EnergyPlus Testing with HVAC Equipment Performance Tests CE300 to CE545 from ANSI/ASHRAE Standard 140-2007

EnergyPlus Version 3.0.0.028

December 2008

Prepared for:

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Office of Building Technologies
Washington, D.C.

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This report is based upon work supported by the Ernest Orlando Lawrence Berkeley National Laboratory and the Department of Energy National Energy Technology Laboratory under award number DE-FC26-06NT42768 by subcontract through the University of Central Florida/Florida Solar Energy Center.

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1 TEST OBJECTIVES AND OVERVIEW

1.1 Introduction

This report describes the modeling methodology and results for testing done of HVAC system tests designated as Cases CE300 through CE545 of ANSI/ASHRAE Standard 140-2007 titled *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* with the EnergyPlus Version 3.0.0.028. The results of EnergyPlus are also compared with results from several other whole building energy analysis programs that simulated the same test cases.

1.2 Test Type: Comparative - HVAC

Comparative tests compare a program to itself or to other simulation programs. This type of testing accomplishes results on two different levels, both validation and debugging.

From a validation perspective, comparative tests will show that EnergyPlus is computing solutions that are reasonable compared to other energy simulation programs. This is a very powerful method of assessment, but it is no substitute for determining if the program is absolutely correct since it may be just as equally incorrect as the benchmark program or programs. The biggest strength of comparative testing is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation. The ANSI/ASHRAE Standard 140-2007 procedures discussed below take advantage of the comparative test method and have the added advantage that for the specific tests included in Standard 140 have already been run by experts of the other simulation tools.

Comparative testing is also useful for field-by-field input debugging. Energy simulation programs have so many inputs and outputs that the results are often difficult to interpret. To ascertain if a given test passes or fails, engineering judgment or hand calculations are often needed. Field by field comparative testing eliminates any calculational requirements for the subset of fields that are equivalent in two or more simulation programs. The equivalent fields are exercised using equivalent inputs and relevant outputs are directly compared.

1.3 Test Suite: ANSI/ASHRAE Standard 140-2007 Space Cooling Performance Tests

The tests described in Sections 5.3.3 and 5.3.4 of ANSI/ASHRAE Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (ASHRAE 2007), were performed using the EnergyPlus program. This standard builds upon work previously performed by the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 22 *Building Energy Simulation Test and Diagnostic Method for HVAC*

Equipment Models (HVAC BESTEST), Volume 2: Cases E300 – E545, (Neymark & Judkoff 2004) which contains the results of the IEA HVAC BESTEST activities. The results of EnergyPlus testing with HVAC BESTEST Volume 1, Cases E100-E200 which are limited to steady-state cases that have analytical solutions have been previously reported in *EnergyPlus Testing with HVAC Equipment Performance Tests CE100 to CE200 from ANSI/ASHRAE Standard 140-2004* (Henninger, et. al. 2008). The testing done with EnergyPlus actually started as part of the IEA HVAC BESTEST activities before these HVAC equipment performance testing procedures were incorporated into ANSI/ASHRAE Standard 140. The discussion which follows chronicles the experiences that occurred while using EnergyPlus to simulate the HVAC BESTEST suite, the same tests that are now part of ANSI/ASHRAE Standard 140-2007 where the test cases are referenced as Cases CE300 – CE545. In the following discussions where sections, tables or figures are referenced from Standard 140-2007, the corresponding reference in the HVAC BESTEST specification follows in parentheses. Beginning with the results for EnergyPlus version 2.2.0.023, the new "CE" test case designation is used in tables and charts while for all previous versions of EnergyPlus results the "E" test case designation from HVAC BESTEST was used.

HVAC BESTEST Cases CE300-CE545 represent an extension of the first set of tests reported in HVAC BESTEST Volume 1 but are tests that include hourly dynamic effects that cannot be solved analytically. These new cases test a program's modeling capabilities on the working-fluid side of the coil, but in hourly dynamic context over an expanded range of performance conditions. These cases also test the ability to model outside air mixing, infiltration, thermostat set up, overload conditions, and various economizer control schemes.

The following tests were performed with EnergyPlus as specified in ANSI/ASHRAE Standard 140-2007, Sections 5.3.3 and 5.3.4:

- Case CE300 – Base Case Building and Mechanical System
- Basic Tests - Cases CE310, CE320, CE330, CE340, CE350 and CE360 as described in Section 5.3.4.1 of Standard 140 (Section 1.3.2 of the HVAC BESTEST specification)
- Economizer Series - Cases CE400, CE410, CE420, CE430, and CE440 as described in Section 5.3.4.2 of Standard 140 (Section 1.3.3 of HVAC BESTEST specification)
- No Outside Air Series – Cases CE500, CE510, CE520, CE522, CE525, CE530, CE540 and CE545 as described in Section 5.3.4.3 of Standard 140 (Section 1.3.4 of HVAC BESTEST specification)

Further specifics regarding how test parameters varied between tests are presented in Table 1.

1.3.1 Case CE300 – Base Case Building and Mechanical System

The basic test building (Figure 1) is a square 196 m^2 single zone (14 m wide x 14 m long x 3 m high) with no interior partitions and no windows. The building is intended as a near-adiabatic cell with cooling load driven by user specified internal gains, infiltration and outside air.

Material properties are described below. For further details refer to Section 5.3.3 of Standard 140.

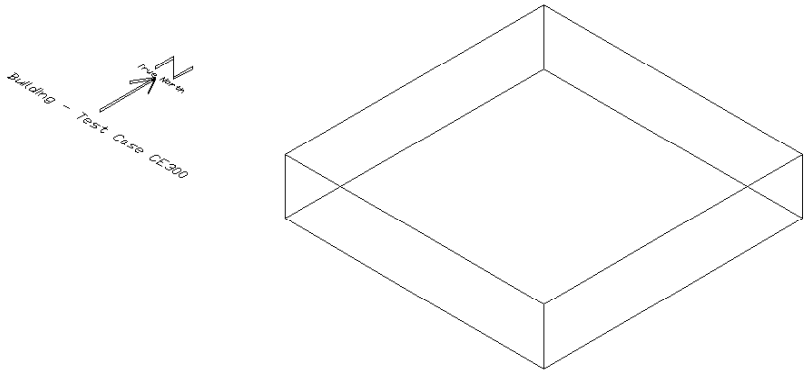


Figure 1 Base Building (Case CE300) - Isometric View of Southeast Corner

Wall, Roof and Floor Construction:

Element	k (W/m-K)	Thickness (m)	U (W/m^2-K)	R (m^2-K/W)
Int. Surface Coeff.			8.290	0.121
Insulation	0.00308	1.000	0.00308	325.000
Ext. Surface Coeff.			29.300	0.034
Overall, air-to-air			0.00308	325.155

Opaque Surface Radiative Properties:

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

Infiltration: None

Internal Load: 18,758 W sensible peak, scheduled over day, 100% convective
1,466 W latent; scheduled over day

Mechanical System: Simple unitary vapor compression cooling system with air cooled condenser and indoor evaporator coil, 100% convective air system, single speed, draw-through air distribution fan which operates continuously, outdoor fans cycle on/off with compressor, no cylinder unloading, no hot gas bypass, crankcase heater and other auxiliary energy = 0. Performance characteristics at ARI rating conditions of 35.00°C outdoor dry-bulb, 26.67°C cooling coil entering dry-bulb and 19.44°C cooling coil entering wet-bulb are:

Gross Total Capacity	33.28	kW
Gross Sensible Capacity	26.04	kW

Airflow	1.888	m3/s
Compressor Power	10	kW
Indoor Fan Power	1242	W
Outdoor Fan Power	930	W
COP	3.045	
SHR	0.804	

There is a non-proportional-type thermostat, heat always off, cooling on if zone air temperature >25.0°C and heat extraction rate is assumed to equal the maximum capacity of the equipment for the hour's environmental conditions. For further specifications and equipment's full-load and part load performance map, see Section 5.3.3.10.3 and Tables 31a and 31b of Standard 140 (Section 1.3.1.4.3 and Tables 1-7a and 1-7b in HVAC BESTEST specification).

1.3.2 Weather Data

An hourly weather data file for a one year period labeled CE300.TM2 in TMY2 format was provided with Standard 140-2007 for use with all of the test cases. This weather file was converted to EnergyPlus format using the latest EnergyPlus weather conversion program and was then used to generate the EnergyPlus Version 2.2.0.023 results reported later. Prior to EnergyPlus Version 2.2.0.023, all testing was done in accordance with the IEA HVAC BESTEST specification which used a weather file labeled NEW-ORL.TM2 which was in TMY2 format and contained the same weather set as the CE300.TM2 weather file.

1.3.3 Simulation and Reporting Period

Simulations for all cases were run for a full 12 month period. Results for each test case were to be entered into spreadsheets provided with Standard 140.

Table 1 Standard 140-2007 Space Cooling Performance Test Case Descriptions

Case #	Zone					Comments
	Internal Gains		Setpoint	Infil.	Outside Air	
	Sensible	Latent	Cooling (C)	(ACH)	(ACH)	
Basic Tests						
CE300 Base Case (15% OA)	mid	mid	25	0	1.734	Supply fans run continuously, compressor cycles, expanded performance data.
CE310 High latent load	mid	high	25	0	1.734	Tests high latent load versus CE300.
CE320 Infiltration	mid	mid	25	11.558	0	Tests high infiltration versus CE300, CE330.
CE330 Outside air	mid	mid	25	0	11.558	Tests high outside air versus CE300, CE320.
CE340 Infil./OA Interaction	mid	mid	25	5.779	5.779	Tests infil./OA interaction versus CE300, and CE320 or CE330.
CE350 Thermostat set up	mid	mid	25/35	0	1.734	Tests thermostat set up control versus CE300.
CE360 Undersize	high	mid	25	0	1.734	Tests overload system versus CE300.
Economizer Series						
CE400 Temperature control	mid	mid	25	0	1.734	Tests temperature economizer versus CE300.
CE410 Compressor lockout	mid	mid	25	0	1.734	Tests CE400 with compressor lockout versus CE300.
CE420 ODB limit	mid	mid	25	0	1.734	Tests ODB limit (20C) control versus CE300.
CE430 Enthalpy limit	mid	mid	25	0	1.734	Tests enthalpy control versus CE300.
CE440 Outdoor enthalpy limit	mid	mid	25	0	1.734	Tests outdoor enthalpy limit control versus CE300.
No Outside Air Series						
CE500 Base Case (0% OA)	mid2	mid2	25	0	0	Wet coil, supply fan cycles with compressor
CE510 High PLR	high2	high2	25	0	0	Wet coil, high PLR
CE520 Low EDB=15C	mid2	mid2	15	0	0	Wet coil, tests EDB=15C
CE522 Low EDB=20C	mid2	mid2	20	0	0	Wet coil, tests EDB=20C
CE525 High EDB	mid2	mid2	35	0	0	Wet coil, tests EDB=35C
CE530 Dry coil	mid2	0	25	0	0	Dry coil
CE540 Dry coil, low EDB	mid2	0	15	0	0	Dry coil, tests EDB=15C
CE545 Dry coil, high EDB	mid2	0	35	0	0	Dry coil, tests EDB=35C

Abbreviations: PLR = part load ratio; OA = outside air;
EDB = cooling coil entering dry-bulb temperature; ODB = outdoor dry bulb temperature

Notes: "mid" internal gains schedules are relatively high daytime and low nighttime
"mid2" is similar to "mid" but with 0 cooler-month internal gains and 0 cooling at ODB<55F for OA
"high and high2" are greater loads relative to "mid" and "mid2"

2 MODELER REPORT

The material included in this section up through Section 2.15 is a slightly revised copy of the Modeler Report which was prepared by GARD Analytics at NREL's request for inclusion in their final report to the International Energy Agency (IEA) Tool Evaluation and Improvement Experts Group. It documents the modeling approach taken to simulate the HVAC BESTEST cases using EnergyPlus. During the early rounds of testing only cases E300 - E360 were analyzed. Beginning with Round 3C, the results for cases E400 – E440 and cases E500 – E545 were also included. Several iterations occurred during which the input models were fine tuned, bugs were found in EnergyPlus and software changes were made. This Modeler Report was written to chronicle these experiences and demonstrate how the HVAC BESTEST test suite can be used in the development of whole building energy analysis software.

2.1 Modeling Methodology

For modeling of the simple unitary vapor compression cooling system, the EnergyPlus Unitary Air-to-Air Heat Pump model was utilized. The Heat Pump model was the only DX cooling system available in EnergyPlus which allowed both a draw-thru fan configuration and an economizer. Since cooling only was required during the simulation, the heat pump controls were set to prevent operation of the heat pump in the heating mode. As configured for this test series, the following heat pump modules were exercised: a DX cooling coil, an indoor fan and outside air mixer.

The building envelope loads and internal loads were calculated each hour to determine the zone load that the mechanical HVAC system must satisfy. The EnergyPlus DX coil model then uses performance information at rated conditions along with curve fits for variations in total capacity, energy input ratio and part load fraction to determine performance at part load conditions. Sensible/latent capacity splits are determined by the rated sensible heat ratio (SHR) and the apparatus dew-point/bypass factor approach.

The EnergyPlus DX coil model requires that the rated total cooling capacity, rated sensible heat ratio, rated COP and rated air volume flow rate be specified for the ARI rating condition of 35 C outside air dry-bulb, 26.7 C entering evaporator dry-bulb and 19.4 C entering evaporator wet-bulb. Since the equipment performance data as provided in the BESTEST specification dated March 2002 did not include equipment performance data at the ARI rating point, the performance data were first curve fit and then the resulting curves were used to determine the cooling capacity, energy consumption and SHR at the ARI rating condition. In September 2002, revised specifications were provided which included performance at the ARI rating point. The revised rating point was used in Round 3B and later.

Five equipment performance curves were required:

1) The Total Cooling Capacity Modifier Curve (function of temperature) is a bi-quadratic curve with two independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and outdoor dry bulb temperature (ODB) of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated total cooling capacity to give the total cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

2) The Total Cooling Capacity Modifier Curve (function of flow fraction) is a quadratic curve with the independent variable being the ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total cooling capacity and the total cooling capacity modifier curve (function of temperature) to give the total cooling capacity at the specific temperature and air flow conditions at which the coil is operating.

3) The Energy Input Ratio (EIR) Modifier Curve (function of temperature) is a bi-quadratic curve with two independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and outdoor dry bulb temperature (ODB) of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated EIR (inverse of the rated COP) to give the EIR at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

4) The Energy Input Ratio (EIR) Modifier Curve (function of flow fraction) is a quadratic curve with the independent variable being the ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and airflow conditions at which the coil is operating.

5) The part load fraction correlation (function of part load ratio) is a quadratic curve with the independent variable being part load ratio (sensible cooling load / steady-state sensible cooling capacity). The output of this curve is used in combination with the rated EIR and EIR modifier curves to give the “effective” EIR for a given simulation time step. The part load fraction correlation accounts for efficiency losses due to compressor cycling.

2.2 Modeling Assumptions

2.2.1 Thermostat Control

Ideal thermostat control was assumed with no throttling range.

2.2.2 ARI Rating Point Conditions

During the early rounds of testing the first draft versions of the modeling specifications (October 2001 and March 2002) did not give the equipment performance at the ARI rated conditions of 35 C outside air dry-bulb, 26.7 C entering evaporator dry-bulb and 19.4 C entering evaporator wet-bulb. The conditions closest to the ARI rating conditions were 35/26.7/18.33C. A set of performance curves for use with EnergyPlus were therefore developed using the data provided for 35/26.7/18.33C as the nominal point. This, however, caused problems with the simulation (see Section 2.4.1). These initial curve fits were then used to interpolate and determine the following estimated ARI standard rated performance:

	Interpolated	From Revised Test Spec
Rated gross cooling capacity	33.084 kW	33.28 kW
Rated sensible heat ratio	0.8043	0.7825
Rated COP	3.028	3.328
Rated energy consumption	10.924 kW	10.0 kW

The rated energy consumption includes the compressor (9.994 kW) and outdoor condenser fans (0.93 kW). These values were revised in Round 3B when an updated HVAC BESTEST E300-E400-E500 test specification was issued in September 2002 which contained the manufacturer performance data for ARI standard conditions.

2.2.3 DX Coil Curve Fits

Equipment performance data from Table 1-7a Equipment Full Load Performance with Gross Capacities (SI Units) of the BESTEST specification were used to develop the input parameters required for the EnergyPlus performance curves. Although performance data for a range of entering dry-bulb temperatures (EDB) is given in the table, the EnergyPlus performance curves were developed for the ARI rated condition of 26.67 C EDB. The resulting coefficients are presented below. These curves were normalized based on the estimated performance (see discussion in Section 2.2.2) at the standard ARI rating conditions of 35 C outside air dry-bulb, 26.7 C entering evaporator dry-bulb and 19.4 C entering evaporator wet-bulb.

1) **Total cooling capacity modifier curve** (function of temperature)
   Form: Bi-quadratic curve
   curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
   Independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and dry bulb temperature of the air entering (ODB) the air-cooled condenser.

   a = 0.953441251
   b = -0.000938414
   c = 0.000932679
   d = -0.001299058
   e = -2.67478E-05
   f = -0.000306850

These values were revised in Round 3B.

2) **Total cooling capacity modifier curve** (function of flow fraction)
Form: Quadratic curve
curve = a + b*FF + c*FF**2
Independent variables: ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow, FF).

Since indoor fan always operates at constant volume flow, modifier will be 1.0, therefore:

a = 1.0
b = 0.0
c = 0.0

3) **Energy input ratio (EIR) modifier curve** (function of temperature)
Form: Bi-quadratic curve
curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
Independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and dry bulb temperature of the air entering (ODB) the air-cooled condenser.

a = 0.537791667
b = -0.000895849
c = -0.000154388
d = 0.012700780
e = 0.000162966
f = -0.000157276

These values were revised in Round 3B.

4) **Energy input ratio (EIR) modifier curve** (function of flow fraction)
Form: Quadratic curve
curve = a + b*FF + c*FF**2
Independent variables: ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow, FF).

Since indoor fan always operates at constant volume flow, modifier will be 1.0, therefore:

a = 1.0
b = 0.0
c = 0.0

5) **Part load fraction correlation** (function of part load ratio, PLR)
Form: Quadratic curve
curve = a + b*PLR + c*PLR**2
Independent variable: part load ratio (sensible cooling load/steady state sensible cooling capacity)

Part load performance specified in Figure 1-3 of the BESTEST specification, therefore:

a = 0.771
b = 0.229
c = 0.0

2.3 Modeling Difficulties

2.3.1 Building Envelope Construction

The BESTEST specification for the building envelope indicates that the exterior walls, roof and floor are made up of one opaque layer of insulation (R=325, SI units) with differing radiative properties for the interior surface and exterior surface (ref. Table 1-5 of BESTEST specification). To allow the interior and exterior surface radiative properties to be set at different values, the exterior wall, roof and floor had to be simulated as two insulation layers, each with an R=162.5. The EnergyPlus description for this construction was as follows:

```
MATERIAL:Regular-R,
    INSULATION-EXT,          ! Material Name
    VerySmooth,              ! Roughness
    162.5,                   ! Thermal Resistance {m2-K/W}
    0.9000,                  ! Thermal Absorptance
    0.1000,                  ! Solar Absorptance
    0.1000;                  ! Visible Absorptance

MATERIAL:Regular-R,
    INSULATION-INT,          ! Material Name
    VerySmooth,              ! Roughness
    162.5,                   ! Thermal Resistance {m2-K/W}
    0.9000,                  ! Thermal Absorptance
    0.6000,                  ! Solar Absorptance
    0.6000;                  ! Visible Absorptance

CONSTRUCTION,
    LTWALL,                  ! Construction Name
        ! Material layer names follow:
    INSULATION-EXT,
    INSULATION-INT;
```

2.3.2 Compressor and Condenser Fan Breakout

The rated COP required as input by the EnergyPlus DX coil model requires that the input power be the combined power for the compressor and condenser fans. As such, there are no separate input variables or output variables available for the compressor or condenser fan. The only

output variable available for reporting in EnergyPlus is the DX coil electricity consumption which includes compressor plus condenser fan.

2.4 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 1

2.4.1 Rated Performance and Bypass Factor Calculations

As mentioned in Section 2.2.2, the initial set of performance data was based on using 18.33C EWB, because this was directly available from the performance data tables. Even though the EnergyPlus documentation stated clearly that the rated performance inputs were to be entered for rated ARI conditions (19.4C EWB), it was wrongly assumed that a different entering condition could be used as long as the performance curves were normalized around the same condition. This caused a fatal error, because EnergyPlus attempts to calculate a rated bypass factor by starting with entering air at ARI standard conditions and then applying the nominal total capacity and SHR. Using a data point corresponding to a drier entering condition caused the leaving air to be supersaturated and the bypass factor search algorithm failed. Further investigation by the EnergyPlus development team resulted in source code changes for additional error checking in the DX coil routines and an improved error message to help users know how to solve this problem.

2.4.2 Temperatures Out of Control

The draft BESTEST specification dated March 2002 did not contain any empirical results or results from other programs to compare to, so it is not possible to determine for certain if any software errors existed. One potential problem was identified however. For cases E300 and E310, the air-conditioner did not maintain the space temperature at the required 25 C. There were hours during periods of low or no internal loads, November 6 for example, when the air-conditioner did not cycle on to provide cooling and subsequently the space temperature rose to as high as 30 C. A change request (bug report) was submitted to the EnergyPlus development team to determine why the air-conditioner would not operate during low part load conditions.

2.5 Results –Round 1

Results from the Round 1 modeling with EnergyPlus Version 1.0.2.004 are presented below.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	35149	24287	Note 1	10862	77308	55108	22199	3.18	24.11	0.0093	48.7	19.9	0.0116
E310	39999	29137	Note 1	10862	97350	55157	42193	3.34	24.10	0.0114	59.0		
E320	39274	28411	Note 1	10862	94961	61250	33712	3.34	24.26	0.0101	52.0		
E330	40373	29511	Note 1	10862	101066	62845	38221	3.42	24.29	0.0100	51.3		
E340	39997	29135	Note 1	10862	98579	62053	36526	3.38	24.31	0.0100	51.2		
E350	31447	20585	Note 1	10862	65640	48271	17369	3.19	26.26	0.0100	45.3		
E360	55351	44489	Note 1	10862	160883	134944	25940	3.62	25.41	0.0088	42.4		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption	Evaporator Coil Loads											Weather Data Checks					
	Compr + Both Fans	Sensible			Latent			Sensible + Latent					ODB			Outdoor Humidity Ratio		
	Wh	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour			°C	Date	Hour	kg/kg	Date	Hour
E300	11841	23280	08/16	15:00	10406	09/03	15:00	32620	07/08	15:00			34.775	07/20	14:00	0.0218	10/02	08:00
E310	12574	22975	07/11	16:00	16529	09/18	15:00	37342	09/03	16:00								
E320	13049	31697	04/24	15:00	21150	10/01	20:00	39583	09/03	16:00								
E330	13436	34709	06/14	13:00	27032	09/18	15:00	42547	10/02	09:00								
E340	13265	32657	05/16	15:00	23236	10/02	09:00	40741	09/03	15:00								
E350	11841	23280	08/16	15:00	10425	10/02	08:00	32620	07/08	15:00								
E360	12910	32542	04/24	15:00	8471	09/03	17:00	38331	09/03	12:00								

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2175	Note 1	7507	5853	1653	0.0094	3.45	18.1	24.0		0.0113
2	2155	Note 1	7454	5809	1645	0.0094	3.46	18.0	23.9		0.0112
3	2116	Note 1	7338	5744	1594	0.0093	3.47	17.8	23.9		0.0111
4	2037	Note 1	7096	5614	1482	0.0092	3.48	17.4	23.9		0.0105
5	2184	Note 1	7430	6015	1415	0.0090	3.40	18.6	24.0		0.0106
6	2924	Note 1	9221	7531	1689	0.0093	3.15	22.9	24.7		0.0123
7	3563	Note 1	10614	8756	1859	0.0096	2.98	26.4	25.2		0.0118
8	3862	Note 1	11106	9419	1687	0.0096	2.88	28.3	25.5		0.0116
9	4928	Note 1	14389	11995	2393	0.0099	2.92	28.9	25.6		0.0124
10	5467	Note 1	15785	12488	3297	0.0105	2.89	30.3	25.8		0.0140
11	5729	Note 1	16519	12671	3848	0.0109	2.88	30.8	25.9		0.0138
12	5605	Note 1	16018	12705	3312	0.0107	2.86	30.9	25.9		0.0120
13	7212	Note 1	21103	17594	3508	0.0102	2.93	31.5	26.0		0.0115
14	7259	Note 1	20979	17785	3194	0.0100	2.89	32.0	26.1		0.0121
15	8968	Note 1	27032	22559	4472	0.0100	3.01	32.2	26.1		0.0135
16	9036	Note 1	27537	22458	5079	0.0102	3.05	31.9	26.0		0.0145
17	5818	Note 1	16600	12868	3733	0.0108	2.85	31.3	26.0		0.0153
18	5620	Note 1	16757	12171	4586	0.0112	2.98	29.4	25.7		0.0149
19	5353	Note 1	16539	11556	4983	0.0113	3.09	27.6	25.4		0.0159
20	5429	Note 1	17030	11414	5616	0.0117	3.14	27.2	25.3		0.0168
21	4416	Note 1	13615	8952	4663	0.0118	3.08	26.9	25.3		0.0168
22	4273	Note 1	13287	8753	4534	0.0117	3.11	26.3	25.2		0.0168
23	4236	Note 1	13230	8674	4556	0.0117	3.12	26.1	25.2		0.0171
24	4007	Note 1	12742	8297	4444	0.0117	3.18	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	4.33	11/06	17:00	2.75	06/14	12:00	30.7	11/06	16:00	8.7	01/06	05:00
E310	4.31	11/06	17:00	2.84	12/01	14:00	30.7	11/06	16:00	8.7	01/06	05:00
E320	4.26	11/06	17:00	2.79	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.33	11/06	17:00	2.80	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	4.33	11/06	17:00	2.80	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.59	10/13	01:00	1.60	04/28	07:00	38.1	10/12	07:00	8.7	01/06	05:00
E360	4.40	10/04	23:00	2.80	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00
E310	0.0159	10/02	08:00	0.0020	01/05	07:00	79.9	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	13.2	11/06	15:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	13.0	11/06	15:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	13.0	11/06	15:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00

2.6 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 3A

Note: Other whole building energy analysis programs participating in this IEA comparative study had gone through two rounds of testing while EnergyPlus, which joined in later, had only gone through one round of testing. To be consistent with results reported by other program participants, the round of testing with EnergyPlus as reported below is being referred to as Round 3 testing and results.

As a result of testing done during Round 1, two changes were made to the EnergyPlus code to correct algorithm errors and bring results more in line with what the BESTEST specification called for.

1) Latent Cooling Loads
   In EnergyPlus Version 1.0.3.001, an h_g function replaced the h_{fg} function in the psychrometric routines. This change produced only small changes in the results.

2) Dry Coil Conditions
   An error found during Round 1 with calculating outlet conditions (humidity ratio and temperature) from the cooling coil when dry conditions (no dehumidification) occurred was corrected in EnergyPlus Version 1.0.3.005. This error was causing the cooling coil not to operate during certain hours. The change made to the code to correct this problem in EnergyPlus Version 1.0.3.005 corrected the zone temperature control problems in

cases E300 and E310 and corrected the low minimum COP that had occurred in case E350.

2.7 Results – Round 3A

Results from the Round 3A modeling with EnergyPlus Version 1.0.3.005 are presented below.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity	Zone Relative		Outdoor Humidity
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Ratio (kg/kg)	Humidity (%)	ODB (°C)	Ratio (kg/kg)
E300	34879	24016	Note 1	10862	77352	55255	22097	3.22	24.09	0.0093	48.6	19.9	0.0116
E310	39445	28583	Note 1	10862	96434	55232	41201	3.37	24.09	0.0113	58.6		
E320	38983	28121	Note 1	10862	95107	61455	33652	3.38	24.24	0.0101	51.9		
E330	40074	29212	Note 1	10862	101239	63043	38196	3.47	24.27	0.0100	51.2		
E340	39694	28832	Note 1	10862	98715	62234	36482	3.42	24.29	0.0100	51.2		
E350	31256	20394	Note 1	10862	65804	48541	17263	3.23	26.24	0.0099	45.2		
E360	54849	43987	Note 1	10862	160937	135106	25831	3.66	25.38	0.0088	42.3		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima				
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks				
				Sensible			Latent			Sensible + Latent				ODB			Outdoor Humidity Ratio	
Cases	Compr + Both Fans Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11703	07/08	15:00	23280	08/16	15:00	10355	09/03	15:00	32570	07/08	15:00	34.775	07/20	14:00	0.0218	10/02	08:00
E310	12423	08/16	15:00	23003	07/11	16:00	16224	09/18	15:00	37073	09/03	16:00						
E320	12907	07/20	14:00	31693	04/24	15:00	21134	10/01	20:00	39574	09/03	16:00						
E330	13291	07/20	14:00	34709	06/14	13:00	27032	09/18	15:00	42547	10/02	09:00						
E340	13121	07/20	14:00	32676	05/16	15:00	23232	10/02	09:00	40738	10/02	09:00						
E350	11703	07/08	15:00	23280	08/16	15:00	10425	10/02	08:00	32570	07/08	15:00						
E360	12766	07/20	14:00	32539	04/24	15:00	8426	09/03	17:00	38300	09/03	12:00						

	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
Hour	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2149	Note 1	7506	5853	1653	0.0094	3.49	18.1	24.0		0.0113
2	2129	Note 1	7454	5809	1645	0.0094	3.50	18.0	23.9		0.0112
3	2091	Note 1	7338	5744	1594	0.0093	3.51	17.8	23.9		0.0111
4	2013	Note 1	7096	5614	1482	0.0092	3.53	17.4	23.9		0.0105
5	2158	Note 1	7430	6015	1415	0.0090	3.44	18.6	24.0		0.0106
6	2889	Note 1	9221	7531	1689	0.0093	3.19	22.9	24.7		0.0123
7	3520	Note 1	10614	8756	1859	0.0096	3.02	26.4	25.2		0.0118
8	3817	Note 1	11106	9419	1687	0.0096	2.91	28.3	25.5		0.0116
9	4868	Note 1	14383	11995	2388	0.0099	2.95	28.9	25.6		0.0124
10	5395	Note 1	15758	12488	3270	0.0105	2.92	30.3	25.8		0.0140
11	5651	Note 1	16484	12671	3813	0.0109	2.92	30.8	25.9		0.0138
12	5529	Note 1	15983	12705	3277	0.0107	2.89	30.9	25.9		0.0120
13	7115	Note 1	21059	17594	3465	0.0101	2.96	31.5	26.0		0.0115
14	7163	Note 1	20939	17785	3154	0.0100	2.92	32.0	26.1		0.0121
15	8850	Note 1	26984	22559	4424	0.0100	3.05	32.2	26.1		0.0135
16	8918	Note 1	27492	22458	5034	0.0101	3.08	31.9	26.0		0.0145
17	5740	Note 1	16570	12868	3702	0.0108	2.89	31.3	26.0		0.0153
18	5544	Note 1	16721	12171	4550	0.0112	3.02	29.4	25.7		0.0149
19	5280	Note 1	16502	11557	4946	0.0113	3.13	27.6	25.4		0.0159
20	5355	Note 1	16992	11414	5578	0.0116	3.17	27.2	25.3		0.0168
21	4357	Note 1	13589	8952	4637	0.0118	3.12	26.9	25.3		0.0168
22	4220	Note 1	13279	8753	4525	0.0117	3.15	26.3	25.2		0.0168
23	4185	Note 1	13227	8674	4553	0.0117	3.16	26.1	25.2		0.0171
24	3959	Note 1	12741	8297	4444	0.0117	3.22	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.89	04/30	16:00	2.79	06/14	12:00	25.0	09/23	07:00	8.7	01/06	05:00
E310	4.12	04/30	15:00	2.87	12/01	14:00	26.4	07/08	16:00	8.7	01/06	05:00
E320	3.89	09/16	15:00	2.83	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.06	06/17	16:00	2.83	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	3.96	09/16	16:00	2.83	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.57	10/13	01:00	2.79	06/14	12:00	35.0	09/23	07:00	8.7	01/06	05:00
E360	4.45	10/04	23:00	2.83	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00
E310	0.0158	10/02	08:00	0.0020	01/05	07:00	79.4	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	14.7	11/06	05:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	14.5	11/06	05:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	14.5	11/06	05:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00

2.8 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 3B

With the issuance of a revised draft HVAC BESTEST specification in September 2002 with equipment performance data for the ARI rating condition of 35C ODB/26.7C EDB/19.4C EWB, a new set of performance curve fits were generated for EnergyPlus based on this new data point. The coefficients for those curves that changed are shown below. The coefficients for the other EnergyPlus curves as described in Section 2.2.3 remained unchanged.

1) **Total cooling capacity modifier curve** (function of temperature)
   Form: Bi-quadratic curve
   curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
   Independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and dry bulb temperature of the air entering (ODB) the air-cooled condenser.

   a = 0.952735372
   b = -0.000932873
   c = 0.000927172
   d = -0.001291389
   e = -2.65899E-05
   f = -0.000305038

2) **Energy input ratio (EIR) modifier curve** (function of temperature)
Form: Bi-quadratic curve

curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB

Independent variables: wet bulb temperature of the air entering (EWB) the cooling coil, and dry bulb temperature of the air entering (ODB) the air-cooled condenser.

a = 0.535665387
b = -0.000900699
c = -0.000155223
d = 0.012769543
e = 0.000163848
f = -0.000158128

Use of the new curve fits lowered the annual cooling energy consumption slightly which resulted in a correspondingly small increase in the COP.

2.9 Results – Round 3B

Results from the Round 3B modeling with EnergyPlus Version 1.0.3.005 are presented below.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34719	23857	Note 1	10862	77332	55255	22077	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39250	28388	Note 1	10862	96412	55231	41181	3.40	24.09	0.0113	58.6		
E320	38785	27923	Note 1	10862	95041	61439	33601	3.40	24.25	0.0101	51.9		
E330	39859	28997	Note 1	10862	101146	63023	38122	3.49	24.27	0.0100	51.2		
E340	39486	28624	Note 1	10862	98636	62216	36420	3.45	24.29	0.0100	51.2		
E350	31119	20257	Note 1	10862	65782	48540	17241	3.25	26.24	0.0099	45.2		
E360	54530	43668	Note 1	10862	160828	135068	25760	3.68	25.39	0.0088	42.3		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima				
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks				
	Compr + Both Fans			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
Cases	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11643	07/08	15:00	23280	08/16	15:00	10350	09/03	15:00	32565	07/08	15:00	34.775	07/20	14:00	0.0218	10/02	08:00
E310	12349	08/16	15:00	23004	07/11	16:00	16215	09/18	15:00	37057	09/03	16:00						
E320	12825	07/20	14:00	31671	04/24	15:00	21097	10/01	20:00	39512	09/03	16:00						
E330	13200	07/20	14:00	34708	06/14	13:00	26976	09/18	15:00	42458	10/02	09:00						
E340	13034	07/20	14:00	32676	05/16	15:00	23182	10/02	09:00	40665	10/02	09:00						
E350	11643	07/08	15:00	23280	08/16	15:00	10424	10/02	08:00	32565	07/08	15:00						
E360	12689	07/20	14:00	32527	04/24	15:00	8403	09/03	17:00	38262	09/03	12:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2133	Note 1	7503	5853	1650	0.0094	3.52	18.1	24.0		0.0113
2	2113	Note 1	7451	5809	1642	0.0094	3.53	18.0	23.9		0.0112
3	2075	Note 1	7335	5744	1591	0.0093	3.54	17.8	23.9		0.0111
4	1997	Note 1	7093	5614	1479	0.0092	3.55	17.4	23.9		0.0105
5	2141	Note 1	7427	6015	1412	0.0090	3.47	18.6	24.0		0.0106
6	2869	Note 1	9217	7531	1686	0.0093	3.21	22.9	24.7		0.0123
7	3497	Note 1	10611	8756	1855	0.0096	3.03	26.4	25.2		0.0118
8	3793	Note 1	11102	9419	1684	0.0096	2.93	28.3	25.5		0.0116
9	4838	Note 1	14379	11995	2383	0.0099	2.97	28.9	25.6		0.0124
10	5362	Note 1	15754	12488	3266	0.0105	2.94	30.3	25.8		0.0140
11	5617	Note 1	16480	12671	3809	0.0109	2.93	30.8	25.9		0.0138
12	5496	Note 1	15979	12705	3273	0.0107	2.91	30.9	25.9		0.0120
13	7074	Note 1	21054	17594	3460	0.0101	2.98	31.5	26.0		0.0115
14	7121	Note 1	20935	17785	3150	0.0100	2.94	32.0	26.1		0.0121
15	8799	Note 1	26978	22559	4419	0.0100	3.07	32.2	26.1		0.0135
16	8866	Note 1	27488	22458	5029	0.0101	3.10	31.9	26.0		0.0145
17	5707	Note 1	16567	12868	3699	0.0108	2.90	31.3	26.0		0.0153
18	5509	Note 1	16717	12171	4546	0.0112	3.03	29.4	25.7		0.0149
19	5246	Note 1	16498	11557	4942	0.0113	3.14	27.6	25.4		0.0159
20	5320	Note 1	16988	11414	5574	0.0116	3.19	27.2	25.3		0.0168
21	4328	Note 1	13586	8952	4634	0.0118	3.14	26.9	25.3		0.0168
22	4192	Note 1	13275	8753	4522	0.0117	3.17	26.3	25.2		0.0168
23	4157	Note 1	13224	8674	4550	0.0117	3.18	26.1	25.2		0.0171
24	3932	Note 1	12737	8297	4440	0.0117	3.24	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.92	04/30	16:00	2.80	06/14	12:00	25.0	09/23	07:00	8.7	01/06	05:00
E310	4.15	04/30	15:00	2.89	12/01	14:00	26.4	07/08	16:00	8.7	01/06	05:00
E320	3.92	09/16	15:00	2.84	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.08	06/17	16:00	2.85	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	3.99	09/16	16:00	2.85	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.61	10/13	01:00	2.80	06/14	12:00	35.0	09/23	07:00	8.7	01/06	05:00
E360	4.49	10/04	23:00	2.85	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00
E310	0.0158	10/02	08:00	0.0020	01/05	07:00	79.4	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	14.7	11/06	05:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	14.5	11/06	05:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	14.5	11/06	05:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00

2.10 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 3C

2.10.1 Change in Weather Data Interpolation

In a report by NREL dated July 11, 2002 prepared for the IEA SHC Task 22, Subtask A2 working group, the results of the second round of testing for Cases E300 – E545 were presented and discussed. One of the comments made by the authors was that the outdoor dry-bulb temperature reported by EnergyPlus seemed to be one hour out of phase with some of the other programs and that the method of "weather averaging" that EnergyPlus used may be at fault. EnergyPlus does not do any weather averaging but rather uses weather interpolation to estimate the value of outdoor parameters when simulation time steps less than one hour are used. The EnergyPlus simulations performed for the HVAC BESTEST E300 – E360 test series used a TIMESTEP = 4 which means the building envelope time step is 15 minutes, or 4 time steps per hour. In EnergyPlus Version 1.0.3.006, the interpolation method was changed and better agreement resulted with what other programs were using.

2.11 Results – Round 3C

Results from the Round 3C modeling with EnergyPlus Version 1.0.3.006 are presented below. During Round 3C testing the following additional tests cases were simulated for the first time: cases E400 – E440 and cases E500 – E545. The following comments are provided regarding certain input parameters, assumptions and results related to modeling of these new cases with EnergyPlus:

1) Case E410 Compressor Lockout
   Case E410 required the air conditioning compressor to be locked out from operation anytime the economizer was operating. The EnergyPlus CONTROLLER:OUTSIDE AIR input object does have an optional compressor lockout feature but at the time of testing it has not been implemented yet within the code. The EnergyPlus results for cases E400 and E410 are therefore identical.

2) Cases E500 – E545 No Outside Air
   For cases E500 through E545, during the initial period of simulation there is no sensible heat gain in the space due to the adiabatic building envelope, no outside air or infiltration, no fan heat because fan operates in a cycling mode, and no sensible internal load due to the schedule which does not allow either a sensible or latent internal load until March 11th. During the simulation of these cases EnergyPlus issued a warning that "Loads initialization did not converge." Putting a sensible load as small as 750 W for the first hour of the simulation or even changing to a continuous fan operation eliminated this error. The results reported below for cases E500 through E525 were simulated as per the specification with no sensible or latent loads from January 1 through March 10th. The initialization warning issued by EnergyPlus appeared to have very minimal impact on the results. For cases E530, E540 and E545, see discussion which follows in item (3) below.

3) Dry Coil cases E530, E540 and E545

Initial simulations with EnergyPlus for these cases resulted in very low humidity levels in the space. This situation is due to EnergyPlus' initialization methodology and was alleviated by introducing a small amount of infiltration during the first week of the simulation. Even though EnergyPlus initializes all nodes to the outdoor humidity ratio at the beginning of the simulation, conditions during the simulation warmup days overdry the zone for these cases. Without the infiltration during the first week, there is no source of moisture to overcome the overdrying and establish the desired equilibrium. For cases E330, E340 and E345, a constant infiltration load of 1.0 m3/s was turned on for January 1 through January 7 and then turned off.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34728	23866	Note 1	10862	77323	55252	22071	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39260	28398	Note 1	10862	96409	55220	41189	3.39	24.09	0.0113	58.6		
E320	39017	28154	Note 1	10862	95927	61950	33977	3.41	24.26	0.0101	51.8		
E330	40079	29217	Note 1	10862	102038	63648	38390	3.49	24.28	0.0100	51.2		
E340	39719	28856	Note 1	10862	99548	62780	36768	3.45	24.30	0.0100	51.1		
E350	31125	20263	Note 1	10862	65775	48543	17232	3.25	26.24	0.0099	45.2		
E360	54533	43670	Note 1	10862	160834	135067	25767	3.68	25.39	0.0088	42.3		
E400	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E410	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E420	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E430	34035	23173	Note 1	10862	74860	52808	22052	3.23	24.09	0.0093	48.7		
E440	34035	23173	Note 1	10862	74860	52808	22052	3.23	24.09	0.0093	48.7		
E500	23055	20410	Note 1	2645	65621	47507	18114	3.22	20.38	0.0096	60.5		
E500 May-Sep	18006	15965	Note 1	2041	50369	36487	13882	3.15	24.98	0.0113	57.4		
E510 May-Sep	35720	31637	Note 1	4083	112814	81586	31228	3.57	24.96	0.0113	57.4		
E520	24051	21203	Note 1	2848	65968	47815	18153	3.11	13.57	0.0063	63.6		
E522	24027	21183	Note 1	2845	65904	47759	18145	3.11	16.99	0.0079	62.9		
E525	20718	18525	Note 1	2194	65013	46943	18070	3.51	27.10	0.0140	55.6		
E530	17738	15639	Note 1	2099	46953	46953	0	3.00	20.58	0.0067	48.9		
E540	17789	15683	Note 1	2106	47094	47084	10	3.00	13.79	0.0039	41.9		
E545	16643	14762	Note 1	1882	46622	46622	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
				Evaporator Coil Loads									Weather Data Checks					
	Energy Consumption			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
Cases	Compr + Both Fans Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11887	07/20	15:00	23531	07/20	15:00	10238	07/10	13:00	32738	07/20	15:00	34.775	07/20	15:00	0.0218	10/02	09:00
E310	12479	07/20	15:00	23209	07/11	16:00	16234	08/04	15:00	37009	09/17	15:00						
E320	12889	07/20	15:00	31800	04/24	15:00	22072	10/02	10:00	39559	09/03	16:00						
E330	13200	07/20	15:00	34709	06/14	14:00	26976	09/18	16:00	42458	10/02	10:00						
E340	13066	07/20	15:00	32753	04/24	15:00	23767	10/02	10:00	41085	10/02	10:00						
E350	11887	07/20	15:00	23531	07/20	15:00	10239	07/10	13:00	32738	07/20	15:00						
E360	12690	07/20	15:00	32528	04/24	16:00	8448	10/02	11:00	38319	10/02	11:00						
E400	11887	07/20	15:00	23531	07/20	15:00	26261	09/16	14:00	40488	09/16	15:00						
E410	11887	07/20	15:00	23531	07/20	15:00	26261	09/16	14:00	40488	09/16	15:00						
E420	11887	07/20	15:00	23531	07/20	15:00	26261	09/16	14:00	40488	09/16	15:00						
E430	11887	07/20	15:00	23531	07/20	15:00	10344	05/21	15:00	32738	07/20	15:00						
E440	11887	07/20	15:00	23531	07/20	15:00	10344	05/21	15:00	32738	07/20	15:00						
E500	9223	07/20	15:00	19845	07/29	16:00	7750	06/29	16:00	27563	06/29	16:00						
E510	10230	07/20	15:00	22296	07/20	15:00	10439	04/21	01:00	32485	04/21	01:00						
E520	9485	07/20	15:00	19936	07/29	16:00	7661	06/29	16:00	27560	06/29	16:00						
E522	9487	07/20	15:00	19927	07/29	16:00	7698	06/29	16:00	27589	06/29	16:00						
E525	8581	07/20	15:00	19660	07/20	15:00	7812	06/29	16:00	27445	06/29	16:00						
E530	7301	07/20	15:00	19643	07/20	15:00	2	03/16	10:00	19643	07/20	15:00						
E540	7315	07/20	15:00	19663	07/20	15:00	1791	03/11	10:00	19663	07/20	15:00						
E545	6975	07/20	15:00	19544	07/20	15:00	0	09/21	13:00	19544	07/20	15:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2119	Note 1	7476	5811	1666	0.0094	3.53	18.0	23.9		0.0112
2	2131	Note 1	7497	5853	1644	0.0094	3.52	18.1	24.0		0.0113
3	2113	Note 1	7449	5809	1639	0.0094	3.53	18.0	23.9		0.0112
4	2075	Note 1	7334	5744	1590	0.0093	3.54	17.8	23.9		0.0111
5	1997	Note 1	7093	5614	1479	0.0092	3.55	17.4	23.9		0.0105
6	2141	Note 1	7427	6015	1412	0.0090	3.47	18.6	24.0		0.0106
7	2869	Note 1	9218	7532	1686	0.0093	3.21	22.9	24.7		0.0123
8	3497	Note 1	10611	8756	1855	0.0096	3.03	26.4	25.2		0.0118
9	4650	Note 1	13922	11767	2156	0.0097	2.99	28.3	25.5		0.0116
10	4929	Note 1	14720	11997	2723	0.0102	2.99	28.9	25.6		0.0124
11	5399	Note 1	15889	12488	3401	0.0106	2.94	30.3	25.8		0.0140
12	5628	Note 1	16519	12671	3848	0.0109	2.94	30.8	25.9		0.0138
13	7127	Note 1	21590	17401	4189	0.0104	3.03	30.9	25.9		0.0120
14	6978	Note 1	20681	17592	3089	0.0100	2.96	31.5	26.0		0.0115
15	8564	Note 1	26137	22481	3657	0.0098	3.05	32.0	26.1		0.0121
16	8724	Note 1	26669	22557	4111	0.0099	3.06	32.2	26.1		0.0135
17	5715	Note 1	16347	13062	3285	0.0106	2.86	31.9	26.0		0.0145
18	5877	Note 1	17196	12870	4326	0.0112	2.93	31.3	26.0		0.0153
19	5552	Note 1	16881	12170	4710	0.0113	3.04	29.4	25.7		0.0149
20	5256	Note 1	16539	11556	4983	0.0113	3.15	27.6	25.4		0.0159
21	4354	Note 1	13565	9063	4502	0.0117	3.12	27.2	25.3		0.0168
22	4292	Note 1	13448	8953	4495	0.0116	3.13	26.9	25.3		0.0168
23	4175	Note 1	13210	8753	4457	0.0116	3.16	26.3	25.2		0.0168
24	4152	Note 1	13204	8674	4530	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.18	04/30	15:00	2.89	12/01	15:00	26.6	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.8	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.85	03/31	15:00	31.2	07/20	15:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.85	03/31	15:00	31.6	07/20	15:00	8.7	01/06	06:00
E350	4.58	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.49	10/05	01:00	2.85	03/31	15:00	32.7	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E420	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E430	3.80	04/30	14:00	2.78	06/13	17:00	25.0	10/10	09:00	8.7	01/06	06:00
E440	3.80	04/30	14:00	2.78	06/13	17:00	25.0	10/10	09:00	8.7	01/06	06:00
E500	4.17	04/30	16:00	2.71	07/30	12:00	25.0	03/31	18:00	14.5	11/23	09:00
E510	4.69	10/05	01:00	2.90	03/31	18:00	25.0	03/31	18:00	14.5	11/23	09:00
E520	4.06	04/30	16:00	2.62	07/30	12:00	15.0	03/25	08:00	12.8	11/14	08:00
E522	4.06	04/30	16:00	2.62	07/30	12:00	20.0	04/02	08:00	13.8	11/23	09:00
E525	4.65	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	15.4	12/01	01:00
E530	3.88	03/16	11:00	2.53	07/30	12:00	25.0	04/17	18:00	14.5	11/23	09:00
E540	3.88	03/16	10:00	2.53	07/30	12:00	15.0	04/16	01:00	12.8	11/14	08:00
E545	4.10	03/16	11:00	2.66	07/30	12:00	35.0	07/09	22:00	15.4	12/01	01:00

Humidity Ratio						Relative Humidity						Cases
Maximum			Minimum*			Maximum*			Minimum*			
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.6	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.7	11/06	06:00	E320
0.0181	07/10	12:00	0.0019	01/11	03:00	76.8	09/17	12:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E400
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E410
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E420
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.2	11/06	06:00	E430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.2	11/06	06:00	E440
0.0134	04/18	19:00	0.0102	11/23	10:00	100.0	11/13	09:00	54.4	04/30	13:00	E500
0.0154	10/12	02:00	0.0102	11/23	10:00	100.0	11/13	09:00	55.2	11/04	13:00	E510
0.0087	04/18	19:00	0.0064	04/30	13:00	84.1	10/18	08:00	60.7	04/30	13:00	E520
0.0108	04/18	19:00	0.0084	04/30	13:00	100.0	11/22	02:00	57.9	04/30	13:00	E522
0.0199	04/18	19:00	0.0109	11/30	24:00	100.0	11/12	01:00	47.3	04/30	13:00	E525
0.0091	01/03	15:00	0.0067	10/18	12:00	66.3	11/23	09:00	33.9	09/28	18:00	E530
0.0091	01/03	15:00	0.0033	10/17	09:00	36.0	11/22	10:00	30.8	09/28	18:00	E540
0.0091	01/03	15:00	0.0068	04/01	01:00	62.3	11/30	23:00	19.2	04/18	17:00	E545

	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	4032	3510	Note 1	522	13659	9887	3773	0.0110	3.85	16.8	24.98
June 25	5232	4663	Note 1	569	13737	9956	3781	0.0115	2.95	29.5	24.98

	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3094	2681	Note 1	413	9775	9775	0	0.0067	3.45	16.8	25.00
June 25	4030	3578	Note 1	453	9838	9838	0	0.0067	2.78	29.5	25.00

2.12 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 4

A comparison of EnergyPlus results from Round 3C with results from other programs (Ref: *HVAC BESTEST Cases E300-E545, Summary of 3rd Set of Results*, 12 Nov. 2002, J. Neymark) indicated that there were disagreements with regard to economizer control results (Cases E400 - E440) and DX cooling system performance for Cases E500 – E545. Further investigation into the reasons for these differences indicated several input errors had been made:

2.13 Results – Round 4

1) Cases 400 - 440
   A fan outlet node name for the mixed air set point manager had been incorrectly identified and caused the economizer control to operate not in accordance with the specification.

2) Case 410
   This case required that the DX cooling compressor be locked out from operating whenever the economizer was in operation. This capability has not yet been implemented in EnergyPlus so no results are being shown for this case.

3) Case 420
   The economizer high temperature limit of 20C for this case had not been specified as required and was defaulting to a different setting.

4) Cases 500 – 545
   The EnergyPlus total electricity consumption results for these cases are consistently low compared to the results of other programs. The DX coil model may be imposing some temperature limits on the use of the performance curves. During Round 4 the input temperature limits which defined the boundaries of the performance curves were opened up and some slight improvement in results occurred for Cases 520 and 540. This problem will be further investigated.

The results for Round 4 which are presented below were produced using EnergyPlus 1.0.3.013.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34743	23881	Note 1	10862	77307	55252	22055	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39282	28420	Note 1	10862	96404	55225	41179	3.39	24.09	0.0113	58.6		
E320	39084	28222	Note 1	10862	96103	62045	34058	3.41	24.25	0.0101	51.9		
E330	40151	29289	Note 1	10862	102242	63778	38463	3.49	24.27	0.0100	51.2		
E340	39789	28927	Note 1	10862	99731	62887	36844	3.45	24.30	0.0100	51.2		
E350	31138	20276	Note 1	10862	65763	48545	17218	3.24	26.24	0.0099	45.2		
E360	54703	43841	Note 1	10862	161241	135286	25955	3.68	25.32	0.0088	42.4		
E400	31009	20147	Note 1	10862	65399	40691	24708	3.25	24.09	0.0101	52.5		
E410			Note 1										
E420	32734	21872	Note 1	10862	70343	49527	20816	3.22	24.09	0.0094	49.4		
E430	31769	20907	Note 1	10862	67129	46733	20396	3.21	24.09	0.0095	49.6		
E440	31770	20908	Note 1	10862	67131	46734	20397	3.21	24.09	0.0095	49.6		
E500	23049	20419	Note 1	2630	65605	47492	18113	3.21	20.38	0.0096	60.5		
E500 May-Sep	18001	15972	Note 1	2030	50357	36476	13881	3.15	24.98	0.0113	57.4		
E510 May-Sep	35732	31669	Note 1	4063	112793	81566	31226	3.56	24.96	0.0113	57.4		
E520	25043	22021	Note 1	3022	66154	47989	18165	3.00	13.58	0.0064	64.7		
E522	24099	21254	Note 1	2845	65904	47760	18144	3.10	16.99	0.0079	63.0		
E525	20710	18529	Note 1	2181	65000	46930	18069	3.51	27.10	0.0140	55.7		
E530	17742	15652	Note 1	2090	46944	46944	0	3.00	20.58	0.0067	49.0		
E540	19061	16752	Note 1	2309	47296	47288	9	2.82	13.79	0.0043	46.3		
E545	16636	14765	Note 1	1871	46612	46612	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks					
	Compr + Both Fans			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11900	07/20	15:00	23531	07/20	15:00	10234	07/10	13:00	32734	07/20	15:00	34.775	07/20	15:00	0.0218	10/02	09:00
E310	12541	07/20	15:00	23276	07/11	16:00	16272	08/04	15:00	37125	09/17	15:00						
E320	12954	07/20	15:00	31972	04/24	15:00	22198	10/02	10:00	39765	09/03	16:00						
E330	13314	07/20	15:00	34765	06/14	15:00	27134	09/18	16:00	43445	10/02	09:00						
E340	13134	07/20	15:00	32888	04/24	15:00	23911	10/02	10:00	41327	10/02	10:00						
E350	11900	07/20	15:00	23531	07/20	15:00	10235	07/10	13:00	32734	07/20	15:00						
E360	12744	07/20	15:00	32621	04/24	16:00	8514	10/02	11:00	38451	10/02	11:00						
E400	11900	07/20	15:00	23531	07/20	15:00	26317	09/16	14:00	40728	09/16	15:00						
E410																		
E420	11900	07/20	15:00	23531	07/20	15:00	10234	07/10	13:00	32734	07/20	15:00						
E430	11900	07/20	15:00	23531	07/20	15:00	11074	10/24	13:00	32734	07/20	15:00						
E440	11900	07/20	15:00	23531	07/20	15:00	11074	10/24	13:00	32734	07/20	15:00						
E500	10286	07/20	15:00	19839	07/29	16:00	7751	06/29	16:00	27558	06/29	16:00						
E510	11410	07/20	15:00	22291	07/20	15:00	10425	04/21	01:00	32466	04/21	01:00						
E520	10968	07/20	15:00	19990	07/29	16:00	7661	06/29	16:00	27616	06/29	16:00						
E522	10640	07/20	15:00	19924	07/29	16:00	7707	06/29	16:00	27596	06/29	16:00						
E525	9476	07/20	15:00	19656	07/20	15:00	7812	06/29	16:00	27440	06/29	16:00						
E530	8171	07/20	15:00	19639	07/20	15:00	1	03/16	10:00	19639	07/20	15:00						
E540	8678	07/20	15:00	19727	07/20	15:00	1650	03/11	10:00	19727	07/20	15:00						
E545	7763	07/20	15:00	19540	07/20	15:00	0	05/03	16:00	19540	07/20	15:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2119	Note 1	7475	5811	1664	0.0094	3.53	18.0	23.9		0.0112
2	2132	Note 1	7496	5853	1643	0.0094	3.52	18.1	24.0		0.0113
3	2113	Note 1	7447	5809	1638	0.0094	3.52	18.0	23.9		0.0112
4	2075	Note 1	7332	5744	1589	0.0093	3.53	17.8	23.9		0.0111
5	1997	Note 1	7091	5614	1477	0.0092	3.55	17.4	23.9		0.0105
6	2142	Note 1	7425	6015	1410	0.0090	3.47	18.6	24.0		0.0106
7	2869	Note 1	9215	7532	1683	0.0093	3.21	22.9	24.7		0.0123
8	3498	Note 1	10609	8756	1853	0.0096	3.03	26.4	25.2		0.0118
9	4652	Note 1	13919	11767	2152	0.0097	2.99	28.3	25.5		0.0116
10	4931	Note 1	14717	11997	2720	0.0102	2.98	28.9	25.6		0.0124
11	5401	Note 1	15886	12488	3398	0.0106	2.94	30.3	25.8		0.0140
12	5631	Note 1	16516	12671	3845	0.0109	2.93	30.8	25.9		0.0138
13	7132	Note 1	21586	17401	4185	0.0104	3.03	30.9	25.9		0.0120
14	6983	Note 1	20677	17592	3086	0.0100	2.96	31.5	26.0		0.0115
15	8572	Note 1	26133	22481	3652	0.0098	3.05	32.0	26.1		0.0121
16	8733	Note 1	26665	22557	4107	0.0099	3.05	32.2	26.1		0.0135
17	5718	Note 1	16345	13062	3283	0.0106	2.86	31.9	26.0		0.0145
18	5881	Note 1	17194	12870	4324	0.0112	2.92	31.3	26.0		0.0153
19	5555	Note 1	16878	12170	4708	0.0113	3.04	29.4	25.7		0.0149
20	5259	Note 1	16537	11556	4981	0.0113	3.14	27.6	25.4		0.0159
21	4356	Note 1	13563	9063	4500	0.0117	3.11	27.2	25.3		0.0168
22	4294	Note 1	13446	8953	4493	0.0116	3.13	26.9	25.3		0.0168
23	4177	Note 1	13208	8753	4455	0.0116	3.16	26.3	25.2		0.0168
24	4153	Note 1	13202	8674	4528	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
E350	4.56	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410												
E420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E440	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E500	4.22	03/16	10:00	2.71	07/30	12:00	25.0	03/31	18:00	14.5	11/23	09:00
E510	4.68	10/05	01:00	2.91	03/31	18:00	25.0	03/31	18:00	14.5	11/23	09:00
E520	3.93	04/30	16:00	2.53	07/30	12:00	15.0	03/25	08:00	12.8	11/14	08:00
E522	4.06	03/16	10:00	2.61	07/30	12:00	20.0	04/02	08:00	13.8	11/23	09:00
E525	4.73	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	15.4	12/01	01:00
E530	3.92	03/16	10:00	2.53	07/30	12:00	25.0	04/17	18:00	14.5	11/23	09:00
E540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	04/16	01:00	12.8	11/14	08:00
E545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/09	22:00	15.4	12/01	01:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone										
Humidity Ratio						Relative Humidity				
Maximum			Minimum*			Maximum*			Minimum*			Cases
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.6	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.7	11/06	06:00	E320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.9	09/03	10:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	E400
												E410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	E420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.8	04/02	05:00	13.9	11/06	06:00	E430
0.0160	04/02	05:00	0.0019	01/11	03:00	79.9	04/02	05:00	13.9	11/06	06:00	E440
0.0134	04/18	19:00	0.0102	11/23	10:00	100.0	11/13	09:00	54.4	04/30	13:00	E500
0.0154	10/12	02:00	0.0102	11/23	10:00	100.0	11/13	09:00	55.3	11/04	13:00	E510
0.0088	04/18	19:00	0.0066	04/30	13:00	85.7	10/18	08:00	62.4	04/30	13:00	E520
0.0109	04/18	19:00	0.0085	04/30	13:00	100.0	11/22	02:00	58.2	04/30	13:00	E522
0.0199	04/18	19:00	0.0109	11/30	24:00	100.0	11/11	24:00	47.4	04/30	13:00	E525
0.0091	01/03	15:00	0.0067	10/18	12:00	66.5	11/23	09:00	34.0	09/28	18:00	E530
0.0091	01/03	15:00	0.0038	10/18	09:00	42.1	11/22	10:00	36.0	09/28	16:00	E540
0.0091	01/03	15:00	0.0068	04/01	01:00	62.3	11/30	23:00	19.2	04/18	17:00	E545

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	4030	3511	Note 1	519	13656	9884	3772	0.0110	3.85	16.8	24.98
June 25	5230	4665	Note 1	566	13734	9953	3781	0.0115	2.94	29.5	24.98

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3102	2689	Note 1	412	9775	9775	0	0.0067	3.44	16.8	25.00
June 25	4029	3579	Note 1	450	9835	9835	0	0.0067	2.78	29.5	25.00

2.14 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 5

2.14.1 Error in Reporting Round 4 Results

An error was made in the Round 4 "Energy Consumption – Compr + Both Fans" results reported in the "Annual Hourly Integrated Maxima Consumptions and Loads" table for Cases E500 through E545. The indoor fan energy consumption had been omitted from the totals. This error has been corrected in the results reported below for Round 5.

2.14.2 Error in Space Humidity Ratio Algorithm

A comparison of EnergyPlus results from Round 4 to the results of other programs indicated that the maximum space humidity ratios for Cases E500 through E545 were high. Further investigation into the problem indicated that these maximum values were actually happening one to two hours after the internal loads and HVAC system had been scheduled off. This was occurring because of the way the moisture balance algorithm had been set up. Internal loads during each time step of the simulation in EnergyPlus were being accounted for after the HVAC system simulation. With EnergyPlus version 1.1.0.004 and subsequent releases the space internal loads are now accounted for before the system simulation. This brought the EnergyPlus results more in line with the results of the other programs. Also, for cases E530, E540 and E545 the maximum space humidity ratio was occurring during the beginning of the year before the AC unit came on for the first time (March 11). The period for determining maximum space humidity ratio was therefore changed to March 11 through December 31. This then brought the EnergyPlus results for cases E530 and E540 closer to results for the other programs. The Round 5 results which follow present the revised results.

2.14.3 Error in Economizer Enthalpy Limit for Case E440

In accordance with changes to the test suite specification, the economizer enthalpy limit for case E440 was changed from 65.13 kJ/kg to 47.25 kJ/kg.

The results for Round 5 which are presented below were produced using EnergyPlus 1.1.0.020.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34746	23884	Note 1	10862	77318	55252	22066	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39290	28428	Note 1	10862	96448	55225	41222	3.39	24.09	0.0113	58.6		
E320	39079	28217	Note 1	10862	96084	62043	34040	3.41	24.25	0.0101	51.8		
E330	40143	29281	Note 1	10862	102211	63779	38433	3.49	24.27	0.0100	51.2		
E340	39783	28921	Note 1	10862	99709	62886	36823	3.45	24.30	0.0100	51.1		
E350	31145	20283	Note 1	10862	65790	48545	17245	3.24	26.24	0.0099	45.2		
E360	54705	43843	Note 1	10862	161248	135287	25961	3.68	25.32	0.0088	42.4		
E400	31013	20151	Note 1	10862	65414	40688	24726	3.25	24.09	0.0101	52.5		
E410			Note 1										
E420	32736	21873	Note 1	10862	70349	49524	20826	3.22	24.09	0.0094	49.4		
E430	31772	20910	Note 1	10862	67141	46739	20403	3.21	24.09	0.0095	49.6		
E440	33032	22170	Note 1	10862	71417	50060	21357	3.22	24.09	0.0093	48.8		
E500	23035	20406	Note 1	2628	65571	47491	18080	3.21	20.38	0.0094	59.2		
E500 May-Sep	17996	15967	Note 1	2029	50354	36476	13879	3.15	24.98	0.0113	57.3		
E510 May-Sep	35732	31669	Note 1	4063	112793	81566	31226	3.56	24.96	0.0113	57.4		
E520	25017	21999	Note 1	3019	66088	47986	18101	3.00	13.58	0.0060	61.4		
E522	24078	21235	Note 1	2843	65851	47758	18093	3.10	17.00	0.0076	60.8		
E525	20702	18522	Note 1	2180	64973	46930	18044	3.51	27.10	0.0138	55.0		
E530	17742	15652	Note 1	2090	46944	46944	0	3.00	20.59	0.0067	49.0		
E540	19061	16752	Note 1	2309	47297	47288	9	2.82	13.79	0.0043	46.3		
E545	16636	14765	Note 1	1871	46612	46612	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

	Annual Hourly Integrated Maxima Consumptions and Loads									E300 Only, Maxima			
			Evaporator Coil Loads							Weather Data Checks			
	Energy Consumption		Sensible		Latent		Sensible + Latent			ODB		Outdoor Humidity Ratio	
Cases	Compr + Both Fans Wh	Date Hour	Wh	Date Hour	Wh	Date Hour	Wh	Date Hour		°C	Date Hour	kg/kg	Date Hour
E300	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00		34.775	07/20 15:00	0.0218	10/02 09:00
E310	12541	07/20 15:00	23276	07/11 16:00	16275	08/04 15:00	37126	09/17 15:00					
E320	12954	07/20 15:00	31972	04/24 15:00	22195	10/02 10:00	39765	09/03 16:00					
E330	13314	07/20 15:00	34765	06/14 15:00	27134	09/18 16:00	43445	10/02 09:00					
E340	13134	07/20 15:00	32888	04/24 15:00	23911	10/02 10:00	41328	10/02 10:00					
E350	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00					
E360	12744	07/20 15:00	32621	04/24 16:00	8520	10/02 11:00	38460	10/02 11:00					
E400	11900	07/20 15:00	23531	07/20 15:00	26317	09/16 14:00	40728	09/16 15:00					
E410													
E420	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00					
E430	11900	07/20 15:00	23531	07/20 15:00	11074	10/24 13:00	32733	07/20 15:00					
E440	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00					
E500	10399	07/20 15:00	19849	07/20 15:00	7839	06/29 16:00	27646	06/29 16:00					
E510	11410	07/20 15:00	22290	07/20 15:00	8955	06/17 14:00	31178	06/17 14:00					
E520	11101	07/20 15:00	19999	07/20 15:00	7699	06/29 16:00	27653	06/29 16:00					
E522	10762	07/20 15:00	19934	07/20 15:00	7770	06/29 16:00	27659	06/29 16:00					
E525	9570	07/20 15:00	19664	07/20 15:00	7947	06/29 16:00	27577	06/29 16:00					
E530	8171	07/20 15:00	19639	07/20 15:00	1	03/16 10:00	19639	07/20 15:00					
E540	8677	07/20 15:00	19726	07/20 15:00	1655	03/11 10:00	19726	07/20 15:00					
E545	7763	07/20 15:00	19540	07/20 15:00	0	05/23 15:00	19540	07/20 15:00					

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2119	Note 1	7472	5811	1661	0.0094	3.53	18.0	23.9		0.0112
2	2131	Note 1	7494	5853	1641	0.0094	3.52	18.1	24.0		0.0113
3	2113	Note 1	7447	5809	1637	0.0094	3.52	18.0	23.9		0.0112
4	2075	Note 1	7332	5744	1588	0.0093	3.53	17.8	23.9		0.0111
5	1997	Note 1	7091	5614	1477	0.0092	3.55	17.4	23.9		0.0105
6	2142	Note 1	7425	6015	1410	0.0090	3.47	18.6	24.0		0.0106
7	2870	Note 1	9216	7532	1684	0.0093	3.21	22.9	24.7		0.0123
8	3499	Note 1	10609	8757	1853	0.0096	3.03	26.4	25.2		0.0118
9	4682	Note 1	14032	11767	2265	0.0098	3.00	28.3	25.5		0.0116
10	4948	Note 1	14778	11996	2781	0.0102	2.99	28.9	25.6		0.0124
11	5407	Note 1	15905	12488	3417	0.0106	2.94	30.3	25.8		0.0140
12	5632	Note 1	16522	12671	3851	0.0109	2.93	30.8	25.9		0.0138
13	7133	Note 1	21588	17401	4187	0.0104	3.03	30.9	25.9		0.0120
14	6983	Note 1	20678	17592	3086	0.0100	2.96	31.5	26.0		0.0115
15	8572	Note 1	26133	22481	3652	0.0098	3.05	32.0	26.1		0.0121
16	8733	Note 1	26665	22557	4107	0.0099	3.05	32.2	26.1		0.0135
17	5718	Note 1	16345	13061	3283	0.0106	2.86	31.9	26.0		0.0145
18	5881	Note 1	17193	12870	4324	0.0112	2.92	31.3	26.0		0.0153
19	5555	Note 1	16878	12170	4708	0.0113	3.04	29.4	25.7		0.0149
20	5259	Note 1	16536	11556	4981	0.0113	3.14	27.6	25.4		0.0159
21	4326	Note 1	13445	9063	4383	0.0116	3.11	27.2	25.3		0.0168
22	4279	Note 1	13387	8953	4434	0.0116	3.13	26.9	25.3		0.0168
23	4173	Note 1	13191	8753	4437	0.0116	3.16	26.3	25.2		0.0168
24	4152	Note 1	13196	8674	4522	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
E350	4.56	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410												
E420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E440	3.80	05/21	15:00	2.78	06/13	17:00	25.0	04/24	19:00	8.7	01/06	06:00
E500	4.20	03/16	10:00	2.71	07/30	12:00	25.0	03/31	18:00	8.9	12/21	02:00
E510	4.68	10/05	01:00	2.87	03/31	18:00	25.0	03/31	18:00	8.9	12/21	02:00
E520	3.94	04/30	15:00	2.53	07/30	12:00	15.0	04/16	01:00	8.8	12/21	01:00
E522	4.04	04/30	15:00	2.61	07/30	12:00	20.0	04/16	20:00	8.9	12/21	01:00
E525	4.70	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	9.0	12/21	02:00
E530	3.93	03/16	10:00	2.53	07/30	12:00	25.0	03/30	17:00	8.9	12/21	02:00
E540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	03/25	08:00	8.8	12/21	01:00
E545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/09	22:00	9.0	12/21	02:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone												
Humidity Ratio						Relative Humidity						
Maximum			Minimum*			Maximum*			Minimum*			Cases
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.5	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.6	11/06	06:00	E320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.9	09/03	10:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	E400
												E410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	E420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.7	04/02	05:00	13.9	11/06	06:00	E430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	13.9	11/06	06:00	E440
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	09:00	55.2	04/30	04:00	E500
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	09:00	55.3	05/04	03:00	E510
0.0070	07/20	15:00	0.0065	11/10	09:00	93.8	12/20	11:00	61.7	11/27	24:00	E520
0.0091	07/20	15:00	0.0070	12/20	12:00	100.0	12/15	22:00	59.2	04/30	04:00	E522
0.0185	07/20	15:00	0.0070	12/20	12:00	100.0	11/12	19:00	47.9	10/05	02:00	E525
0.0068	03/11	01:00	0.0067	10/18	12:00	96.2	12/20	11:00	34.0	04/18	18:00	E530
0.0068	03/11	01:00	0.0038	10/18	09:00	55.2	12/20	11:00	36.0	09/28	16:00	E540
0.0068	12/31	07:00	0.0068	04/01	02:00	96.2	12/20	11:00	19.2	04/18	17:00	E545

	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	4029	3510	Note 1	519	13655	9884	3772	0.0110	3.85	16.8	24.98
June 25	5229	4663	Note 1	566	13733	9953	3781	0.0115	2.94	29.5	24.98

	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3101	2689	Note 1	412	9775	9775	0	0.0068	3.44	16.8	25.00
June 25	4029	3579	Note 1	450	9835	9835	0	0.0068	2.78	29.5	25.00

2.15 Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 6

During Round 6 Case E410 with compressor lockout was added to the results suite since this feature was now available. The results for Round 6 which are presented below were produced using EnergyPlus 1.2.3.031. Except for a few cases where there are very small changes, the results are the same as Round 5 except that results for Case E410 are now included.

Cases	Annual Sums: Cooling Energy Consumption Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Evaporator Coil Load Total (kWh)	Sensible (kWh)	Latent (kWh)	Annual Means: COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	Annual Means E300 Only: Outdoor ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34768	23906	Note 1	10862	77393	55248	22146	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39313	28451	Note 1	10862	96528	55220	41307	3.39	24.09	0.0113	58.5		
E320	39101	28239	Note 1	10862	96170	62013	34157	3.41	24.25	0.0101	51.8		
E330	40172	29310	Note 1	10862	102328	63723	38606	3.49	24.27	0.0100	51.1		
E340	39808	28946	Note 1	10862	99808	62847	36961	3.45	24.30	0.0100	51.1		
E350	31161	20299	Note 1	10862	65850	48541	17309	3.24	26.24	0.0099	45.1		
E360	54712	43850	Note 1	10862	161277	135248	26029	3.68	25.33	0.0088	42.3		
E400	31097	20235	Note 1	10862	65755	40688	25067	3.25	24.09	0.0101	52.6		
E410	32768	21906	Note 1	10862	70635	49718	20917	3.22	24.09	0.0096	49.9		
E420	32757	21895	Note 1	10862	70423	49523	20899	3.22	24.09	0.0095	49.4		
E430	31795	20933	Note 1	10862	67218	46742	20476	3.21	24.09	0.0095	49.6		
E440	33060	22198	Note 1	10862	71516	50078	21437	3.22	24.09	0.0093	48.8		
E500	23038	20408	Note 1	2629	65567	47488	18079	3.21	20.38	0.0094	59.2		
E500 May-Sep	18000	15970	Note 1	2030	50355	36476	13879	3.15	24.98	0.0113	57.2		
E510 May-Sep	35738	31674	Note 1	4065	112794	81568	31226	3.56	24.96	0.0113	57.3		
E520	25019	22000	Note 1	3019	66088	47986	18101	3.00	13.58	0.0060	61.4		
E522	24081	21237	Note 1	2843	65850	47757	18093	3.10	17.00	0.0076	60.8		
E525	20706	18525	Note 1	2181	64964	46923	18041	3.51	27.10	0.0138	55.0		
E530	17741	15651	Note 1	2090	46940	46940	0	3.00	20.59	0.0067	49.1		
E540	19062	16753	Note 1	2309	47296	47288	9	2.82	13.79	0.0043	46.3		
E545	16636	14765	Note 1	1871	46604	46604	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads: Energy Consumption Compr + Both Fans Wh	Date	Hour	Evaporator Coil Loads Sensible Wh	Date	Hour	Latent Wh	Date	Hour	Sensible + Latent Wh	Date	Hour	E300 Only, Maxima Weather Data Checks ODB °C	Date	Hour	Outdoor Humidity Ratio kg/kg	Date	Hour
E300	11908	07/20	15:00	23532	07/20	15:00	10263	07/10	13:00	32761	07/20	15:00	34.775	07/20	15:00	0.0219	10/02	09:00
E310	12539	07/20	15:00	23267	07/11	16:00	16292	08/04	15:00	37132	09/17	15:00						
E320	12954	07/20	15:00	31953	04/24	15:00	22231	10/02	10:00	39761	09/03	16:00						
E330	13314	07/20	15:00	34710	06/14	14:00	27168	09/18	16:00	43446	10/02	09:00						
E340	13134	07/20	15:00	32882	04/24	15:00	23934	10/02	10:00	41319	10/02	10:00						
E350	11908	07/20	15:00	23532	07/20	15:00	10264	07/10	13:00	32761	07/20	15:00						
E360	12745	07/20	15:00	32615	04/24	16:00	8520	10/02	11:00	38444	10/02	11:00						
E400	11908	07/20	15:00	23532	07/20	15:00	26393	09/16	14:00	40730	09/16	15:00						
E410	11908	07/20	15:00	23532	07/20	15:00	10263	07/10	13:00	32761	07/20	15:00						
E420	11908	07/20	15:00	23532	07/20	15:00	10263	07/10	13:00	32761	07/20	15:00						
E430	11908	07/20	15:00	23532	07/20	15:00	11119	10/24	13:00	32761	07/20	15:00						
E440	11908	07/20	15:00	23532	07/20	15:00	10263	07/10	13:00	32761	07/20	15:00						
E500	10400	07/20	15:00	19850	07/20	15:00	7839	06/29	16:00	27647	06/29	16:00						
E510	11407	07/20	15:00	22290	07/20	16:00	8955	06/17	14:00	31179	06/17	14:00						
E520	11098	07/20	15:00	19993	07/20	15:00	7702	06/29	16:00	27661	06/29	16:00						
E522	10764	07/20	15:00	19934	07/20	15:00	7770	06/29	16:00	27659	06/29	16:00						
E525	9572	07/20	15:00	19664	07/20	15:00	7947	06/29	16:00	27577	06/29	16:00						
E530	8171	07/20	15:00	19639	07/20	15:00	1	03/16	10:00	19639	07/20	15:00						
E540	8678	07/20	15:00	19726	07/20	15:00	1645	03/11	10:00	19726	07/20	15:00						
E545	7764	07/20	15:00	19540	07/20	15:00	0	10/27	15:00	19540	07/20	15:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2121	Note 1	7479	5811	1669	0.0094	3.53	18.0	23.9		0.0112
2	2133	Note 1	7502	5853	1649	0.0094	3.52	18.1	24.0		0.0113
3	2115	Note 1	7454	5809	1644	0.0094	3.52	18.0	23.9		0.0112
4	2077	Note 1	7339	5744	1596	0.0093	3.53	17.8	23.9		0.0111
5	1999	Note 1	7097	5614	1483	0.0092	3.55	17.4	23.9		0.0105
6	2144	Note 1	7432	6015	1417	0.0090	3.47	18.6	24.0		0.0106
7	2873	Note 1	9227	7532	1695	0.0093	3.21	22.9	24.7		0.0123
8	3507	Note 1	10637	8757	1880	0.0097	3.03	26.4	25.2		0.0118
9	4689	Note 1	14055	11767	2288	0.0098	3.00	28.3	25.5		0.0116
10	4952	Note 1	14793	11996	2797	0.0102	2.99	28.9	25.6		0.0124
11	5409	Note 1	15911	12487	3424	0.0106	2.94	30.3	25.8		0.0139
12	5635	Note 1	16530	12671	3859	0.0109	2.93	30.8	25.9		0.0138
13	7139	Note 1	21607	17402	4206	0.0104	3.03	30.9	25.9		0.0120
14	6988	Note 1	20693	17592	3101	0.0100	2.96	31.5	26.0		0.0115
15	8577	Note 1	26149	22481	3669	0.0098	3.05	32.0	26.1		0.0121
16	8738	Note 1	26680	22557	4123	0.0099	3.05	32.2	26.1		0.0135
17	5722	Note 1	16356	13061	3295	0.0106	2.86	31.9	26.0		0.0145
18	5886	Note 1	17210	12869	4341	0.0112	2.92	31.3	26.0		0.0153
19	5561	Note 1	16895	12170	4725	0.0113	3.04	29.4	25.7		0.0149
20	5267	Note 1	16563	11556	5007	0.0114	3.14	27.6	25.4		0.0160
21	4331	Note 1	13461	9062	4399	0.0116	3.11	27.2	25.3		0.0168
22	4283	Note 1	13401	8952	4448	0.0116	3.13	26.9	25.3		0.0168
23	4177	Note 1	13205	8753	4452	0.0116	3.16	26.3	25.2		0.0168
24	4156	Note 1	13210	8674	4536	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
E350	4.58	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410	4.01	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	04/24	20:00	8.7	01/06	06:00
E440	3.80	05/21	15:00	2.78	06/13	17:00	25.0	04/24	20:00	8.7	01/06	06:00
E500	4.20	03/16	10:00	2.71	07/30	12:00	25.0	04/05	19:00	8.9	12/21	02:00
E510	4.68	10/05	01:00	2.84	03/31	18:00	25.0	04/05	19:00	8.9	12/21	02:00
E520	3.94	04/30	15:00	2.53	07/30	12:00	15.0	10/21	03:00	8.8	12/21	01:00
E522	4.04	04/30	15:00	2.61	07/30	12:00	20.0	04/16	20:00	8.9	12/21	01:00
E525	4.70	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	9.0	12/21	02:00
E530	3.92	03/16	10:00	2.53	07/30	12:00	25.0	04/17	18:00	8.9	12/21	02:00
E540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	03/25	08:00	8.8	12/21	01:00
E545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/14	18:00	9.0	12/21	02:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone												
Humidity Ratio						Relative Humidity						
Maximum			Minimum*			Maximum*			Minimum*			Cases
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.5	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	82.9	09/18	10:00	14.6	11/06	06:00	E320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.8	10/02	10:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	E360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	E400
0.0164	04/06	05:00	0.0019	01/11	03:00	82.3	04/06	05:00	14.4	11/06	06:00	E410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	E420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.7	04/02	05:00	13.9	11/06	06:00	E430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.3	11/16	17:00	13.9	11/06	06:00	E440
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	10:00	55.1	04/30	04:00	E500
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	10:00	55.2	05/04	03:00	E510
0.0070	07/20	15:00	0.0065	11/10	09:00	93.7	12/20	11:00	61.6	11/27	24:00	E520
0.0091	07/20	15:00	0.0070	12/20	12:00	100.0	12/15	22:00	59.1	04/30	04:00	E522
0.0185	07/20	15:00	0.0070	12/20	12:00	100.0	11/12	19:00	47.8	10/05	02:00	E525
0.0068	03/16	03:00	0.0068	10/17	10:00	96.7	12/20	11:00	34.1	04/18	17:00	E530
0.0068	03/11	01:00	0.0038	10/18	11:00	55.2	12/20	11:00	36.0	09/28	18:00	E540
0.0068	12/31	08:00	0.0068	04/01	01:00	96.3	12/20	11:00	19.2	04/18	17:00	E545

	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	4030	3511	Note 1	519	13655	9884	3772	0.0110	3.85	16.8	24.98
June 25	5230	4664	Note 1	566	13733	9953	3781	0.0115	2.94	29.5	24.98

	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3101	2689	Note 1	412	9775	9775	0	0.0068	3.44	16.8	25.00
June 25	4029	3579	Note 1	450	9835	9835	0	0.0068	2.78	29.5	25.00

2.16 Results With Subsequent Releases of EnergyPlus

The IEA HVAC BESTEST workgroup has completed their activities and final results are recorded in a report authored and released by NREL in December 2004 (Neymark & Judkoff 2004). Since the completion of that study, further capabilities and improvements have been added to EnergyPlus with new releases occurring in April 2005 (version 1.2.2), October 2005 (version 1.2.3), April 2006 (version 1.3.0), October 2006 (version 1.4.0), April 2007 (version 2.0.0), October 2007 (version 2.1.0), April 2008 (version 2.2.0) and November 2008 (version 3.0.0.028).

With EnergyPlus version 1.3.0.018 a new SITE ATMOSPHERIC VARIATION input object became available to simulate changes in outside air temperature and wind speed that typically occur vertically across building surfaces versus the outdoor air temperature and wind speed that are obtained each hour from the weather file. Typically the meteorological wind speed is measured in an open field at 10m above the ground and meteorological air temperature is measured at 1.5m above ground level. To accommodate atmospheric variation EnergyPlus now automatically calculates the local outdoor air temperature and wind speed separately for each zone and surface exposed to the outdoor environment. The zone centroid or surface centroid are used to determine the height above ground. Only local outdoor air temperature and wind speed are currently calculated because they are important factors for the exterior convection calculation for surfaces and can also be factors in the zone infiltration and ventilation calculations. Since Standard 140 assumes that the temperature of the outside surfaces of the building are at the outdoor dry-bulb temperature read from the weather file, the SITE ATMOSPHERIC VARIATION temperature calculation feature was turned off by setting the air temperature gradient coefficient to 0.0. The wind speed variation calculation was left active but had no effect because the building's exterior surfaces were configured to be near adiabatic with an insulation layer of R-325 m2-K/W. For Cases CE320 and CE340 which had infiltration, there was also no change in results since the infiltration rate was set to a constant. The SITE ATMOSPHERIC VARIATION object was allowed to be active for all of the test cases simulated with EnergyPlus 1.3.0.018 and later versions with the following inputs:

```
SITE ATMOSPHERIC VARIATION,
    0.22,           !- Wind Speed Profile Exponent
    370,            !- Wind Speed Profile Boundary Layer Thickness {m}
    0.0;            !- Air Temperature Gradient Coefficient {K/m}
```

New output variables to report the surface exterior outdoor dry-bulb temperature and surface exterior wind speed allow the user to track hourly changes when the SITE ATMOSPHERIC VARIATION features are active.

With EnergyPlus version 1.4.0.025, a change was made to make the DX coil sensible and latent outputs agree with the Window AC outputs. The total cooling output did not change but there were small changes in sensible cooling (-0.3% or less) and latent cooling (1.0% or less).

The results of running the Standard 140 HVAC Tests CE300-CE545 with the latest release of EnergyPlus, version 3.0.0.028, are presented below. These results for EnergyPlus versions 1.4.0.025 through the current version 2.2.0.023 have remained unchanged.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total	ompressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Zone Humidity Ratio	Zone Relative Humidity	ODB	Outdoor Humidity Ratio
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)	(°C)	(kg/kg)
CE300	34768	23906	Note 1	10862	77393	55168	22225	3.24	24.09	0.0093	48.6	19.9	0.0116
CE310	39313	28451	Note 1	10862	96527	55074	41453	3.39	24.09	0.0113	58.5		
CE320	39101	28239	Note 1	10862	96169	61842	34327	3.41	24.25	0.0101	51.8		
CE330	40172	29310	Note 1	10862	102328	63529	38799	3.49	24.27	0.0100	51.1		
CE340	39808	28946	Note 1	10862	99807	62663	37145	3.45	24.30	0.0100	51.1		
CE350	31161	20299	Note 1	10862	65850	48473	17377	3.24	26.24	0.0099	45.1		
CE360	54712	43850	Note 1	10862	161277	135022	26255	3.68	25.33	0.0088	42.3		
CE400	31097	20235	Note 1	10862	65755	40604	25150	3.25	24.09	0.0101	52.6		
CE410	32768	21906	Note 1	10862	70634	49640	20994	3.22	24.09	0.0096	49.9		
CE420	32757	21895	Note 1	10862	70422	49446	20977	3.22	24.09	0.0095	49.4		
CE430	31795	20933	Note 1	10862	67218	46666	20553	3.21	24.09	0.0095	49.6		
CE440	33060	22198	Note 1	10862	71515	50000	21515	3.22	24.09	0.0093	48.8		
CE500	23037	20408	Note 1	2629	65566	47340	18226	3.21	20.35	0.0094	59.3		
CE500 May-Se	18000	15970	Note 1	2030	50355	36364	13991	3.15	24.98	0.0113	57.2		
CE510 May-Se	35738	31674	Note 1	4065	112794	81314	31480	3.56	24.96	0.0113	57.3		
CE520	25019	22000	Note 1	3019	66087	47857	18230	3.00	13.55	0.0060	61.5		
CE522	24081	21237	Note 1	2843	65849	47620	18229	3.10	16.97	0.0076	60.8		
CE525	20706	18525	Note 1	2181	64963	46747	18217	3.51	27.07	0.0138	55.1		
CE530	17739	15650	Note 1	2090	46940	46940	0	3.00	20.60	0.0067	49.1		
CE540	19063	16753	Note 1	2309	47297	47288	9	2.82	13.80	0.0044	46.3		
CE545	16635	14764	Note 1	1871	46604	46604	0	3.16	27.32	0.0068	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks					
	Compr + Both Fans			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
Cases	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
CE300	11908	07/20	15:00	23464	07/20	15:00	10322	07/10	13:00	32761	07/20	15:00	34.775	07/20	15:00	0.0219	10/02	09:00
CE310	12539	07/20	15:00	23179	07/11	16:00	16397	08/04	15:00	37132	09/17	15:00						
CE320	12954	07/20	15:00	31952	04/24	15:00	22352	10/02	10:00	39761	09/03	16:00						
CE330	13314	07/20	15:00	34707	06/14	14:00	27289	09/18	16:00	43446	10/02	09:00						
CE340	13134	07/20	15:00	32882	04/24	15:00	24063	10/02	10:00	41319	10/02	10:00						
CE350	11908	07/20	15:00	23463	07/20	15:00	10323	07/10	13:00	32761	07/20	15:00						
CE360	12745	07/20	15:00	32614	04/24	16:00	8599	10/02	11:00	38444	10/02	11:00						
CE400	11908	07/20	15:00	23464	07/20	15:00	26504	09/16	14:00	40730	09/16	15:00						
CE410	11908	07/20	15:00	23464	07/20	15:00	10322	07/10	13:00	32761	07/20	15:00						
CE420	11908	07/20	15:00	23464	07/20	15:00	10322	07/10	13:00	32761	07/20	15:00						
CE430	11908	07/20	15:00	23464	07/20	15:00	11154	10/24	13:00	32761	07/20	15:00						
CE440	11908	07/20	15:00	23464	07/20	15:00	10322	07/10	13:00	32761	07/20	15:00						
CE500	10400	07/20	15:00	19793	07/20	15:00	7900	06/29	16:00	27647	06/29	16:00						
CE510	11407	07/20	15:00	22225	07/29	16:00	9027	06/17	14:00	31179	06/17	14:00						
CE520	11098	07/20	15:00	19943	07/20	15:00	7755	06/29	16:00	27661	06/29	16:00						
CE522	10764	07/20	15:00	19881	07/20	15:00	7826	06/29	16:00	27659	06/29	16:00						
CE525	9572	07/20	15:00	19596	07/20	15:00	8022	06/29	16:00	27577	06/29	16:00						
CE530	8171	07/20	15:00	19639	07/20	15:00	1	03/16	10:00	19639	07/20	15:00						
CE540	8678	07/20	15:00	19726	07/20	15:00	1670	03/11	10:00	19726	07/20	15:00						
CE545	7763	07/20	15:00	19540	07/20	15:00	0	09/14	15:00	19540	07/20	15:00						

	June 28 Hourly Output - Case CE300										
	Energy Consumptio		Evaporator Coil Load			Zone					Outdoor
Hour	ompressor	Cond Fan	Total	Sensible	Latent	Hum. Rat.	COP2	ODB	EDB	EWB	Hum. Rat.
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	2121	Note 1	7480	5808	1672	0.0094	3.53	18.0	23.9		0.0112
2	2133	Note 1	7502	5850	1652	0.0094	3.52	18.1	24.0		0.0113
3	2115	Note 1	7454	5806	1647	0.0094	3.52	18.0	23.9		0.0112
4	2077	Note 1	7339	5741	1598	0.0093	3.53	17.8	23.9		0.0111
5	1999	Note 1	7097	5611	1486	0.0092	3.55	17.4	23.9		0.0105
6	2144	Note 1	7432	6012	1420	0.0090	3.47	18.6	24.0		0.0106
7	2873	Note 1	9227	7528	1699	0.0093	3.21	22.9	24.7		0.0123
8	3507	Note 1	10637	8751	1886	0.0097	3.03	26.4	25.2		0.0118
9	4689	Note 1	14055	11758	2297	0.0098	3.00	28.3	25.5		0.0116
10	4953	Note 1	14793	11986	2808	0.0102	2.99	28.9	25.6		0.0124
11	5409	Note 1	15911	12474	3437	0.0106	2.94	30.3	25.8		0.0139
12	5636	Note 1	16530	12656	3875	0.0109	2.93	30.8	25.9		0.0138
13	7139	Note 1	21608	17379	4229	0.0104	3.03	30.9	25.9		0.0120
14	6988	Note 1	20693	17575	3118	0.0100	2.96	31.5	26.0		0.0115
15	8577	Note 1	26150	22455	3695	0.0098	3.05	32.0	26.1		0.0121
16	8738	Note 1	26680	22528	4152	0.0099	3.05	32.2	26.1		0.0135
17	5722	Note 1	16356	13047	3309	0.0106	2.86	31.9	26.0		0.0145
18	5886	Note 1	17210	12852	4358	0.0112	2.92	31.3	26.0		0.0153
19	5561	Note 1	16895	12152	4743	0.0113	3.04	29.4	25.7		0.0149
20	5267	Note 1	16563	11538	5025	0.0114	3.14	27.6	25.4		0.0160
21	4331	Note 1	13461	9050	4411	0.0116	3.11	27.2	25.3		0.0168
22	4283	Note 1	13401	8940	4461	0.0116	3.13	26.9	25.3		0.0168
23	4177	Note 1	13205	8741	4464	0.0116	3.16	26.3	25.2		0.0168
24	4156	Note 1	13210	8661	4548	0.0117	3.18	26.1	25.2		0.0171

	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
Cases	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
CE300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
CE310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
CE320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
CE330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
CE340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
CE350	4.58	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
CE360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
CE400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
CE410	4.01	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
CE420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
CE430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	04/24	20:00	8.7	01/06	06:00
CE440	3.80	05/21	15:00	2.78	06/13	17:00	25.0	04/24	20:00	8.7	01/06	06:00
CE500	4.20	03/16	10:00	2.71	07/30	12:00	25.0	04/05	19:00	8.8	12/21	01:00
CE510	4.68	10/05	01:00	2.85	03/31	18:00	25.0	04/05	19:00	8.8	12/21	01:00
CE520	3.94	04/30	15:00	2.53	07/30	12:00	15.0	03/25	08:00	8.7	12/21	01:00
CE522	4.04	04/30	15:00	2.61	07/30	12:00	20.0	04/02	01:00	8.8	12/21	01:00
CE525	4.70	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	8.9	12/21	02:00
CE530	3.93	03/16	10:00	2.53	07/30	12:00	25.0	04/23	12:00	9.0	12/21	02:00
CE540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	06/28	06:00	8.9	12/21	01:00
CE545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/14	18:00	9.1	12/21	02:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone

Humidity Ratio						Relative Humidity						Cases
Maximum			Minimum*			Maximum*			Minimum*			
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	CE300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.5	11/06	08:00	CE310
0.0178	07/10	13:00	0.0019	01/11	03:00	82.9	09/18	10:00	14.6	11/06	06:00	CE320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.8	10/02	10:00	14.4	11/06	06:00	CE330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	CE340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	CE350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.3	11/16	17:00	14.4	11/06	06:00	CE360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	CE400
0.0164	04/06	05:00	0.0019	01/11	03:00	82.3	04/06	05:00	14.4	11/06	06:00	CE410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	CE420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.7	04/02	05:00	13.9	11/06	06:00	CE430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.3	11/16	17:00	13.9	11/06	06:00	CE440
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	08:00	55.1	04/30	04:00	CE500
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	08:00	55.2	05/04	03:00	CE510
0.0070	07/20	15:00	0.0065	11/10	11:00	94.5	12/20	11:00	61.8	11/10	04:00	CE520
0.0091	07/20	15:00	0.0069	12/20	12:00	100.0	12/15	21:00	59.1	04/30	04:00	CE522
0.0185	07/20	15:00	0.0070	12/20	12:00	100.0	11/12	19:00	47.8	10/05	02:00	CE525
0.0068	03/16	06:00	0.0068	10/17	10:00	96.6	12/20	11:00	34.2	04/18	17:00	CE530
0.0068	03/11	01:00	0.0038	10/18	11:00	55.0	12/20	11:00	36.0	09/28	18:00	CE540
0.0068	12/31	21:00	0.0068	04/01	01:00	96.1	12/20	11:00	19.3	04/18	17:00	CE545

Case CE500 Average Daily Outputs - f(ODB) sensitivity

	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total ompressor	Cond Fan	Indoor Fan		Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	4030	3511	Note 1	519	13655	9851	3804	0.0110	3.85	16.8	24.98
June 25	5230	4664	Note 1	566	13733	9923	3810	0.0115	2.94	29.5	24.98

Case CE530 Average Daily Outputs - f(ODB) sensitivity

	Energy Consumption				Evaporator Coil Load			Zone			
Day	Total ompressor	Cond Fan	Indoor Fan		Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3101	2689	Note 1	412	9775	9775	0	0.0068	3.44	16.8	25.00
June 25	4028	3578	Note 1	450	9835	9835	0	0.0068	2.78	29.5	25.00

2.17 Summary of Changes that were Implemented During Testing

This section documents the comparative changes that took place in results (see Figures 2 through 9) as modifications were made to the EnergyPlus code or changes were made in the modeling approach (see Table 2). No analytical results were available for this series of tests. The results from running the HVAC BESTEST Cases CE300 – CE545 with each release through EnergyPlus version 1.3.0 has remained unchanged except that the results for Case CE410 have now been added since the compressor lockout feature when using an economizer is now activated. With EnergyPlus version 1.4.0 and later very small changes (less than 1%) occurred in the cooling coil sensible and latent loads due to changes described below in Table 2.

Table 2 – Summary of Pertinent EnergyPlus Changes that were Implemented

Version	Input File Changes	Code Changes
Ver 1.0.2.004	Interpolated cooling equipment performance data to get ARI rated conditions	
Ver 1.0.3.001		Added H_g psychrometric function as per ASHRAE equations and now use this for latent gain conversion to humidity ratio
Ver 1.0.3.005	New cooling equipment performance curve fits generated for ARI data point in revised specification	Dry coil outlet condition calculation error fixed
Ver 1.0.3.006	Added infiltration during first week of simulation to overcome overdrying of cooling coil	Weather data subhourly time step interpolation fixed
Ver 1.0.3.013	Corrected error with fan outlet node name for mixed air set point manager which had in specified incorrectly	
Ver 1.1.0.020	Changed economizer enthalpy limit for Case CE440 from 65.13 to 47.25 kJ/kg per change to specification	Changed moisture balance algorithm to account for space internal loads before HVAC system simulation
Ver 1.3.0.018	Turned off the surface vertical temperature calculation in the new SITE ATMOSPHERIC VARIATION object.	
1.4.0.025		Changed DX coil sensible and latent outlet calculations to make them consistent with Window Air Conditioner outlet calculations. DX coil and Window Air Conditioner total cooling remained unchanged but the split between sensible and latent coil load did change. (CR 7092)
2.1.0.023		Changes made to psychrometric routines to make them valid below 0C. (CR 7282 & CR 7331)
2.2.0.023	Used EnergyPlus weather files created from TMY2 formatted files provided with Standard 140-2007	
3.0.0.028		The algorithm for variable system timestep was revised. Changes include uniform system timestep length across zone timestep and stricter management of history terms for zone air conditions.

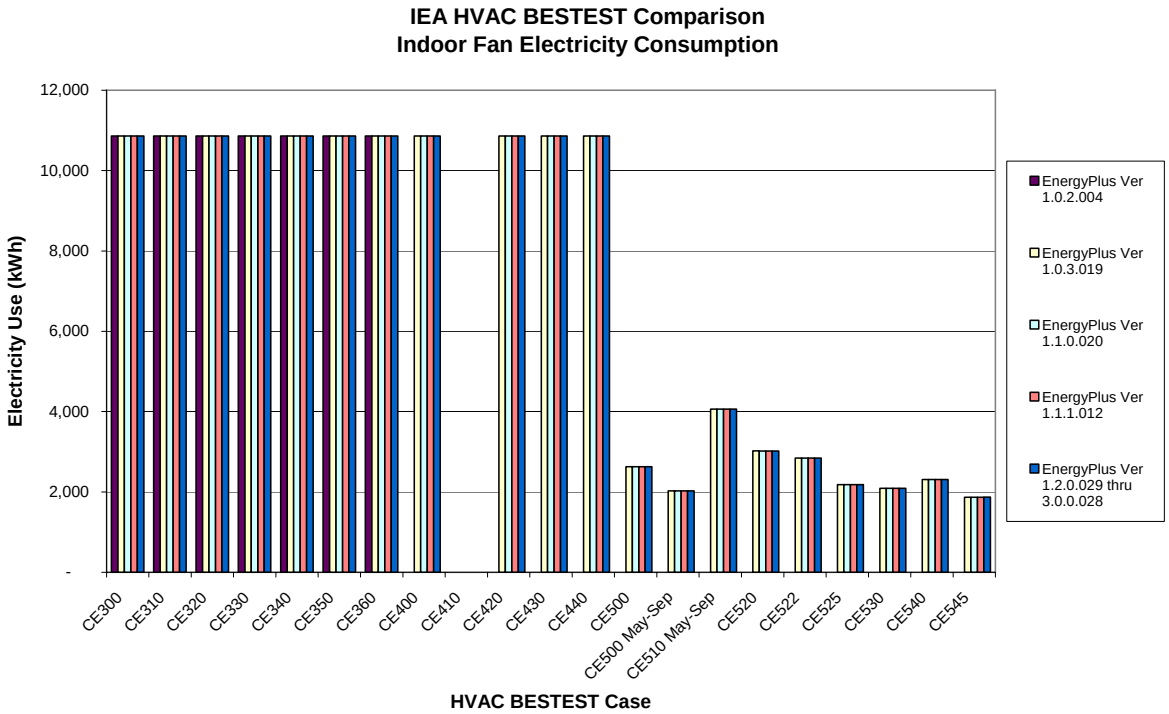


Figure 2 Indoor Fan Power Results for Various Versions of EnergyPlus

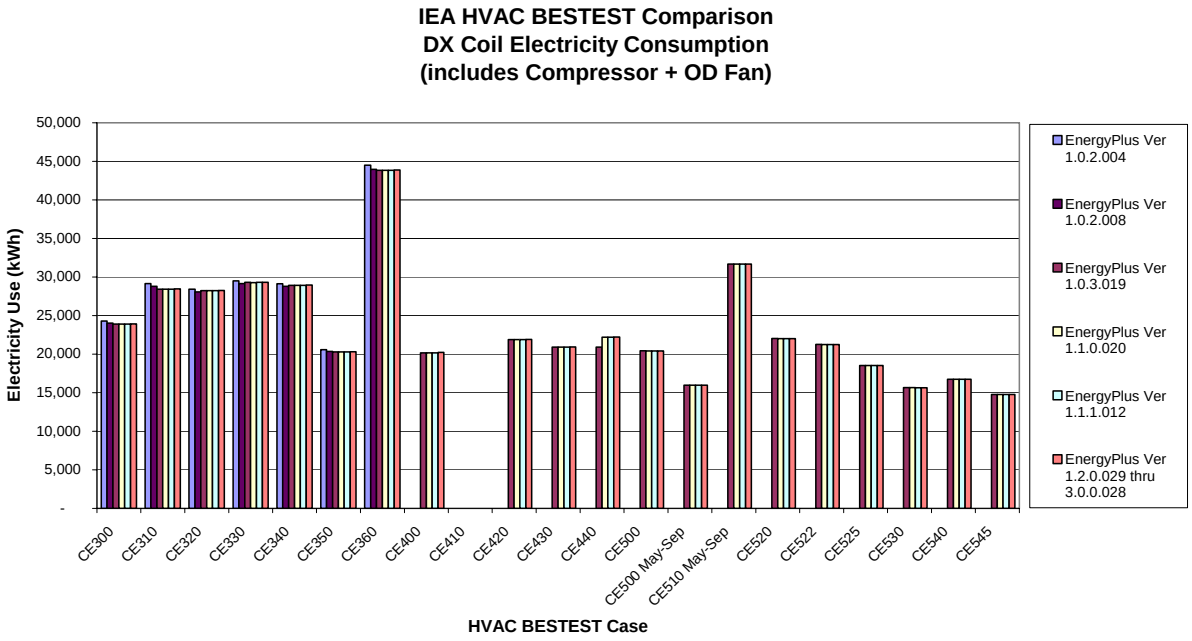


Figure 3 Compressor Plus Outdoor Fan Electricity Consumption Results for Various Versions of EnergyPlus

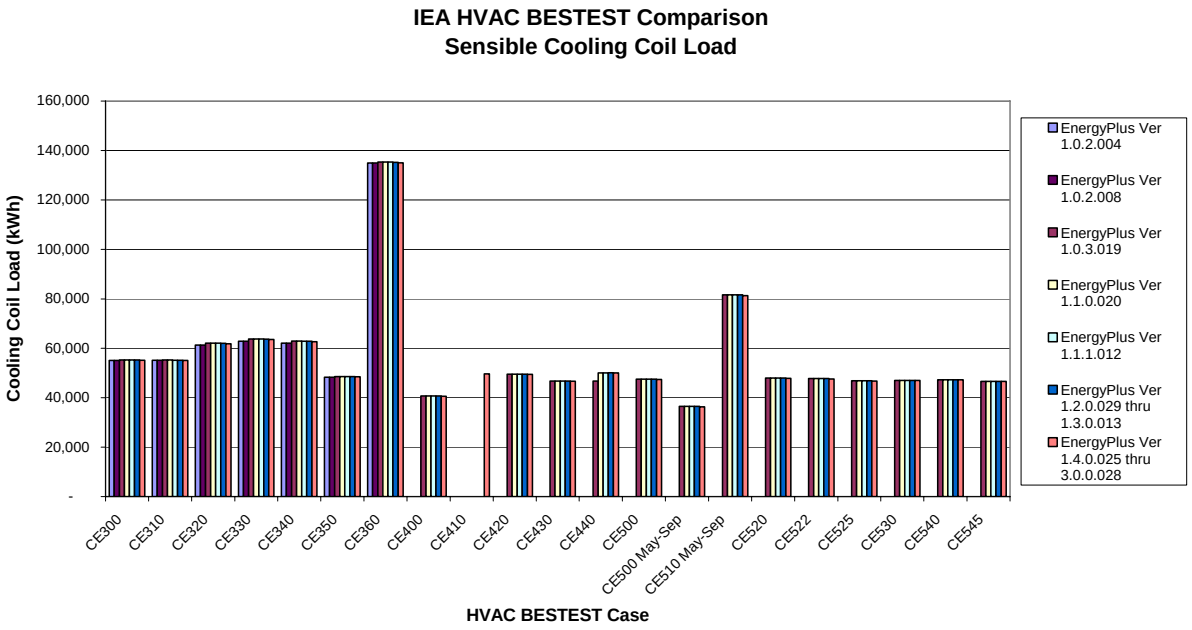


Figure 4 Sensible Cooling Coil Load Results for Various Versions of EnergyPlus

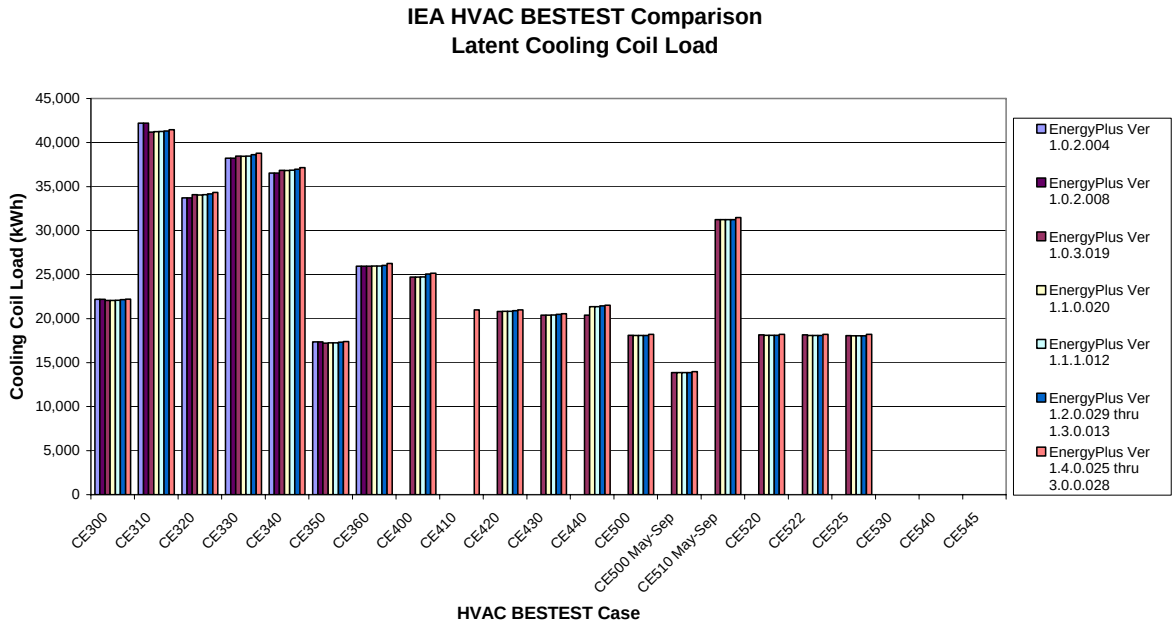


Figure 5 Latent Cooling Coil Load Results for Various Versions of EnergyPlus

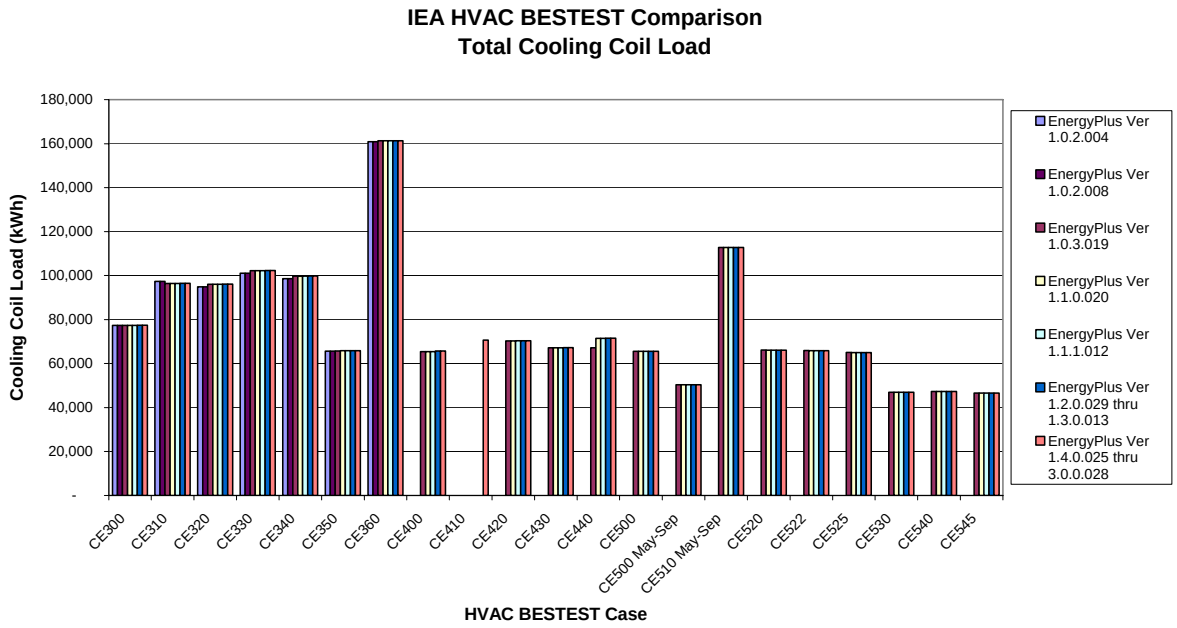


Figure 6 Total Cooling Coil Load Results for Various Versions of EnergyPlus

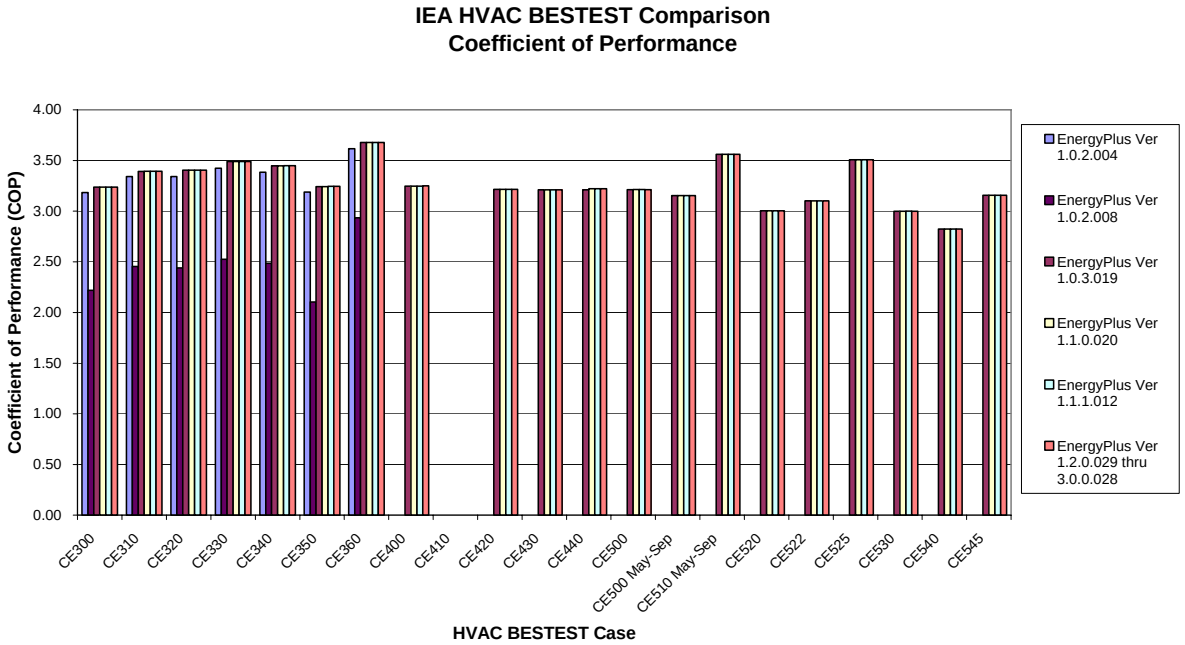


Figure 7 Coefficient of Performance Results for Various Versions of EnergyPlus (*COP results for EnergyPlus 1.0.2.008 mistakenly used total electric consumption (compressor plus outdoor fan plus indoor fan) rather than just compressor consumption plus outdoor fan consumption to calculate COP)*

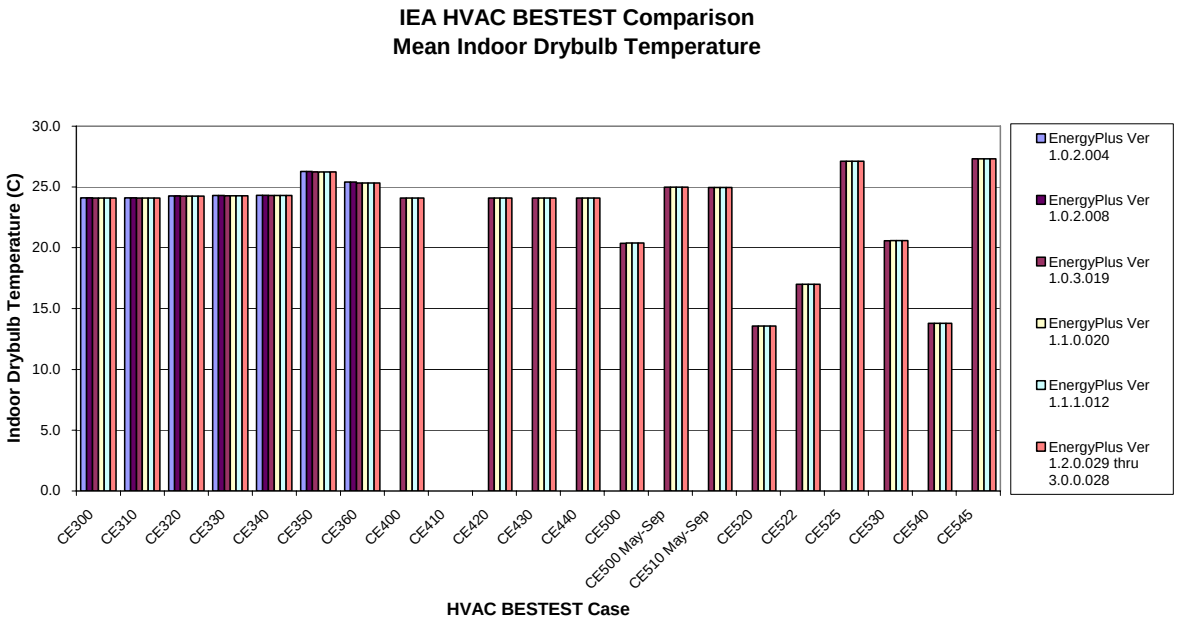


Figure 8 Indoor Dry-Bulb Temperature for Various Versions of EnergyPlus

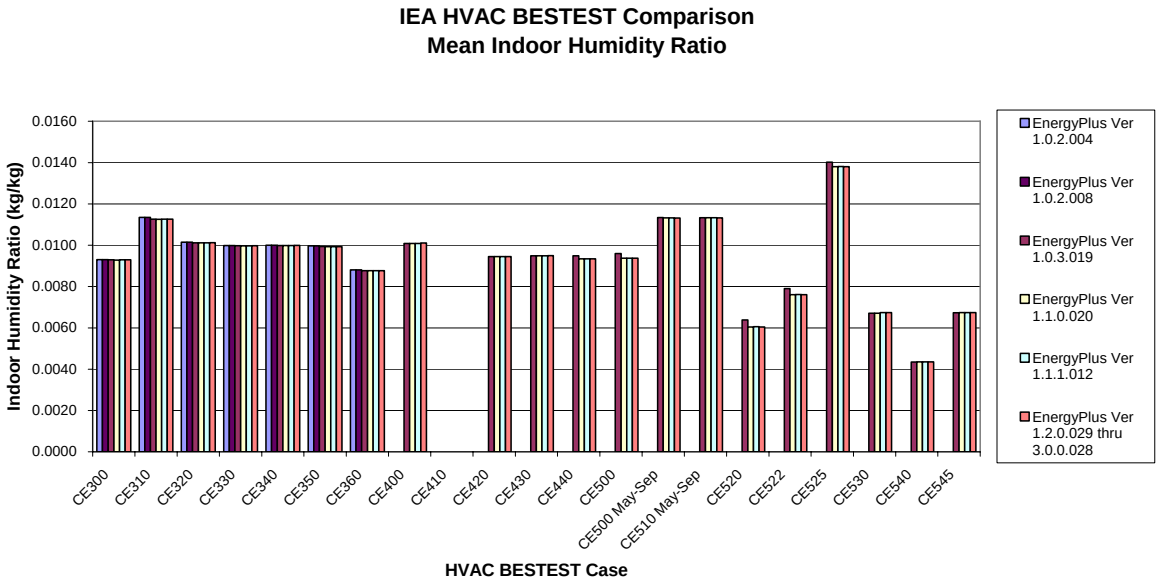


Figure 9 Indoor Humidity Ratio Results for Various Versions of EnergyPlus

3 RESULTS AND DISCUSSION

The results of the EnergyPlus HVAC comparison with other whole building energy analysis programs that participated in the HVAC BESTEST Comparison are summarized on a set of charts which are reproduced in Appendix A. The nomenclature for the various programs referred to on these charts along with the program author and modeler responsible for using the program as part of the HVAC BESTEST project are presented below.

Code Name	Authoring Organization	Implemented by	Chart Abbreviation
CODYRUN/LGIMAT	Universite de la Reunion Island, France	Universite de la Reunion Island, France	CODYRUN/UR
DOE-2.1E-ESTSC version	LANL/LBNL/ESTSC/JJH, U.S.	NREL/JNA, U.S.	DOE-2.1E-E/NREL
DOE-2.2 NT	LBNL/JJH, U.S.	NREL/JNA, U.S.	DOE-2.2/NREL
EnergyPlus version 3.0.0.028	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-BT, U.S	GARD Analytics, U.S.	ENERGY+/GARD
HOT3000	CETC/ESRU, Canada/United Kingdom	CETC, Canada	HOT3000/NRCan
TRNSYS 14.2-TUD with real controller model	University of Wisconsin, U.S.; Technische Univ. Dresden, Germany	Technische Univ. Dresden, Germany	TRNSYS/TUD

LANL/LBNL: Los Alamos National Laboratory/Lawrence Berkeley Laboratory, U.S.
ESTAC: Energy Science & Technology Software Center (at Oak Ridge National Laboratory), U.S.
JJH: James J. Hirsch & Associates, U.S.
NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates, U.S.
UIUC: University of Illinois Urbana/Champaign, U.S.
CERL: U.S. Army Corps of Engineers, Construction Engineering Research laboratories, U.S.
OSU: Oklahoma State University, U.S.
FSEC: University of Central Florida, Florida Solar Energy Center, U.S.
DOE-BT: U.S. Dept. of Energy, Office of Building Technologies, Energy Efficiency and Renewable Energy, U.S.
CETC: CANMET Energy Technology Centre, Natural Resources Canada, Canada
ESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

The series of charts in Appendix A compare the results of EnergyPlus 3.0.0.028 with five other programs. The charts are presented in the following order:

Total Electric Consumption
Indoor Fan Electricity Consumption
Coefficient of Performance
Total Cooling Coil Load
Sensible Cooling Coil Load
Latent Cooling Coil Load
Mean Indoor Dry-bulb Temperature
Mean Indoor Humidity Ratio.

Since there were no analytical results available for Cases CE300 – CE545, comparisons of results can only be limited to the disagreement between the program participant results where disagreement is the difference between the maximum and minimum results for each test case divided by the mean of the results for each test case or ((max- min) / mean). As reported in the IEA/NREL final report, during the initial rounds of testing there was a 3% - 21% disagreement among the cases for the simulated energy consumption results and there was a lot of scatter among all the programs. During the final round of testing, after correcting software errors and input errors, the disagreement of results for annual total energy consumption between all programs was 2% - 6% with very little scatter among the programs. EnergyPlus' results for the various test cases usually fell between the min and max limits of the other programs.

4 CONCLUSIONS

EnergyPlus Version 1.0.0.023 and subsequent versions up through the most recent release, EnergyPlus 3.0.0.028, were used to model a range of HVAC equipment load specifications as specified in ANSI/ASHRAE Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.* The ability of EnergyPlus to predict zone loads, cooling coil loads, cooling equipment energy consumption and resulting zone environment was tested using a test suite of 20 cases which included varying sensible internal gains, latent internal gains, infiltration rates, outside air fraction, thermostat set points and economizer control settings. The results predicted by EnergyPlus for 20 different cases were compared to results from 5 other whole building energy simulation programs that participated in an International Energy Agency (IEA) project. Total energy consumption between the 6 programs for the various test cases differed by 2% - 6% compared to the mean. EnergyPlus results generally fell within the min/max of the results for each case.

The Standard 140 HVAC tests are a very valuable testing tool which provides excellent benchmarks for testing HVAC system and equipment algorithms versus the results of other international building simulation programs. As discussed above, the Standard 140 HVAC tests allowed the developers of EnergyPlus to identify errors in algorithms and improve simulation accuracy.

5 REFERENCES

ANSI/ASHRAE 2007. Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

EnergyPlus 2008. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies. www.energyplus.gov

Henninger, Robert H, Michael J Witte, and Drury B Crawley. 2004. "Analytical and Comparative Testing of EnergyPlus using IEA HVAC BESTEST E100-E200 Test Suite," pp 855-863, *Energy and Buildings*, 36:8.

Henninger, Robert H, Michael .J Witte. 2008. "EnergyPlus Testing with HVAC Equipment Tests CE100 to CE200 from ANSI/ASHRAE Standard 140-2004," May 2008. U.S. Department of Energy, www.energyplus.gov

Neymark, J., and R. Judkoff. 2001. *International Energy Agency Solar Heating and Cooling Programme Task 22 Building Energy Simulation Test and Diagnostic Method for HVAC Equipment Models (HVAC BESTEST)*, National Renewable Energy Laboratory, Golden, Colorado, October 2001.

Neymark, J., and R. Judkoff. 2002. *International Energy Agency Solar Heating and Cooling Programme Task 22 Building Energy Simulation Test and Diagnostic Method for HVAC Equipment Models (HVAC BESTEST)*, National Renewable Energy Laboratory, Golden, Colorado, NREL/TP-550-30152, January 2002.

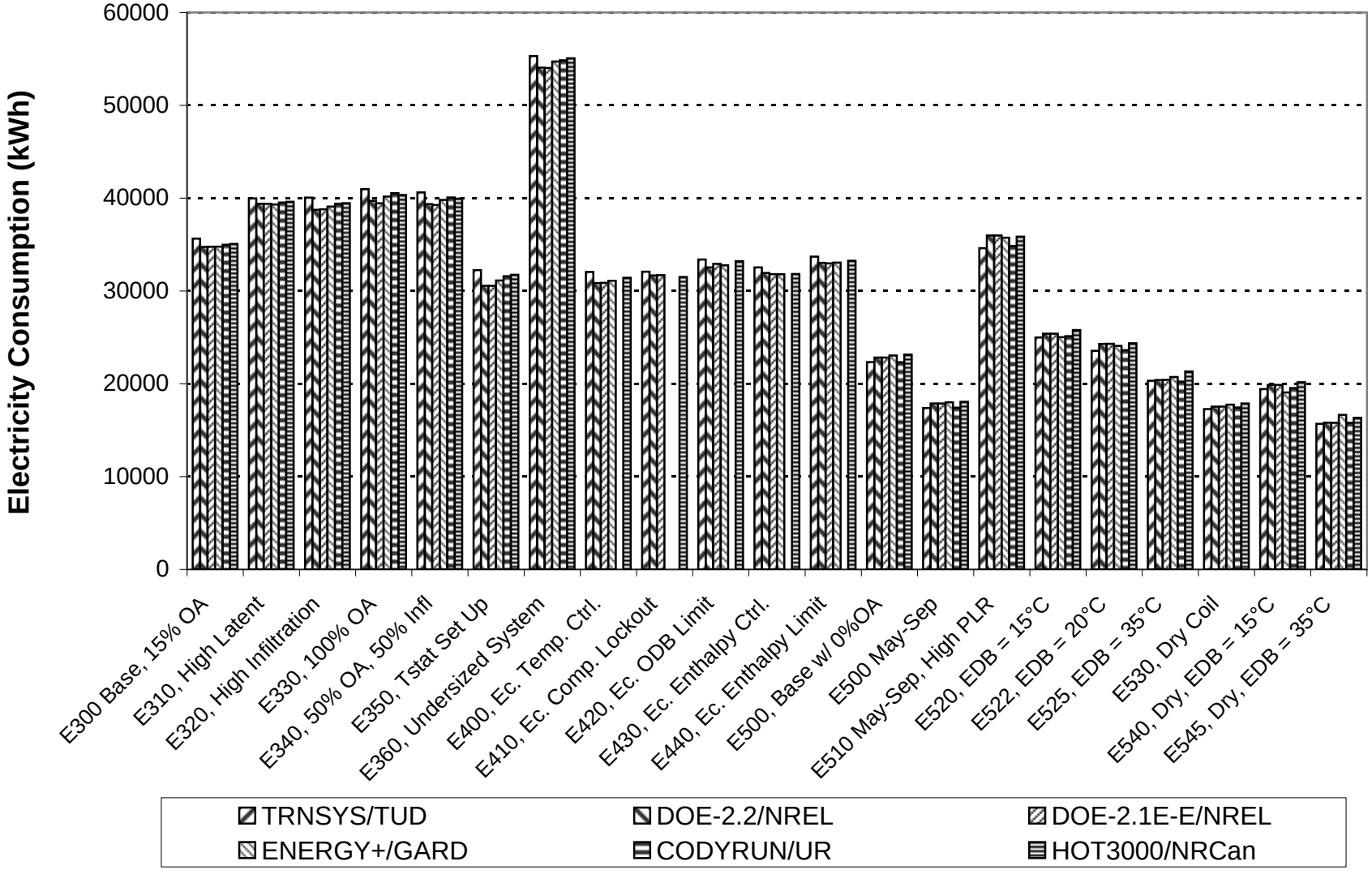
Neymark, J., and R. Judkoff. 2004. *International Energy Agency Building Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 2: Cases E300 – E545*, national Renewable Energy Laboratory, Golden, Colorado, NREL/TP-550-36754, December 2004.

Witte, M. J., Henninger, R.H., Glazer, J., and D. B. Crawley. 2001. "Testing and Validation of a New Building Energy Simulation Program," *Proceedings of Building Simulation 2001*, August 2001, Rio de Janeiro, Brazil, International Building Performance Simulation Association (IBPSA).

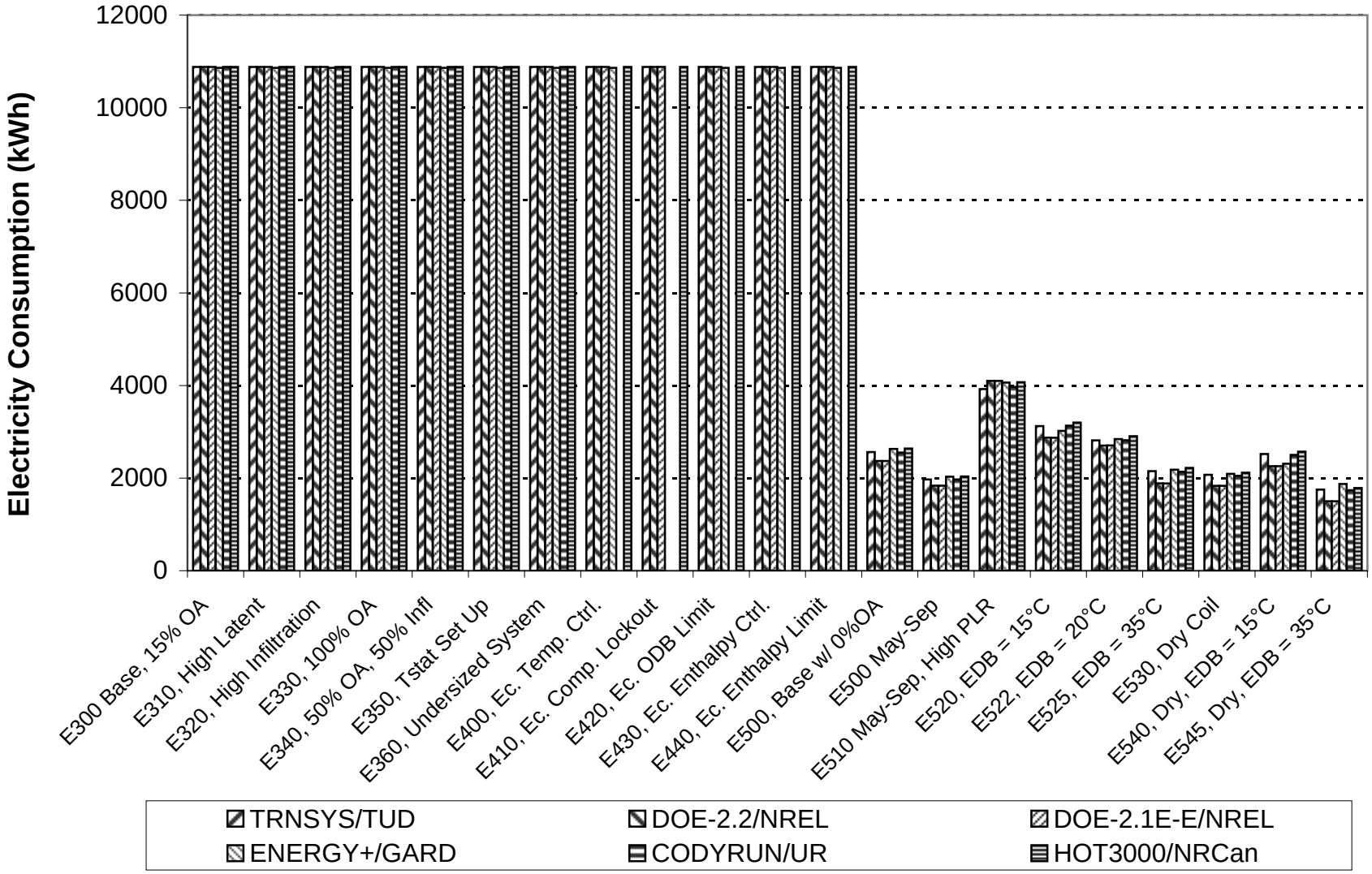
Appendix A

Charts Comparing EnergyPlus 3.0.0.028 Results with Other Whole Building Energy Simulation Programs

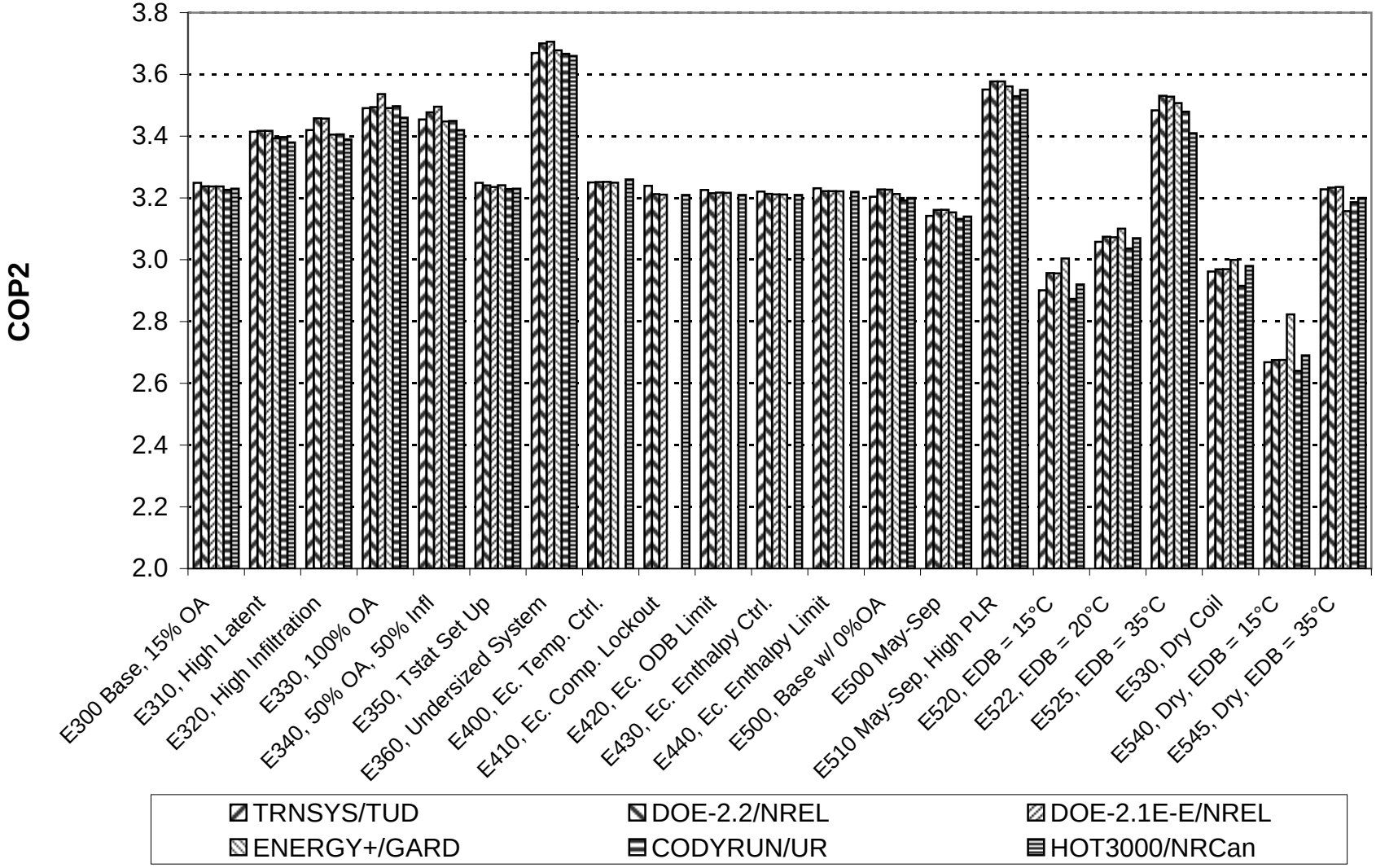
HVAC BESTEST: E300 - E545
Total Electricity Consumption



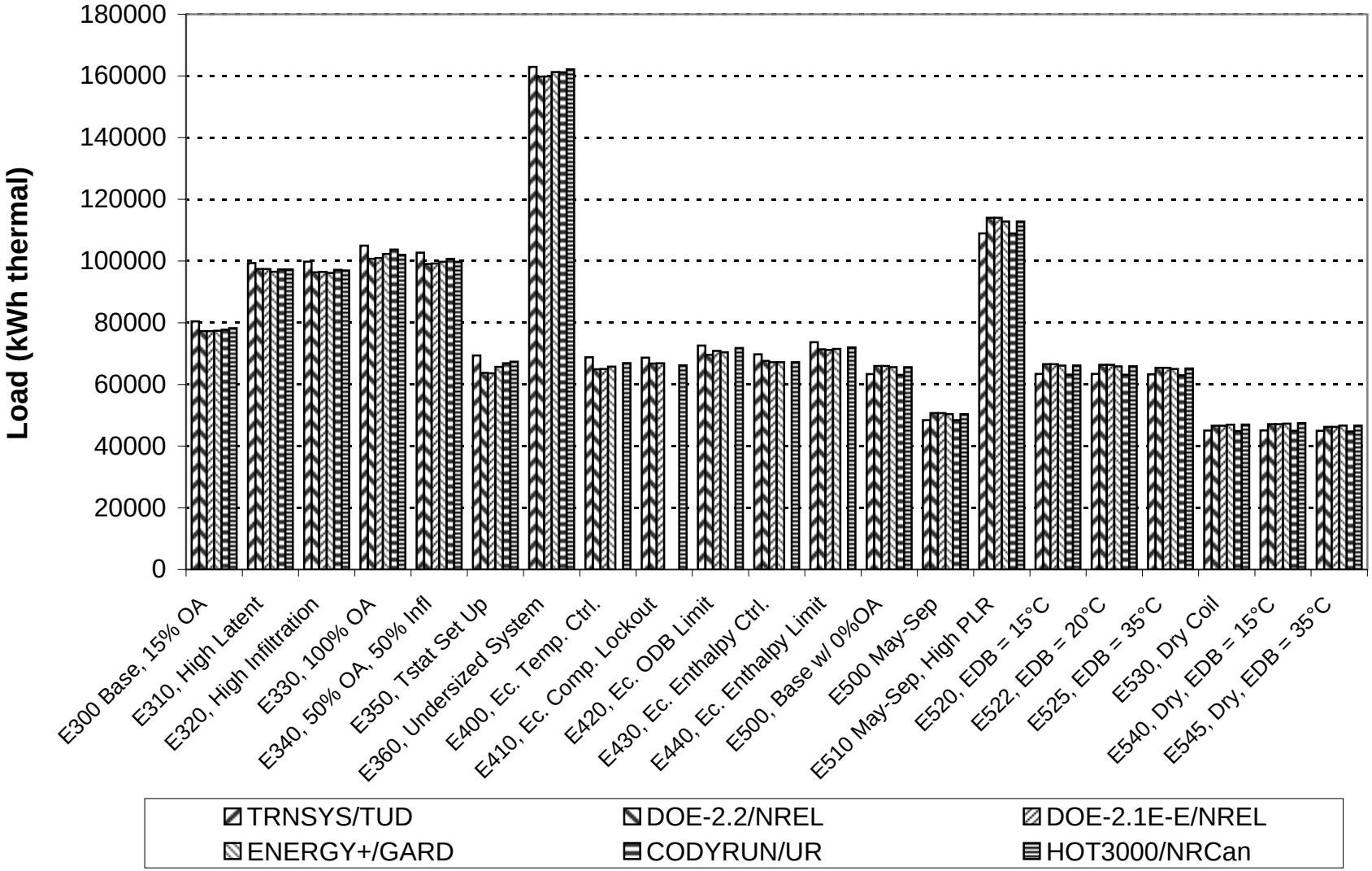
HVAC BESTEST: E300 - E545
Indoor Fan Electricity Consumption



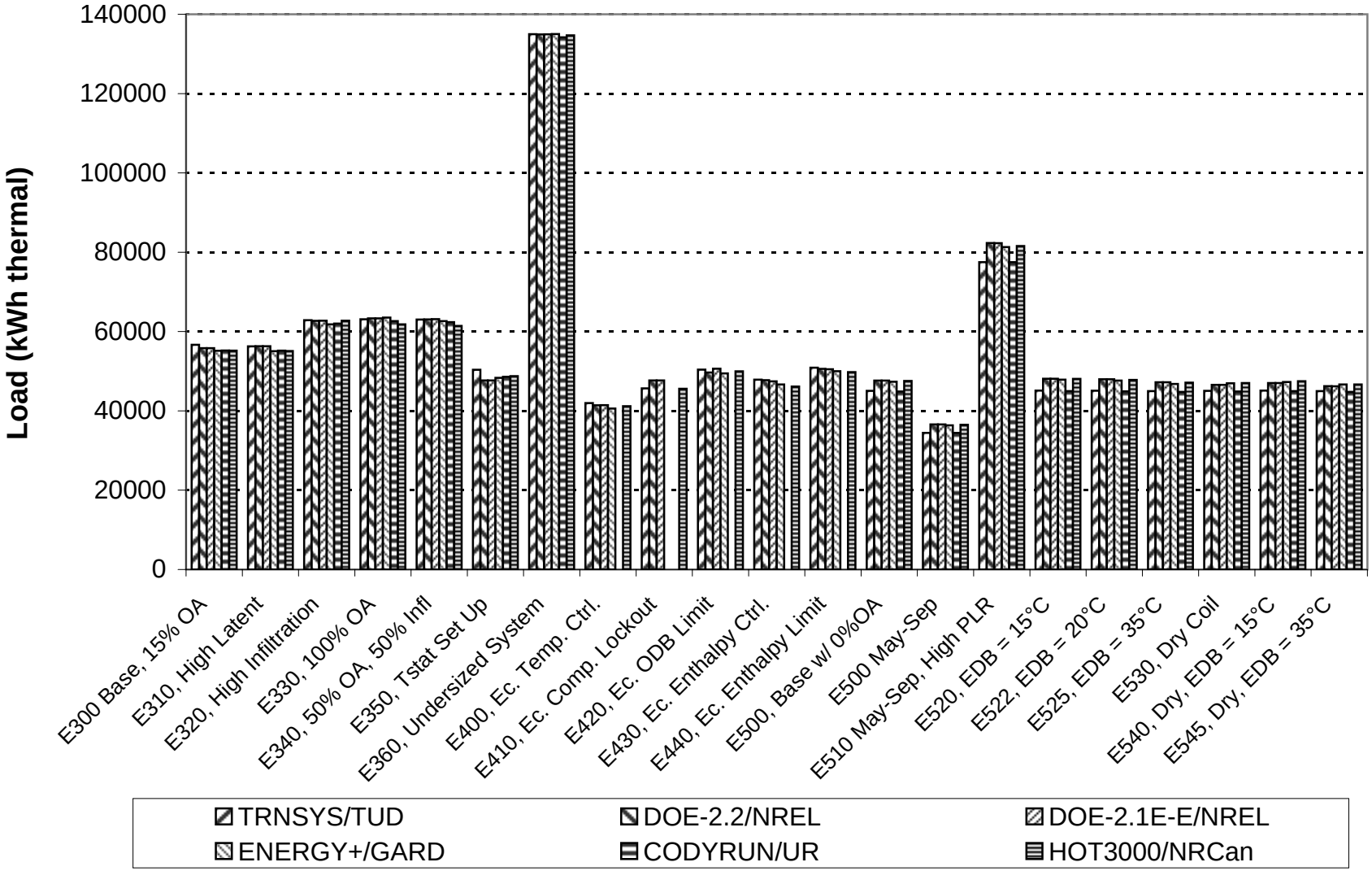
HVAC BESTEST: E300 - E545
COP2



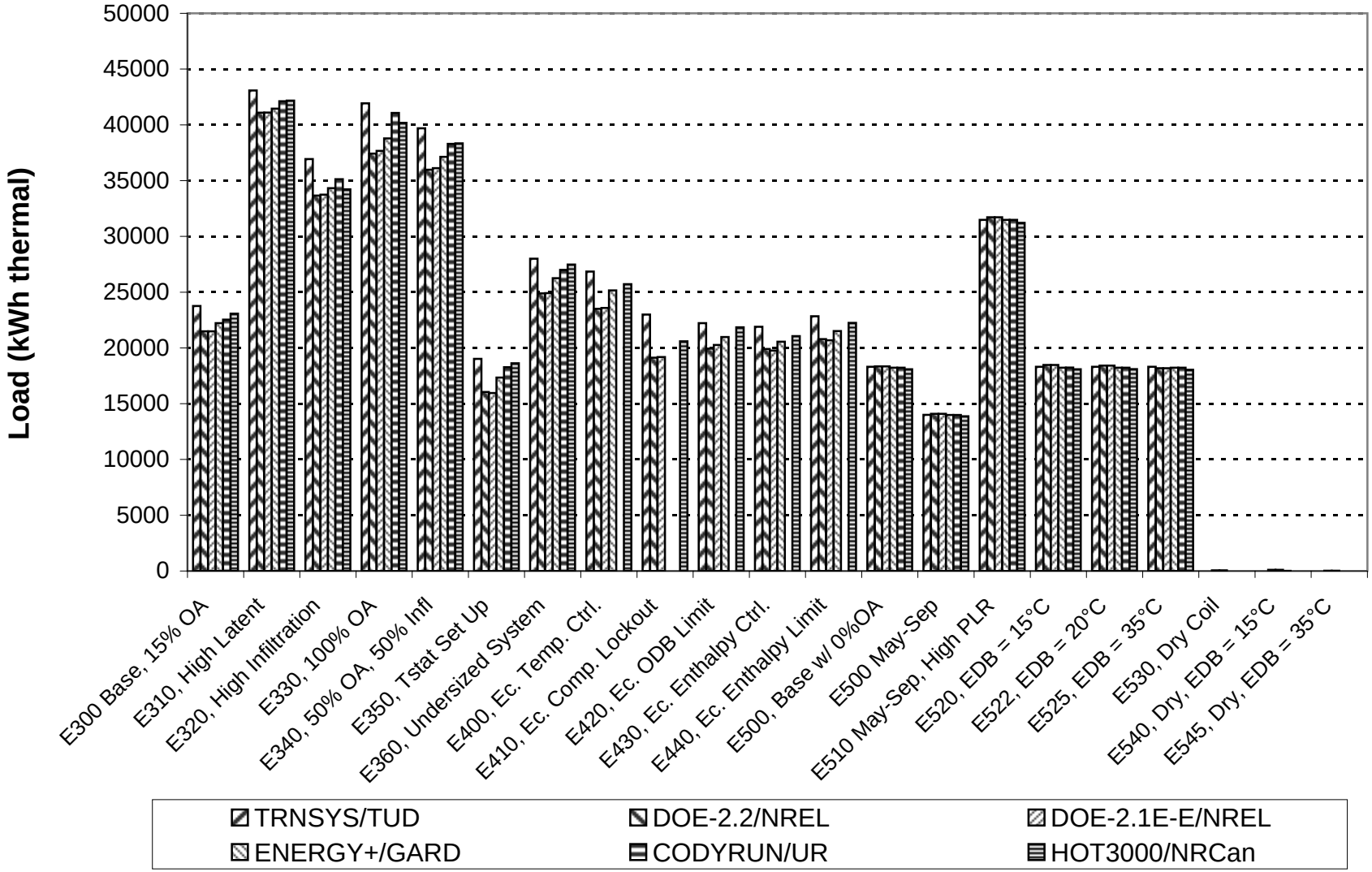
HVAC BESTEST: E300 - E545
Total Coil Load



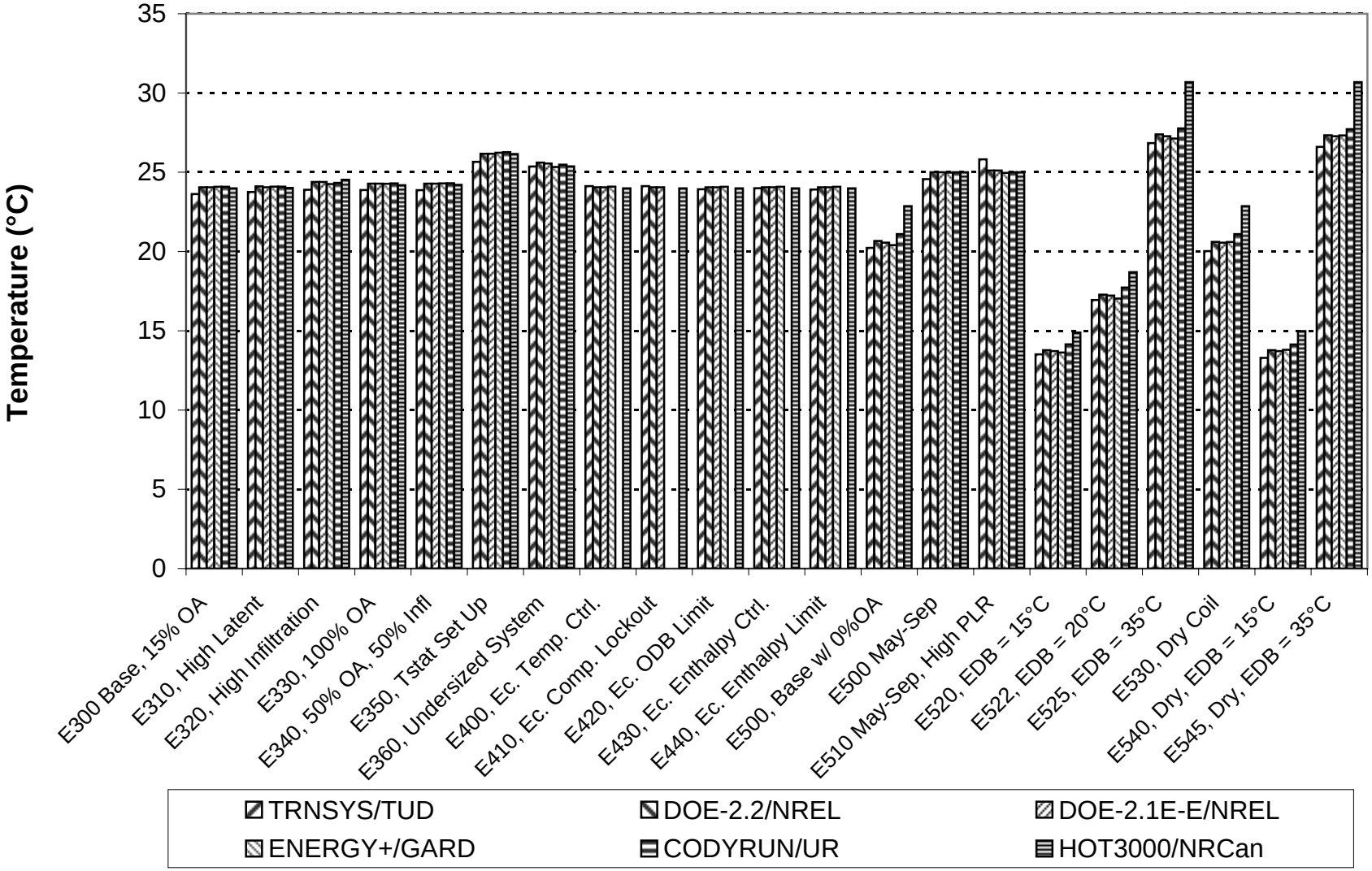
HVAC BESTEST: E300 - E545
Sensible Coil Load



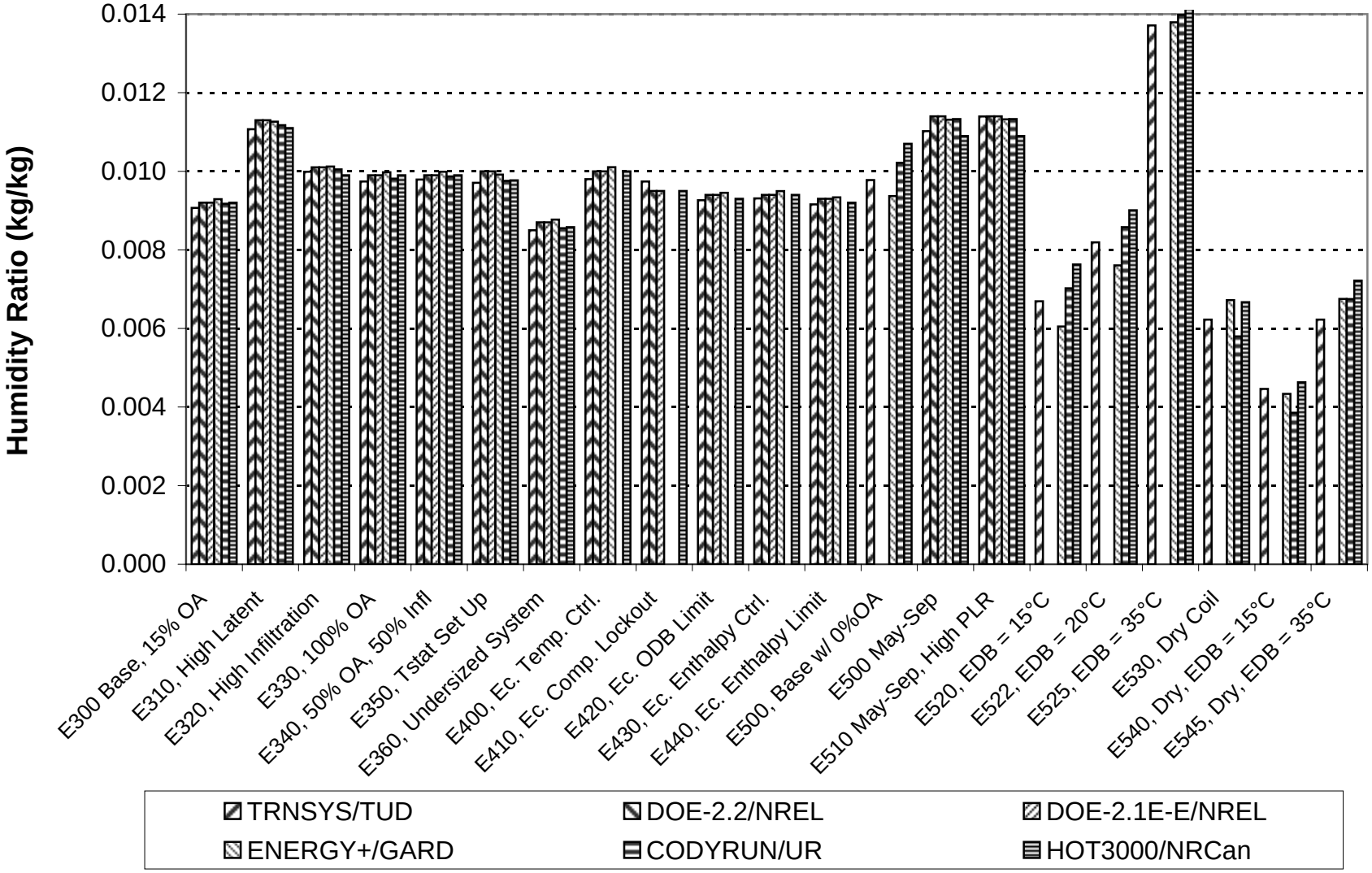
HVAC BESTEST: E300 - E545
Latent Coil Load



HVAC BESTEST: E300 - E545
Indoor Dry-Bulb Temperature



HVAC BESTEST: E300 - E545
Zone Humidity Ratio



Appendix B

EnergyPlus Program Characteristics Summary “Proforma”

Program name (please include version number)

EnergyPlus Version 3.0.0.028

Your name, organisation, and country

Michael J. Witte, GARD Analytics, Inc., United States

Program status

	Public domain
	Commercial:
	Research
x	Other (please specify): *Government-sponsored, end-user license is no charge, other license types have fees associated with them*

Solution method for unitary space cooling equipment

x	Overall Performance Maps
	Individual Component Models
	Constant Performance (no possible variation with entering or ambient conditions)
	Other (please specify)

Interaction between loads and systems calculations

x	Both are calculated during the same timestep
	First, loads are calculated for the entire simulation period, then equipment performance is calculated separately
	Other (please specify)

Time step

	Fixed within code (please specify time step):
x	User-specified (please specify time step): *one hour for envelope*
x	Other (please specify): *program automatically adjusts HVAC time step, <= envelope time step*

Timing convention for meteorological data : sampling interval

	Fixed within code (please specify interval):
x	User-specified: *one hour*

Timing convention for meteorological data : period covered by first record

x	Fixed within code (please specify period or time which meteorological record covers): *0:00 - 1:00*
	User-specified

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
x	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
x	Produces average outputs for each hour (please specify period to which value relates): *user-specified, hourly data is average or sum for previous hour, can specify output at each time step*

Treatment of zone air

x	Single temperature (i.e. good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Zone air initial conditions

x	Same as outside air
	Other (please specify)

Internal gains output characteristics

	Purely convective
	Radiative/Convective split fixed within code
x	Radiative/Convective split specified by user: *100% convective for these tests*
	Detailed modeling of source output

Mechanical systems output characteristics

x	Purely convective
	Radiative/Convective split fixed within code
a	Radiative/Convective split specified by user: *for types of equipment not used in these tests*
	Detailed modeling of source output

Control temperature

x	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control properties

x	Ideal control as specified in the user's manual
	On/Off thermostat control
	On/Off thermostat control with hysteresis
	On/Off thermostat control with minimum equipment on and/or off durations
	Proportional control
	More comprehensive controls (please specify)

Performance Map: characteristics

	Default curves
x	Custom curve fitting
	Detailed mapping not available
	Other (please specify)

Performance Map: independent variables

	Entering Drybulb Temperature: *program calculates adjustments internally*
x	Entering Wetbulb Temperature
x	Outdoor Drybulb Temperature
x	Part Load Ratio
a	Indoor Fan Air Flow Rate: *always=1, because fan always operates at rated conditions*
	Other (please specify)

Performance Map: dependent variables

x	Coefficient of Performance (or other ratio of load to electricity consumption)
x	Total Capacity
	Sensible Capacity: *program calculates internally based on user-specified nominal SHR*
	Bypass Factor: *program calculates internally based on nominal SHR and current conditions*
x	Other (please specify): *indoor fan power (function of PLR)*

Performance Map: available curve fit techniques

x	Linear, f(one independent variable): *flow fraction curves set to constant=1*
x	Quadratic, f(one independent variable) : *PLF-FPLR (cycling loss)*
a	Cubic, f(one independent variable):
a	Bi-Linear, f(two independent variables)
x	Bi-Quadratic, f(two independent variables): *CAP-FT, EIR-FT*
	Other (please specify)

Performance Map: extrapolation limits

x	Limits independent variables: *27.4 <= ODB <=48.1; 13.0 <= EWB <= 23.7, 0.0 <= PLR <= 1.0*
	Limits dependent variables
	No extrapolation limits

	Extrapolation not allowed
	Other (please specify)

Cooling coil and supply air conditions model

	Supply air temperature = apparatus dew point (ADP); supply air humidity ratio = humidity ratio of saturated air at ADP
	Bypass factor model using listed ADP data
x	Bypass factor model with ADP calculated from extending condition line: *nominal BF is calculated from user-specified nominal SHR*
x	Fan heat included
	More comprehensive model (please specify)

Disaggregation of fans' electricity use directly in the simulation and output

x	Indoor fan only
	Outdoor fan only
	Both indoor and outdoor fans disaggregated in the output
	None - disaggregation of fan outputs with separate calculations by the user

Economizer settings available (for E400 series)

a	Temperature *(E400 series not run)*
a	Enthalpy *(E400 series not run)*
a	Compressor Lockout *(E400 series not run)*
	Other (please specify)