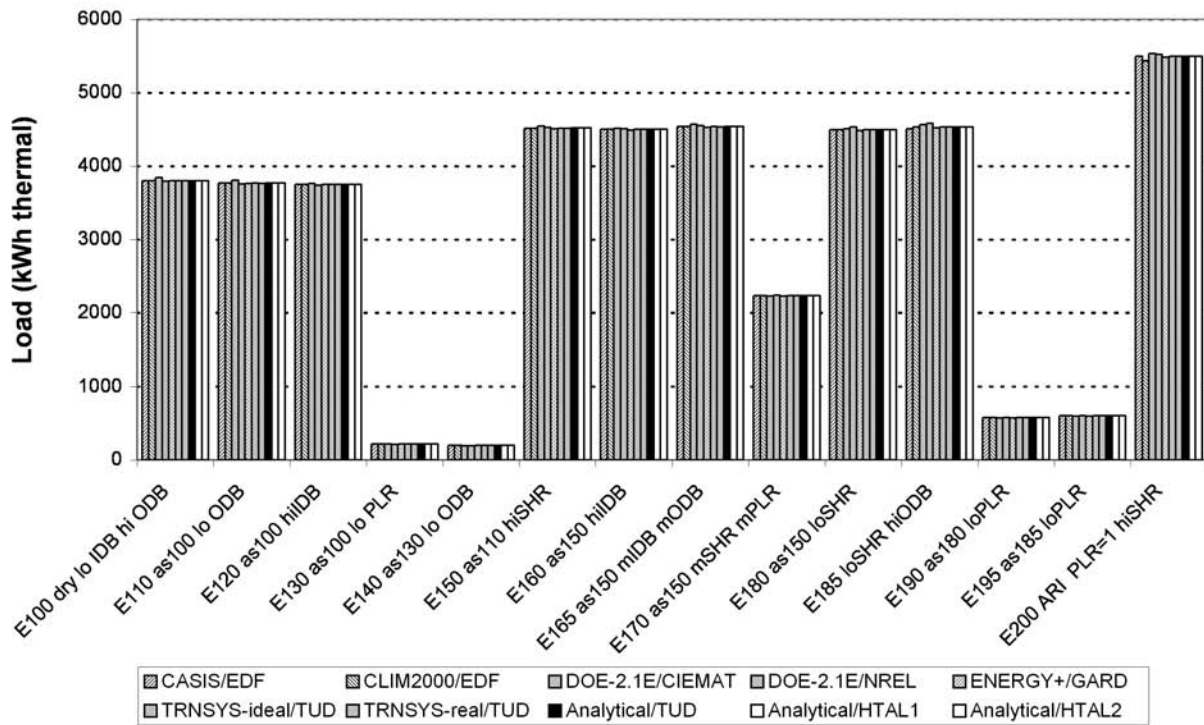
## HVAC BESTEST: Outdoor (Condenser) Fan Electricity Consumption



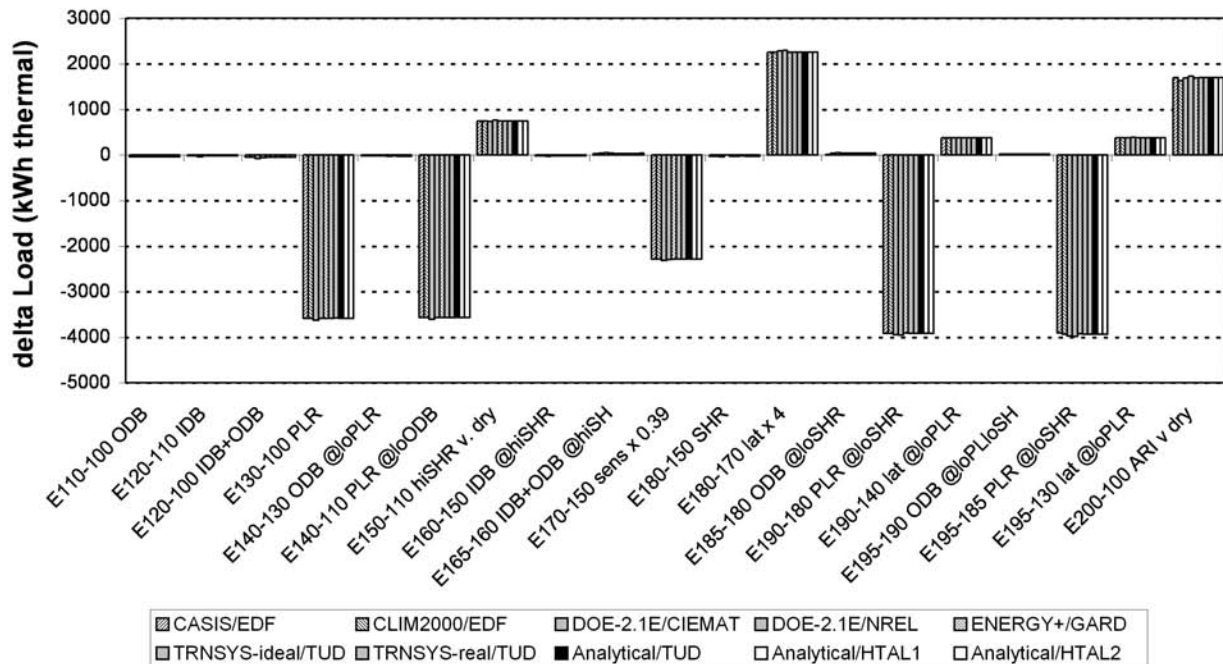
## HVAC BESTEST: Outdoor (Condenser) Fan Electricity Sensitivities



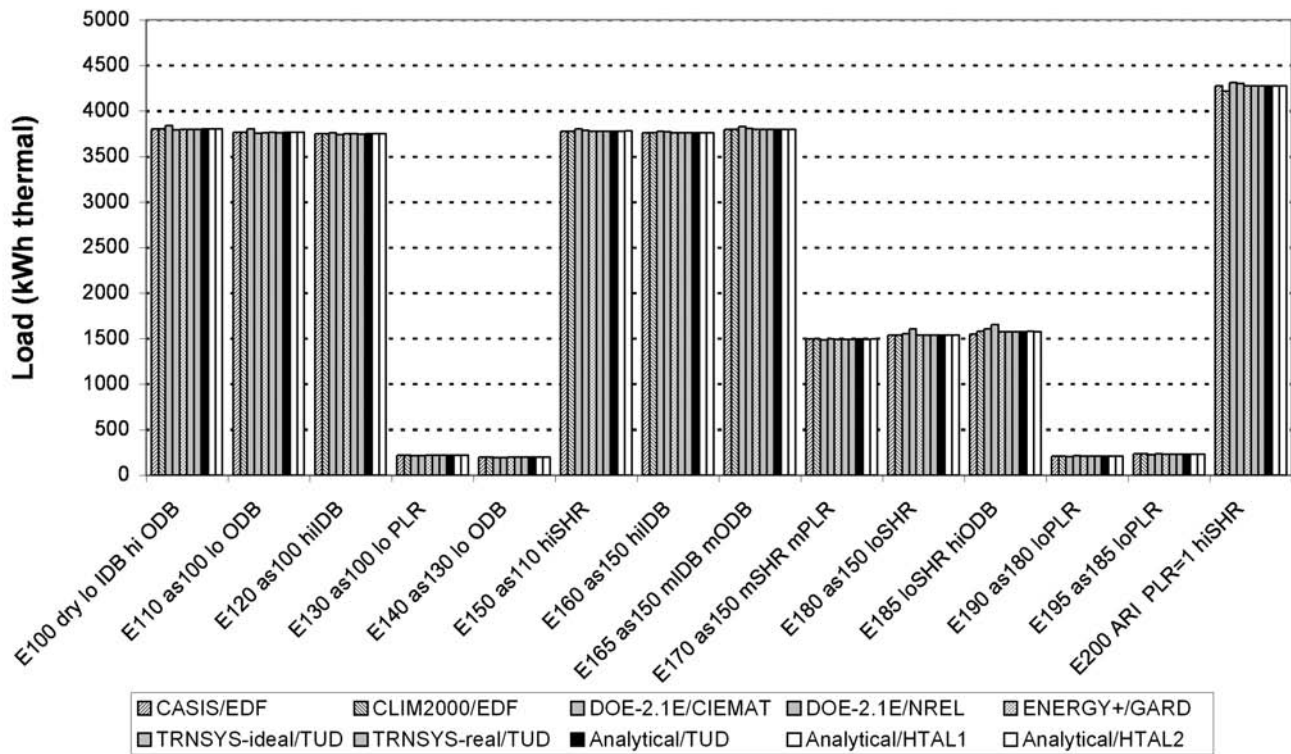
## HVAC BESTEST: Total Coil Load



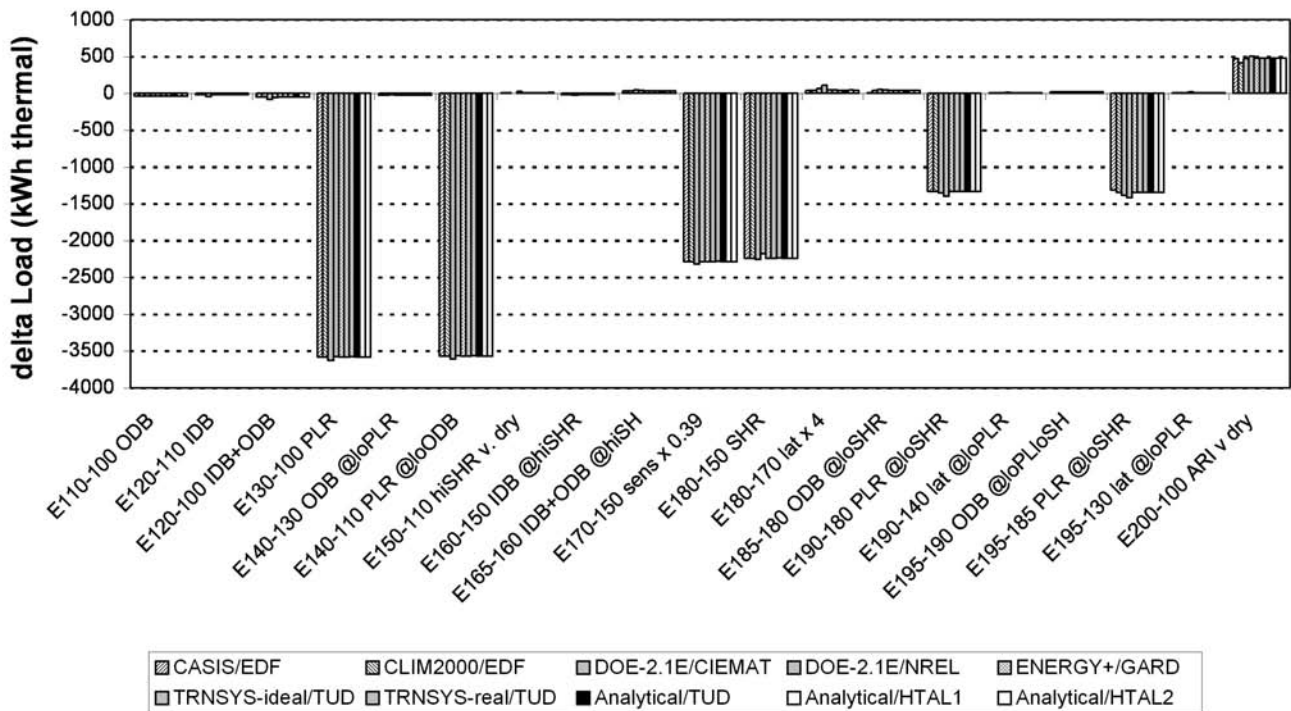
## HVAC BESTEST: Total Coil Load Sensitivities



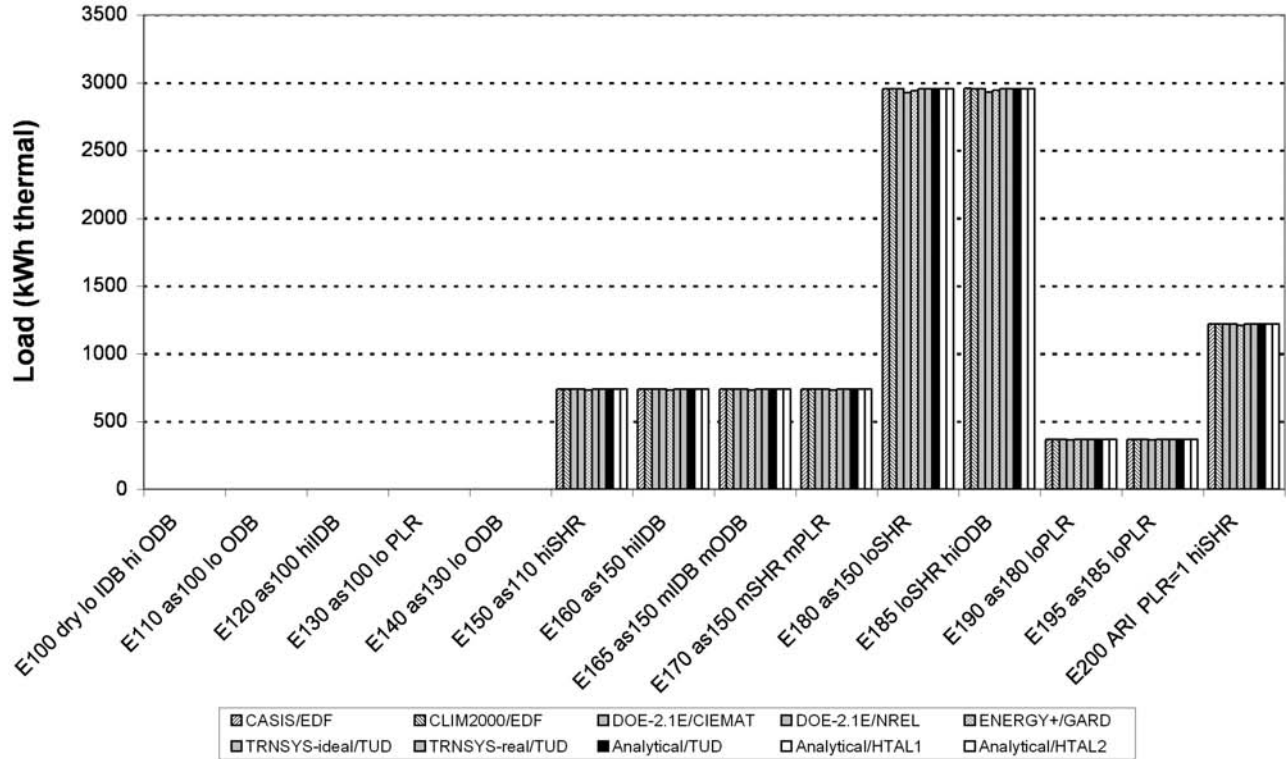
## HVAC BESTEST: Sensible Coil Load



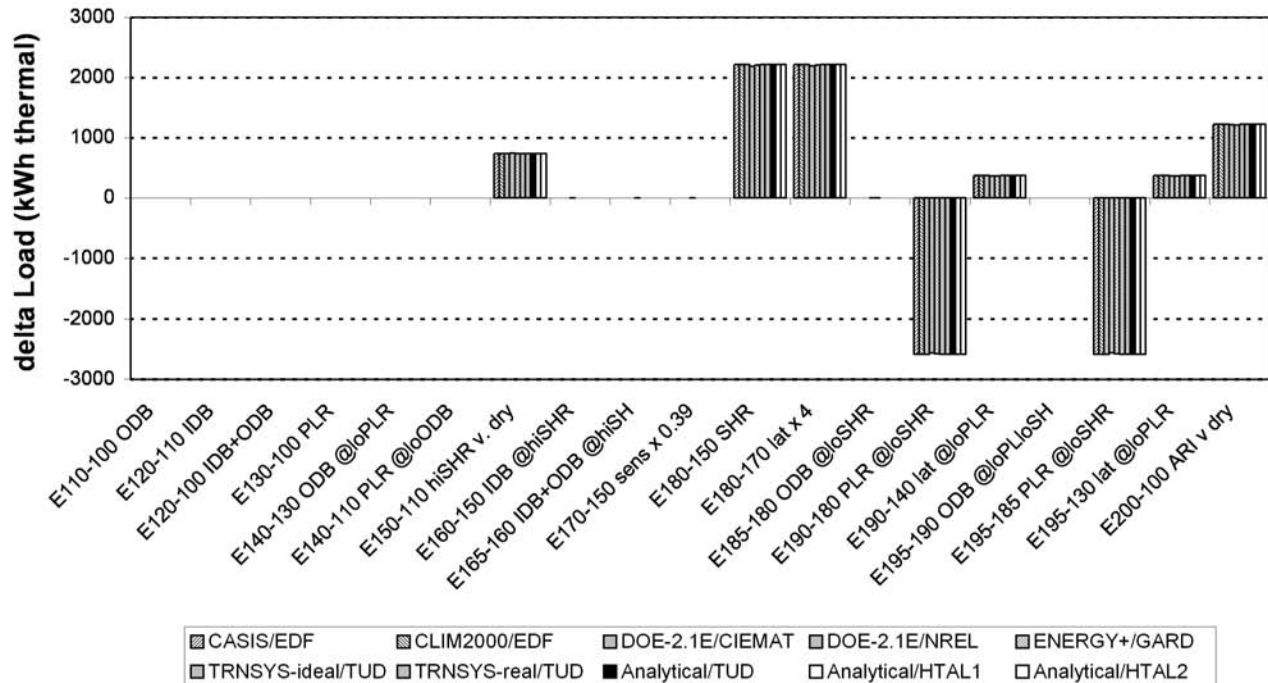
## HVAC BESTEST: Sensible Coil Load Sensitivities



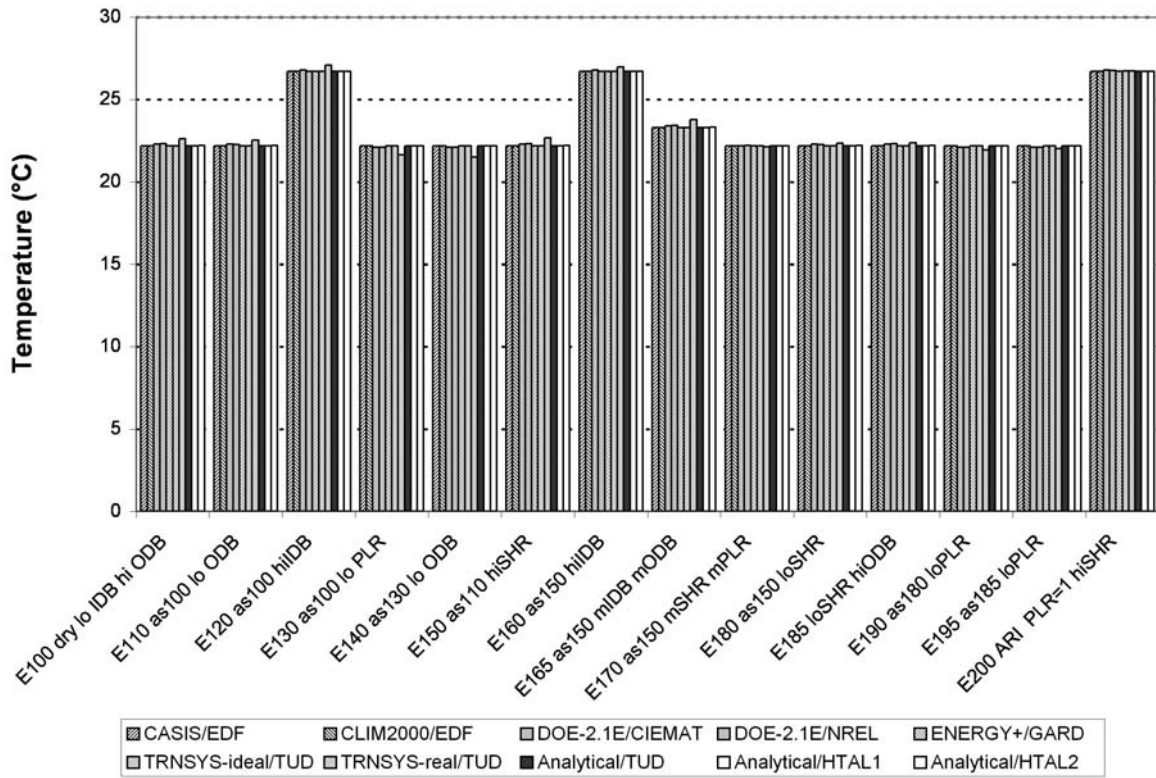
## HVAC BESTEST: Latent Coil Load



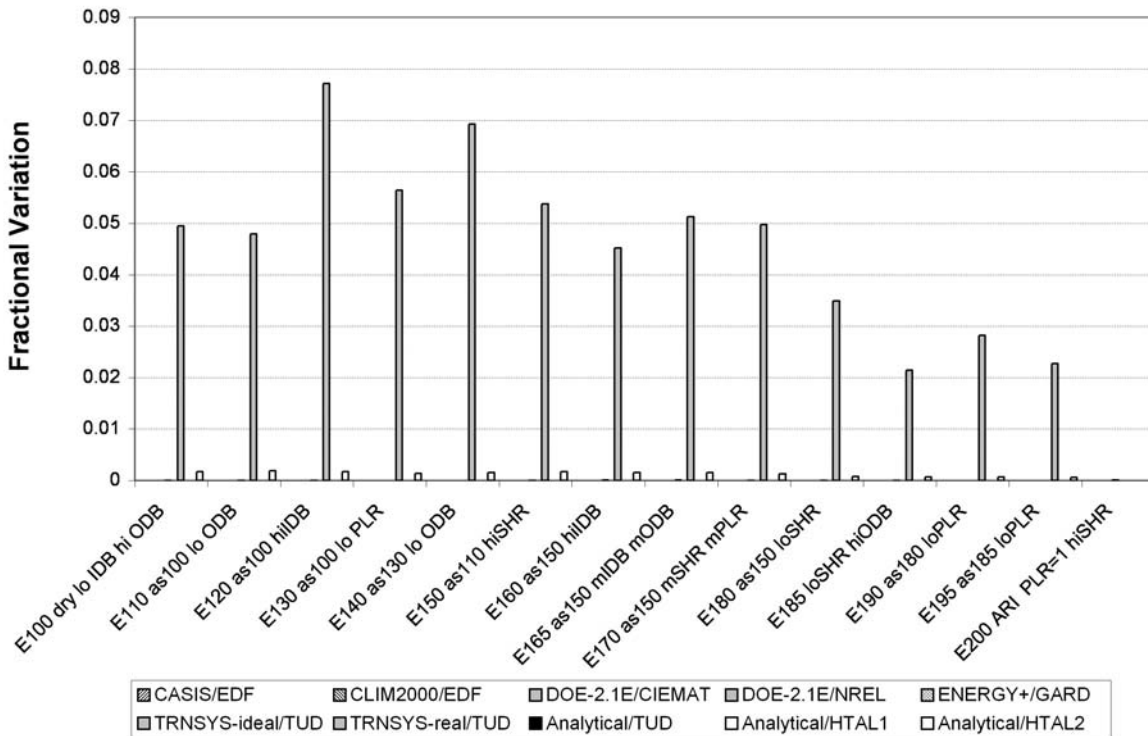
## HVAC BESTEST: Latent Coil Load Sensitivities



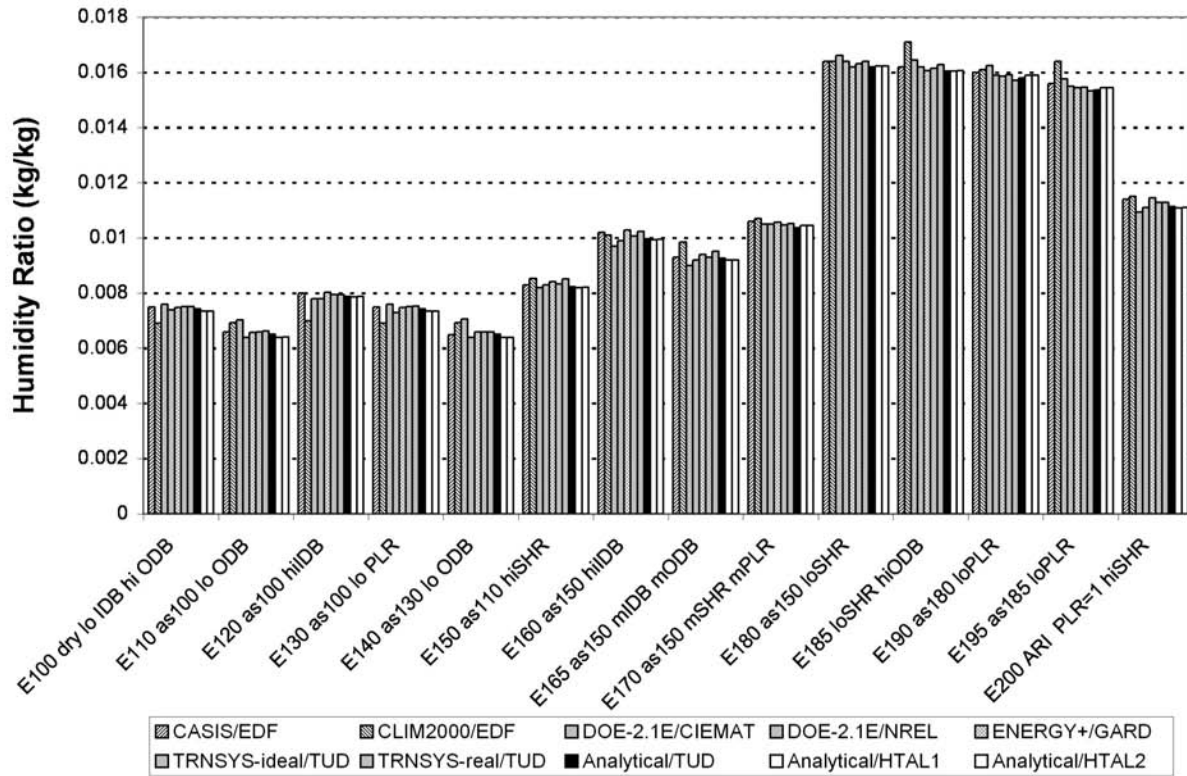
## HVAC BESTEST: Mean Indoor Drybulb Temperature



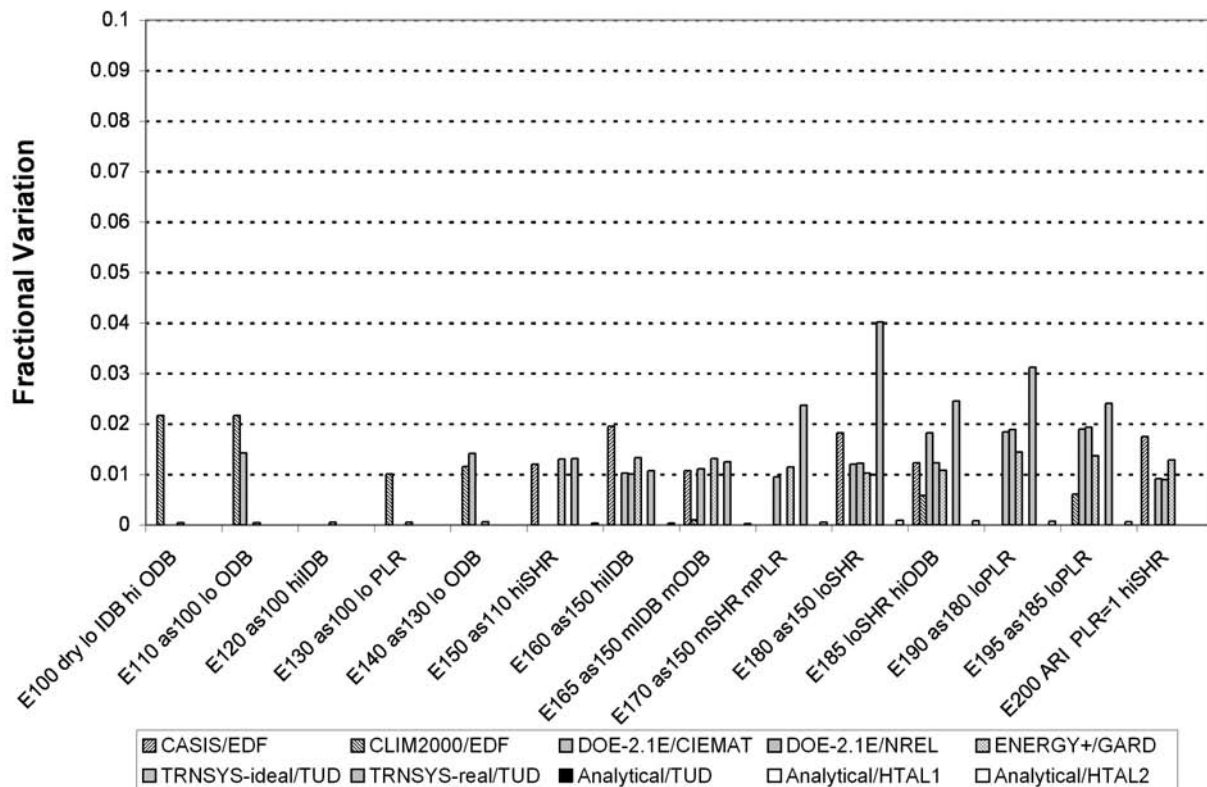
## HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Drybulb Temperature



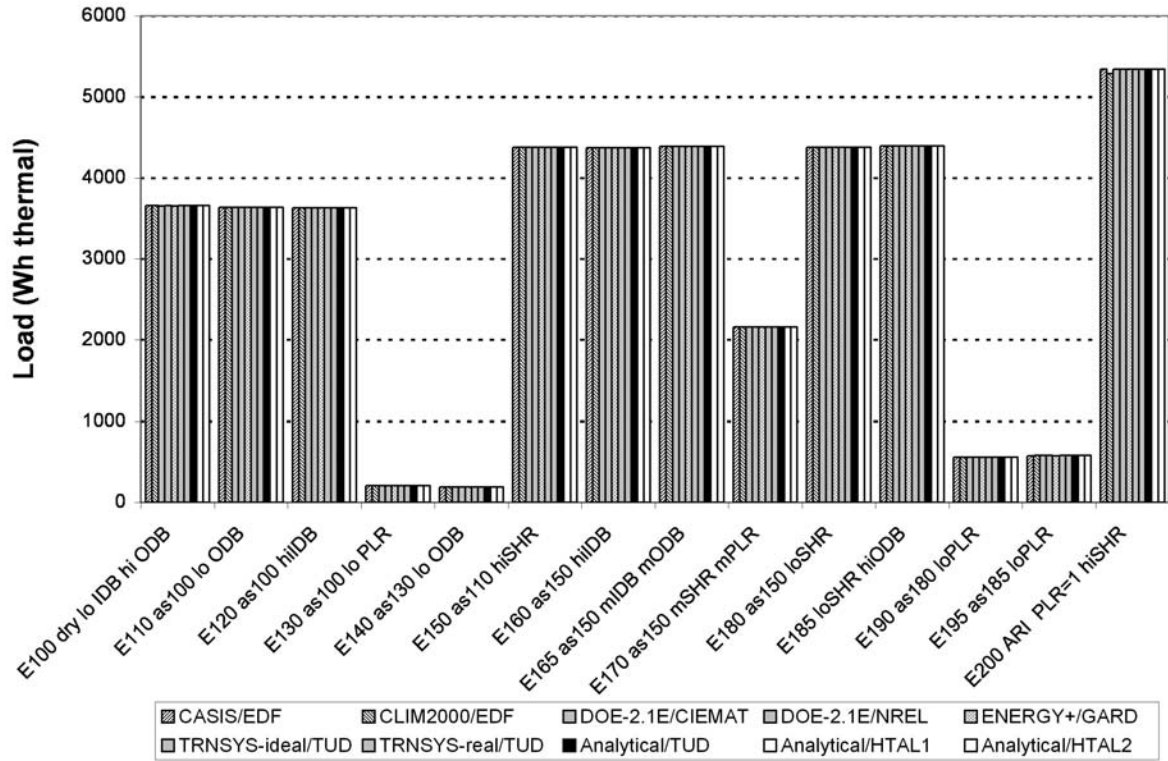
## HVAC BESTEST: Mean Indoor Humidity Ratio



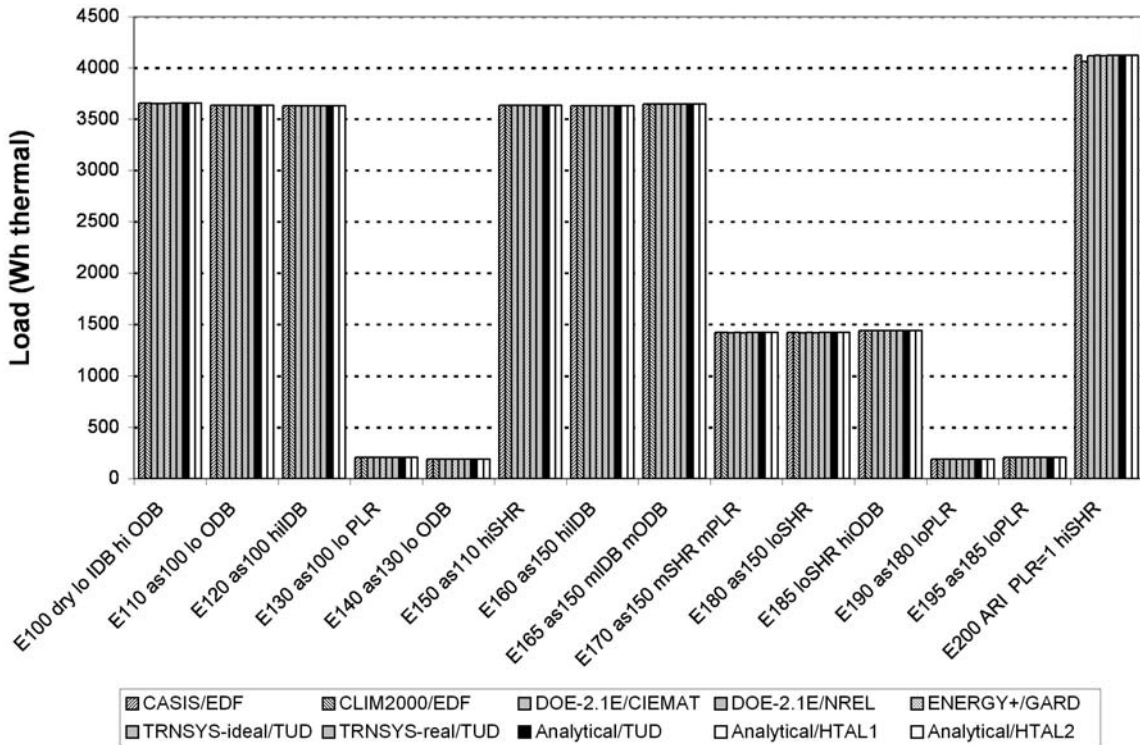
## HVAC BESTEST: (Maximum - Minimum)/Mean Indoor Humidity Ratio



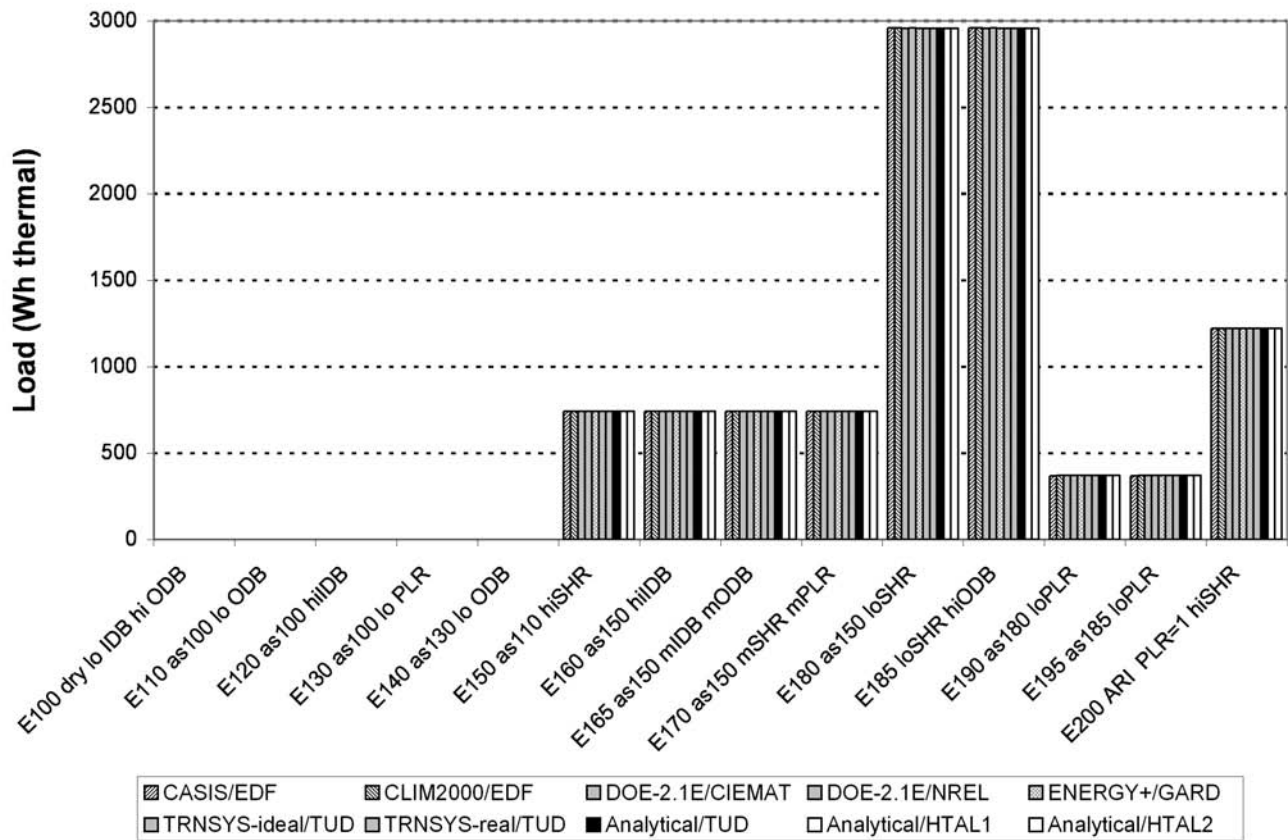
## HVAC BESTEST: Total Zone Load



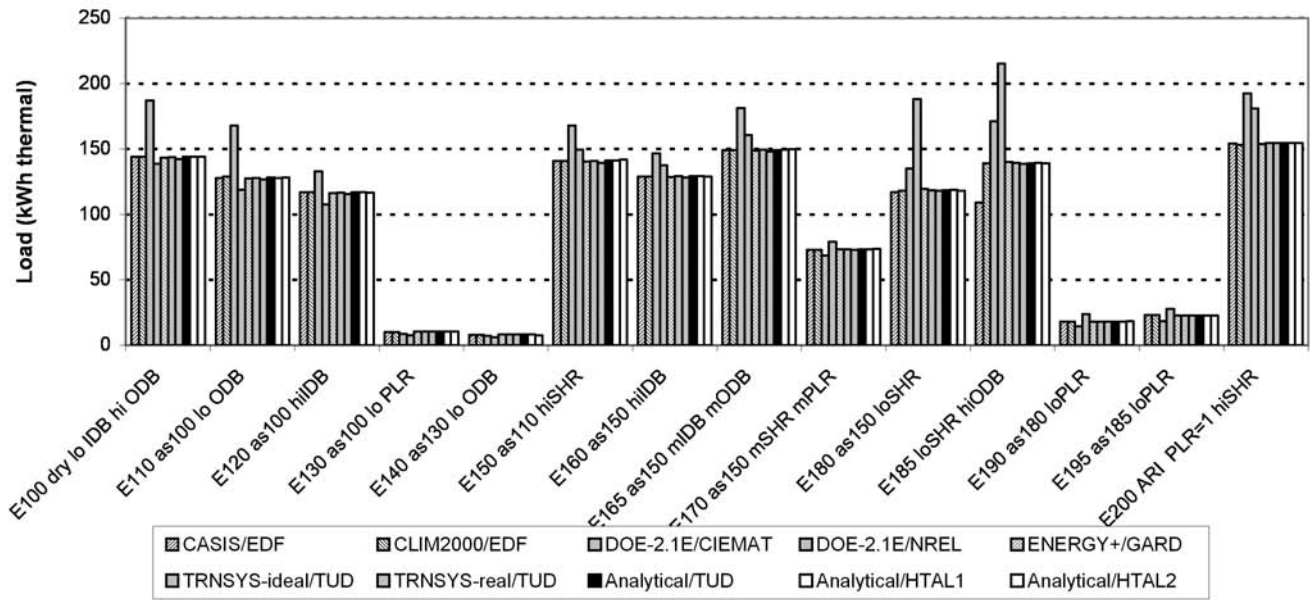
## HVAC BESTEST: Sensible Zone Load



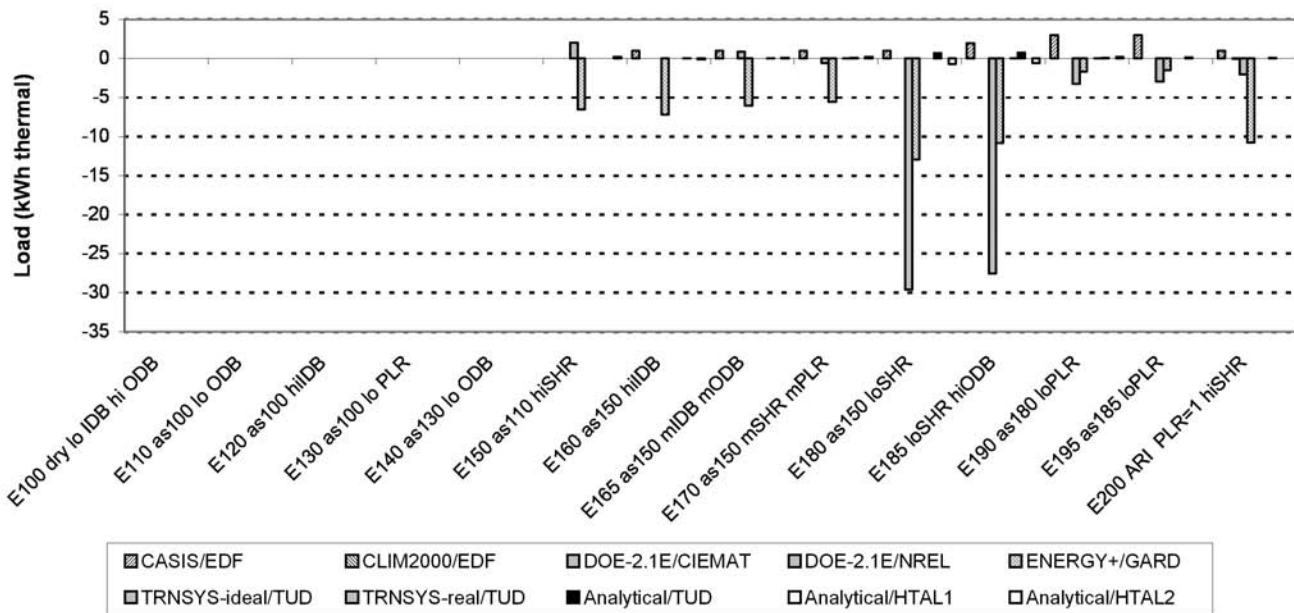
## HVAC BESTEST: Latent Zone Load



### HVAC BESTEST: Sensible Coil Load - Zone Load (Fan Heat)



### HVAC BESTEST: Latent Coil Load - Latent Zone Load (Should = 0)



(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*.<sup>A-5</sup> 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, <sup>a,b,c</sup> USA                                  | CIEMAT, <sup>d</sup> Spain                           | DOE21E/CIEMAT          |
| DOE-2.1E-133                                              | LANL/LBNL/JJH, <sup>a,b,e</sup> USA                                    | NREL/JNA, <sup>f</sup> USA                           | DOE21E/NREL            |
| ENERGYPLUS 1.0.0.023                                      | LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-OBT, <sup>a,g,h,i,j,k</sup> | 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<br>TRNSYS-ideal |
| TRNSYS 14.2-TUD with real controller model                | University of Wisconsin, USA; Technische Universität Dresden, Ger.     | Technische Universität Dresden, Germany              | TRN-re<br>TRNSYS-real  |

<sup>a</sup>LANL: Los Alamos National Laboratory

<sup>b</sup>LBNL: Lawrence Berkeley National Laboratory

<sup>c</sup>ESTSC: Energy Science and Technology Software Center (at Oak Ridge National Laboratory, USA)

<sup>d</sup>CIEMAT: Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas

<sup>e</sup>JJH: James J. Hirsch & Associates

<sup>f</sup>NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates

<sup>g</sup>UIUC: University of Illinois Urbana/Champaign

<sup>h</sup>CERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories

<sup>i</sup>OSU: Oklahoma State University

<sup>j</sup>FSEC: University of Central Florida, Florida Solar Energy Center

<sup>k</sup>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.<sup>A-12, A-13, A-14</sup> 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*.<sup>A-5</sup>

### 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*<sup>A-5</sup> 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.<sup>14,21,22, A-5</sup>

**(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.<sup>A-15, A-5</sup> 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                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Empirical</i><br>Test of model and solution process            | <ul style="list-style-type: none"> <li>• Approximate truth standard within experimental accuracy</li> <li>• Any level of complexity</li> </ul>                                               | <ul style="list-style-type: none"> <li>• Experimental uncertainties: <ul style="list-style-type: none"> <li>- Instrument calibration, spatial/ temporal discretization</li> <li>- Imperfect knowledge/specification of the experimental object (building) being simulated</li> </ul> </li> <li>• Detailed measurements of high quality are expensive and time consuming</li> <li>• Only a limited number of test conditions are practical</li> </ul> |
| <i>Analytical</i><br>Test of solution process                     | <ul style="list-style-type: none"> <li>• No input uncertainty</li> <li>• Exact mathematical truth standard for the given model</li> <li>• Inexpensive</li> </ul>                             | <ul style="list-style-type: none"> <li>• No test of model validity</li> <li>• Limited to highly constrained cases for which analytical solutions can be derived</li> </ul>                                                                                                                                                                                                                                                                           |
| <i>Comparative</i><br>Relative test of model and solution process | <ul style="list-style-type: none"> <li>• No input uncertainty</li> <li>• Any level of complexity</li> <li>• Many diagnostic comparisons possible</li> <li>• Inexpensive and quick</li> </ul> | <ul style="list-style-type: none"> <li>• No truth standard</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                |

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"<sup>A-16</sup>
- (b) "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)"<sup>23</sup>
- (c) ASHRAE RP-865, "Development of Accuracy Tests for Mechanical System Simulation"<sup>A-17</sup>
- (d) "Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Fuel-Fired Furnace Test Suite"<sup>A-18</sup>
- (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"<sup>A-19</sup>
- (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"<sup>A-20</sup>
- (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).<sup>A-21</sup>

(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**<sup>A-16</sup> 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<sup>23</sup> 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**<sup>A-17</sup> 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<sup>A-18</sup>** 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<sup>A-19</sup>** is a comparative test developed by Hochschule für 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<sup>A-20</sup>** 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 B194

### REFERENCES

#### **B19.1 References for ANSI/ASHRAE Standard 140-2001**

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- <sup>18</sup>S3PAS *User's Manual*, Escuela Superior Ingenieros Industriales, Sevilla, Spain
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## **B19.2 References for Addendum a to ANSI/ASHRAE Standard 140-2001**

*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.