FLORIDA SOLAR ENERGY CENTER®

REPORT

ASHRAE Standard 140-2007 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs: Test Results for the DOE-2.1E (v120) incorporated in EnergyGauge Summit 4.0

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Submitted to the:

Florida Building Commission
Building Codes and Standards Office
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Tallahassee, Florida 32399-2100

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ASHRAE Standard 140-2007 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs for the DOE-2.1E (v120) incorporated in EnergyGauge Summit 4.0

SUMMARY

The DOE-2.1E (v120) simulation engine that is incorporated in EnergyGauge Summit 4.0 was tested using the ASHRAE Standard Method of Test for Evaluation of Building Energy Analysis Computer Program (BESTEST), namely the ASHRAE Standard 140-2007. Tests included both the building thermal envelope and fabric load set of tests and the HVAC system component performance suite of tests. Comparative set of results are provided along with this report. The tests were carried out as required by regulations relating to compliance with the COMNET guidelines.

A bulleted list of the submitted material is provided:

- A CD included with this report: The content of the CD is as follows:
  - **File Named "SP140Report.pdf":** is this report
  - **Directory Named "EnergyGaugeSummit":** Contains the install package for EnergyGauge Summit 4.0. Please click the 'Try before you Buy' option after installation.
  - **Directory Named "InputFiles":** Contains all the DOE2.1E input files used for the tests. These are the same files that are contained in the 'C:\Users\CurrentUser\AppData\Local\EnergyGauge\Summit\Sp140Files' subdirectory when installed on a user computer. For this version of EnergyGauge Summit only, please replace all the existing input files after installation in the said sub-directory by the input files from the 'InputFiles' folder sent with this CD.
  - **Directory Named "OutputFiles":** Contains all the DOE2.1E outputs that were obtained by running the input files in the previous directory through EnergyGauge Summit 4.0. These are the same files that are contained in the DOE2.1E\Sp140Files subdirectory of EnergyGauge Summit 4.0 application when installed on a user computer.
  - **Directory Named "WeatherFiles":** Contains all the weather files used for the different SP140 test sets. For this version of EnergyGauge Summit only, please copy all the weather files from this directory and paste them in the '\EnergyGaugeSummit\DOE21E\Weather' subdirectory to replace the existing weather files.
  - **Directory Named "Results":** Contains all the results in spreadsheet form as described in Section 4 of this report. .

- The calculation **algorithms of the DOE-2.1E (v120) simulation engine have not been modified** in any fashion in the process of being incorporated as the simulation engine for EnergyGauge Summit 4.0.

- The DOE-2.1E (v120) simulation engine was compiled into a 'DLL' rather than an 'EXE' for use within all versions of the EnergyGauge Summit software.

- How can one verify that EnergyGauge Summit 4.0 runs exactly those input files included in the **Directory Named "InputFiles",** and produces the output files included in the **Directory Named "OutputFiles"** of the CD? **Answer.** A menu option has been provided in EnergyGauge Summit 4.0 to do just that (See Section 3 of this report).

1. INTRODUCTION AND OVERVIEW

The ASHRAE standard 140 specifies the test procedures for evaluating the technical capabilities and range of applicability of computer programs that calculate thermal performance of buildings and their HVAC systems. The EnergyGauge Summit 4.0 performs annual energy and cost calculations using the DOE-2.1E (v120) simulation engine. As per software verification requirements for COMNET, the software must be tested using the ASHRAE Standard 140 method of test. The DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 complies with requirement stated above (exceptions noted where applicable), and this document further describes the comparative testing carried out as per the ASHRAE Standard 140 and the results thereof.

2. ASHRAE STANDARD 140 TEST SUITE

As stated in the ASHRAE Standard 140 documentation[4], the method of test is provided for analyzing and diagnosing building energy simulation software using software-to-software and software-to-quasi-analytical-solution comparisons. The methodology allows different building energy simulation programs, representing different degrees of modeling complexity, to be tested by comparing the predictions from other building energy programs to the simulation results provided by the program in question, in this case the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0.

The specifications for determining input values, the weather data required and an overview for all the test cases containing information on those building parameters that change from case to case has been provided in the Standard 140 documentation. The cases are grouped as:
(a) Building Thermal Envelope and Fabric Load Base Case
(b) Building Thermal Envelope and Fabric Load Basic Tests
- Low mass
- High mass
- Free float

(c) Building Thermal Envelope and Fabric Load In-Depth Tests
(d) Space-Cooling Equipment Performance Analytical Verification Base Case
(e) Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests
(f) Space-Cooling Equipment Performance Comparative Test Base Case
(g) Space-Cooling Equipment Performance Comparative Tests

(h) Space-Heating Equipment Performance Analytical Verification Base Case
(i) Space-Heating Equipment Performance Analytical Verification Tests
(j) Space-Heating Equipment Performance Comparative Tests

2.1 Building Thermal Envelope and Fabric Load Base Case: The base building plan is a low mass, rectangular single zone with no interior partitions.

2.2 Building Thermal Envelope and Fabric Load Basic Tests: The basic tests analyze the ability of software to model building envelope loads in a low mass configuration with the following variations: window orientation, shading devices, setback thermostat, and night ventilation.

2.2.1 The low mass basic tests (Cases 600 through 650) utilize lightweight walls, floor, and roof.

2.2.2 The high mass basic tests (Cases 900 through 960) utilize masonry walls and concrete slab floor and include an additional configuration with a sunspace.

2.2.3 Free-float basic tests (Cases 600FF, 650FF, 900FF, and 950FF) have no heating or cooling system. They analyze the ability of software to model zone temperature in both low mass and high mass configurations with and without night ventilation.

2.3 Building Thermal Envelope and Fabric Load In-Depth Tests: The in-depth cases are as below

2.3.1 In-depth Cases 195 through 320 analyze the ability of software to model building envelope loads for a non dead-band on/off thermostat control configuration with the following variations among the cases: no windows, opaque windows, exterior infrared emittance, interior infrared emittance, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, window orientation, shading devices, and thermostat set-points. These are a detailed set of tests designed to isolate the effects of specific algorithms. However, some of these cases were incompatible with the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 and are noted in relevant sections of this report.

2.3.2 In-depth Cases 395 through 440, 800, and 810 analyze the ability of software to model building envelope loads in a dead-band thermostat control configuration with the following variations: no windows, opaque windows, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, and thermal mass. This series of in-depth tests is designed to be compatible with more building energy simulation programs.

2.4 Space-Cooling Equipment Performance Analytical Verification Base Case: The configuration of the base-case (Case E100) building is a near adiabatic rectangular single zone with only user-specified internal gains to drive steady-state cooling load. Mechanical equipment specifications represent a simple unitary vapor compression cooling system or, more precisely, a split-system, air-cooled condensing unit with an indoor evaporator coil. Performance of this equipment is typically modeled using manufacturer design data presented in the form of empirically derived performance maps.

2.5 Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests: In these steady-state cases (cases E110 through E200), the following parameters are varied: sensible internal gains, latent internal gains, zone thermostat set-point (entering dry-bulb temperature [EDB]), and ODB. Parametric variations isolate the effects of the parameters singly and in various combinations and isolate the influence of: part-loading of equipment, varying sensible heat ratio, "dry" coil (no latent load) versus "wet" coil (with dehumidification) operation, and operation at typical Air-Conditioning and Refrigeration Institute (ARI) rating conditions. In this way the models are tested in various domains of the performance map.

2.6 Space-Cooling Equipment Performance Comparative Test Base Case: The configuration of this base case (CE300) is a near-adiabatic rectangular single zone with user-specified internal gains and outside air to drive dynamic loads. The cases apply annual hourly data for a hot and humid climate. The mechanical systems in a vapor-compression cooling system and includes an expanded performance data set covering a wide range of operating conditions. Also, an air mixing system is present so that outside-air mixing and economizer control models can be tested.

2.7 Space-Cooling Equipment Performance Comparative Tests: In these cases (case CE310 through CE545) which apply the same weather data as case CE300, the following parameters are varied: sensible internal gains, latent internal gains, infiltration rate, outside air fraction, thermostat set-points, and economizer control settings. Results analysis also isolates the influences of part-loading of equipment, ODB sensitivity, and 'dry' coil (no latent load) versus 'wet' coil (dehumidification) operation

2.8 Space-Heating Equipment Performance Analytical Verification Base Case: The configuration of the base case (HE100) building is a rectangular single zone that is near-adiabatic on five faces with one heat exchange surface (the roof). Mechanical equipment specifications represent a simple unitary fuel-fired furnace with a circulating fan and a draft fan. Performance of this system is typically modeled using manufacturer design data presented in the form of empirically derived performance maps.

2.9 Space-Heating Equipment Performance Analytical Verification Tests: In these cases (HE110 through HE170), the following parameters are varied: efficiency, weather (resulting in different load conditions from full load to part load to no load to time-varying), circulating fan operation, and draft fan operation.

2.10 Space-Heating Equipment Performance Comparative Tests: In these cases (HE210 through HE230), the following parameters are varied: weather, thermostat control strategy, and furnace size.

3. TEST PROCEDURE FOR ENERGYGAUGE SUMMIT 4.0

For running the complete test suite of the ASHRAE Std. 140, a menu item was added to the EnergyGauge Summit 4.0 interface. The screenshots below, Figure 1 and 2, display the menu item location and the form for running either each of the input files individually or a selection of them along with the weather file that should be used for the annual simulations. The form directly picks up the location of DOE-2.1E input files and the ASHRAE standard 140 specific weather files from a default application installation location. Each of the output DOE-2.1E report files are created in the same location as the specified input files.

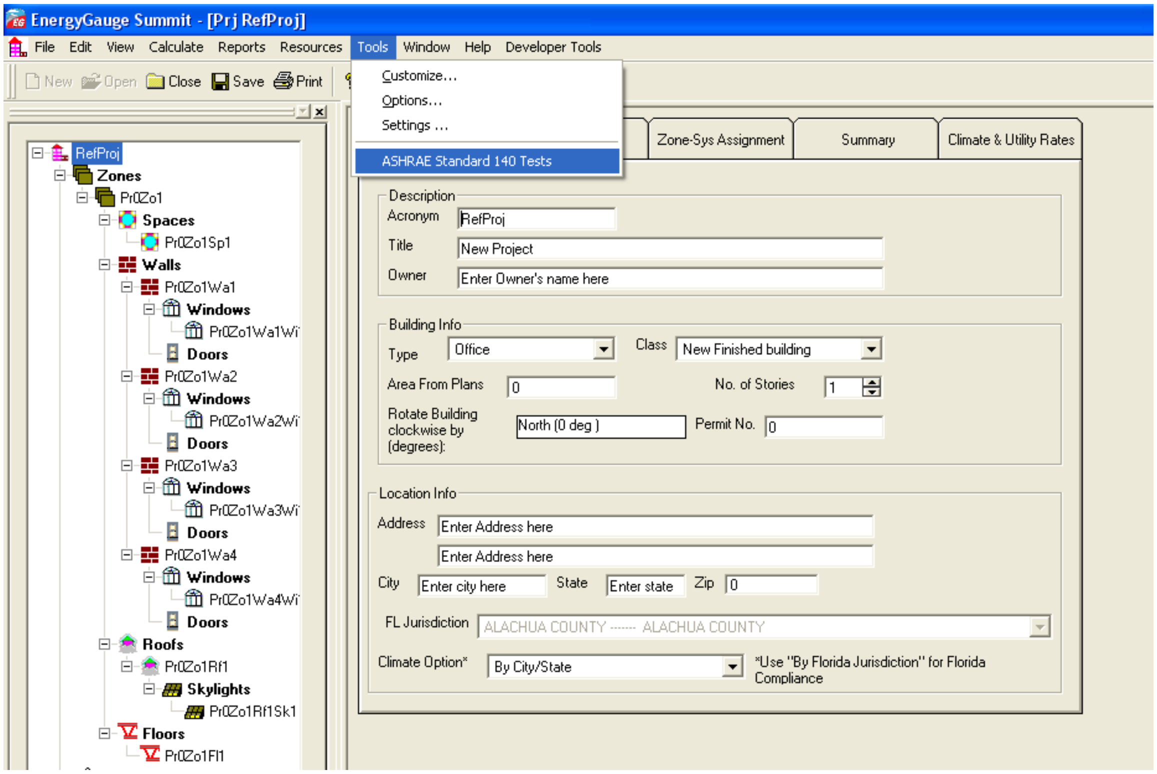

Figure 1: Pull down menu item for running ASHRAE Standard 140 input files in EnergyGauge Summit

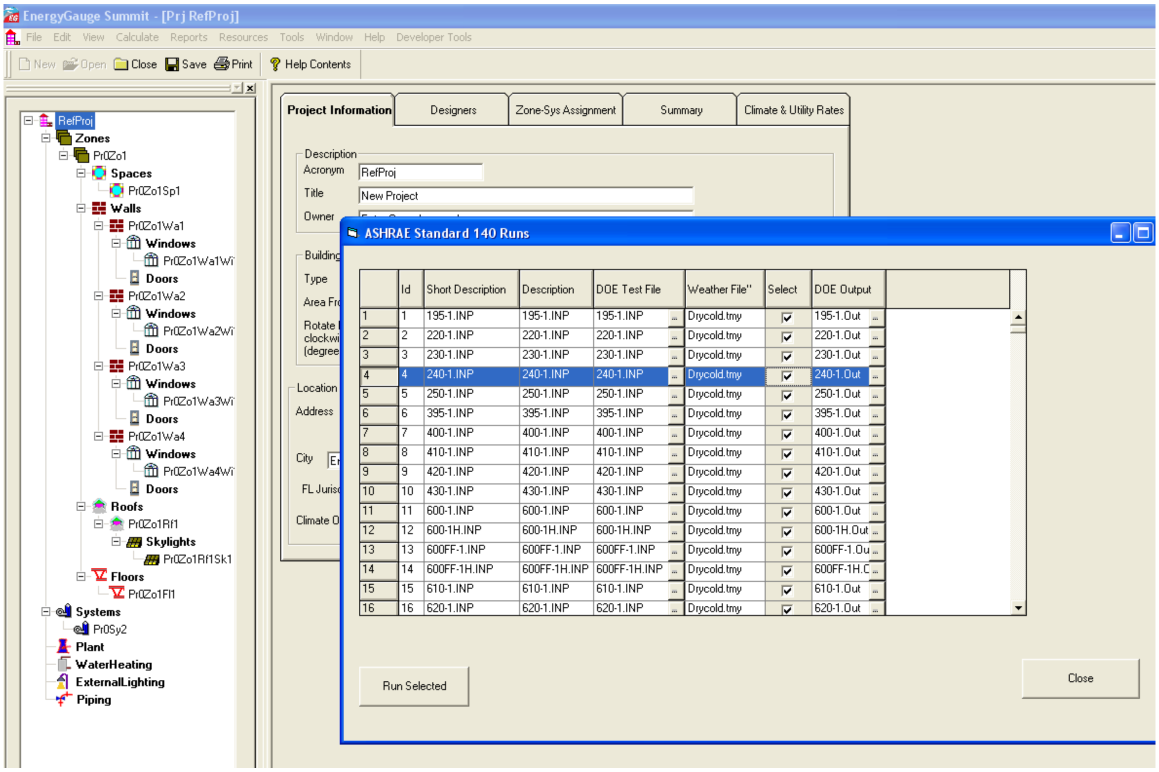

Figure 2: Form for selection and running of ASHRAE Standard 140 input files in EnergyGauge Summit

4. RESULTS AND DISCUSSION

4.1 Building Envelope and Fabric load tests

Annual simulation runs were completed for 27 sets of DOE-2.1E input files for the basic as well as the in depth envelope and fabric tests for the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0. These results were compared to results from reference software' that are provided with the ASHRAE standard 140 test suite. The Standard specifies that the user may choose to compare results output with the example results provided in the documentation or with other results that were generated using this standard method of test (including self-generated quasi-analytical solutions related to the Space Cooling equipment performance tests).

For the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0, results were compared with example results provided in the 'Results5-2.xls' file provided on the accompanying CD with the documentation. The excel spreadsheet has data from the following software:

- ESP-r
- BLAST
- DOE-2.1D
- SRES/SUN
- SERIRES
- S3PAS
- TRNSYS
- TASE

For the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0, input files used were for the cases given below:

- Low Mass Building, Cases 600, 610, 620, 630, 640, 650
- High Mass Building, Cases 900, 910, 920, 930, 940, 950, 960
- Free Float Cases, Cases 600FF, 650FF, 900FF, 950FF
- In-depth Cases – non dead-band control, Cases 220, 230, 240, 250, 395
- In-depth Cases – dead-band control, Cases 400, 410, 420, 430, 800

When compared to the minimum and maximum bounds of the provided results, the annual heating loads and the hourly integrated peak heating loads from the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 are well within bounds (refer Figures 3-6). A few cases for example Cases 200, 210 and 215 have not been run since they model combined convective and radiative surface coefficients which are modeled separately and more accurately in DOE-2.1E. These cases were not run for DOE-2.1E. Section 5.2.3.9.3 requires modeling of cases 270, 280, 290, 300, 310, 320, 440 and 810. These cases were not run because internal solar distribution fractions are already automatically calculated for DOE-2.1E. Note that this follows the same pattern of results not included for DOE-2.1D in the SP140 documentation and results. The closest comparison can be made to results from DOE-2.1D a previous version of the simulation engine used by EnergyGauge Summit 4.0 which usesDOE-2.1E (v120). In terms of the annual cooling loads and in a few low mass building cases, the annual hourly integrated peak cooling loads, are on the higher side for the bounds of minimum and maximum provided in the accompanying Results5-2.xls for other software. This anomaly is explained by official documentation from the Department of Energy (DOE) explaining the differences in the algorithms for modeling and simulation with the DOE-2.1D and DOE-2.1E engines respectively. The document (Appendix A) states that there will be significant difference in loads calculated by the two engines. The changes in loads are said to be due to the following improvements:

- A new correlation between outside air film conductance and wind speed gives air film conductances that are two to three times lower in versions previous to DOE-2.1E. This increases inward-flowing fraction of solar radiation absorbed by walls, roofs and windows and reduces conduction through windows.
- A revision to the calculation of exterior infrared radiation loss to the sky decreases heat loss through the windows and walls compared to 2.1D values.
- The wind speed used to calculate outside air film conductance and wind speed dependant infiltration is now the weather file wind speed with corrections for terrain effects, weather station height above ground and space height above ground level. The correction is generally believed to give wind speeds that are lower than those at weather stations. This results in lower outside air film conductance and lower infiltration rates both of which tend to decrease heating loads and increase cooling loads.

Another significant outcome of a reduced outside air film conductance value is that the DOE-2.1E temperatures are on an average 2° C higher than corresponding values from DOE-2.1D. This is also reflected in the results obtained from the free float cases and the temperature bin for the 8760 hours for the annual hour zone temperature bin data for the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 as compared to other software and especially results obtained from DOE-2.1D. The comparative annual heating and cooling loads as well as the comparative annual hourly integrated peak heating and cooling loads are shown in the figures below.

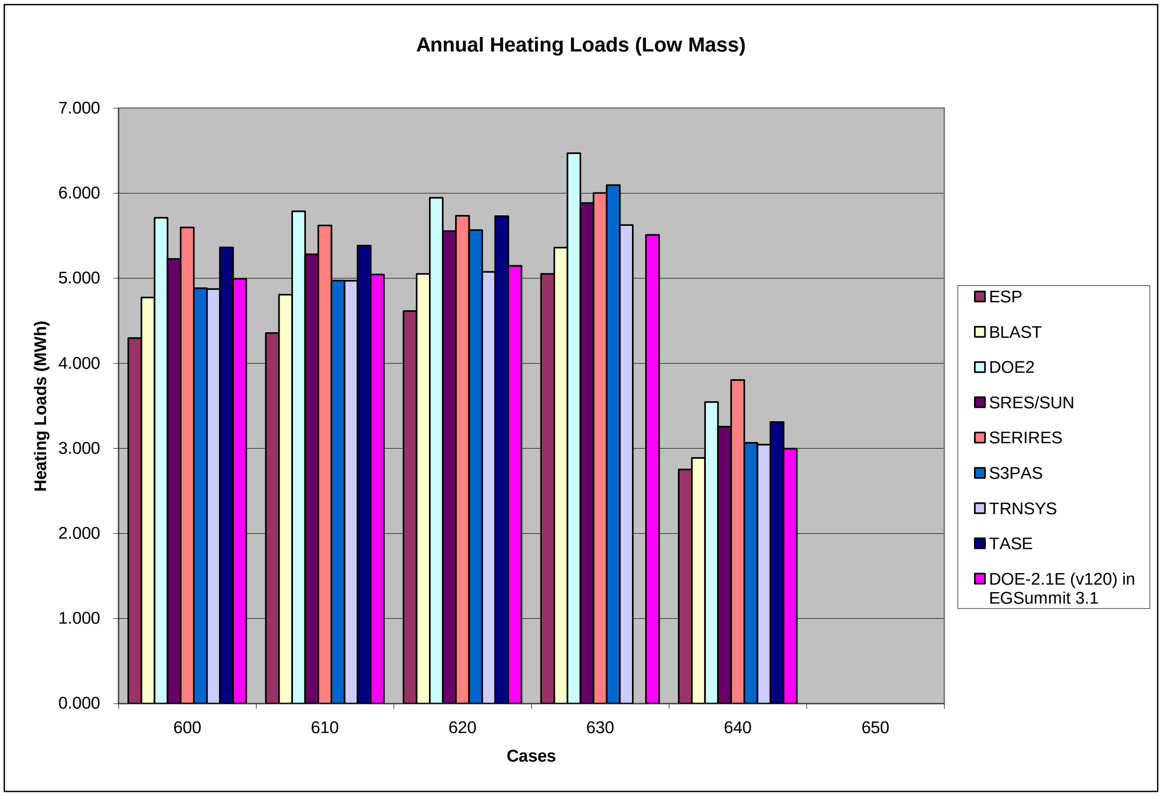

Figure 3: Low Mass Annual Heating Loads result comparison

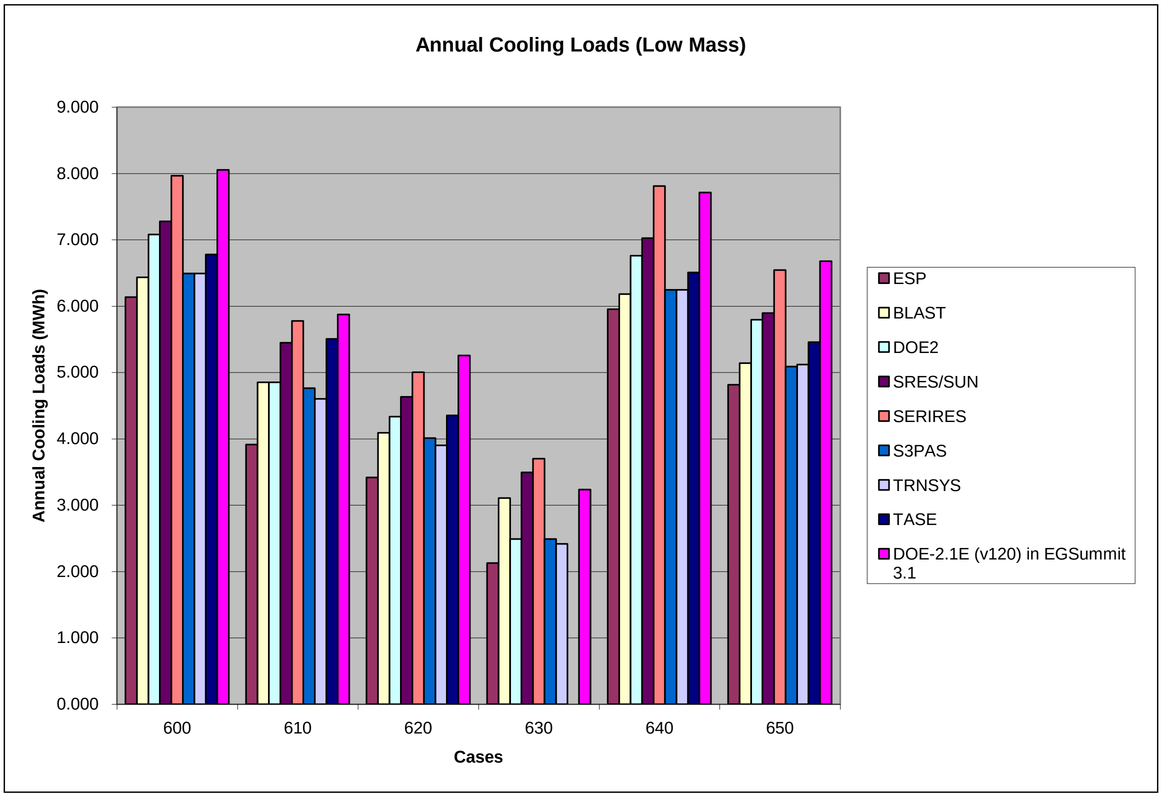

Figure 4: Low Mass Annual Cooling Loads result comparison

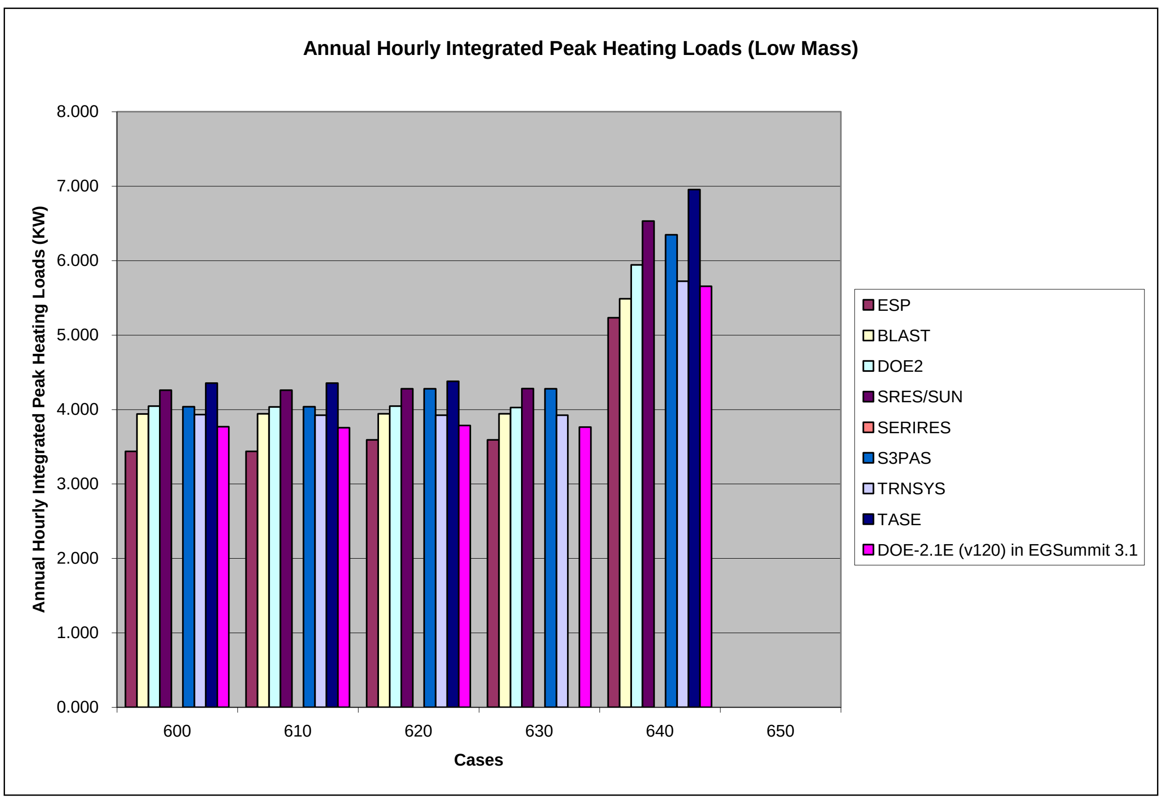

Figure 5: Low Mass Annual Integrated Peak Heating Loads result comparison

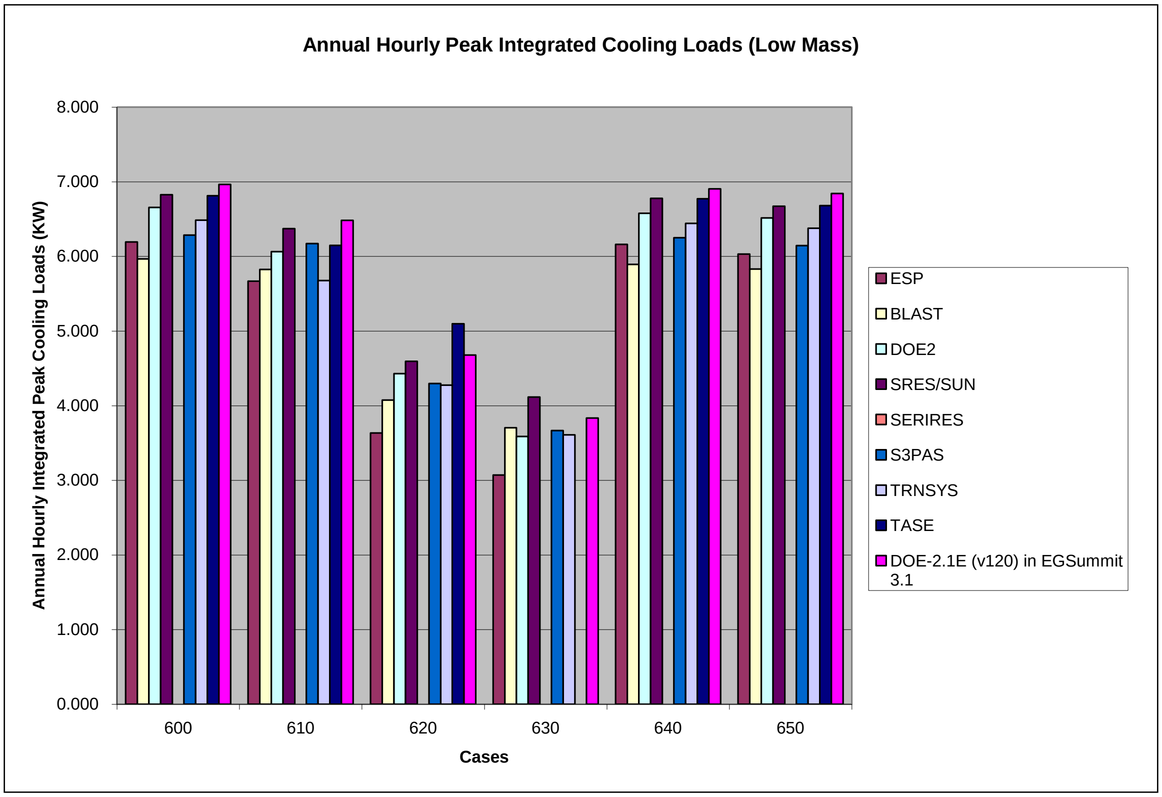

Figure 6: Low Mass Annual Integrated Peak Cooling Loads result comparison

The sensitivity tests (for example, Case 610- Case 600) fall well within the minimum and maximum ranges from the other software results as well as showing consistency in the direction of change. Only the first few cases testing the low mass building sensitivity for annual cooling loads show a slightly higher value as compared to others and this anomaly is also explained by the lowered outside film conductance value.

The Results5-2.xls and well as the Sec5-2out.xls files have been provided with this report. A few comparative results from the high mass building input files are provided in Appendix A.

4.2 Space Cooling and Heating Equipment performance tests

Annual simulation runs were completed for all sets of input files for the space heating and cooling equipment performance and analytical verification test suite. The results were compared with the example results spreadsheet 'Results5-3A.xls', 'Results5-3B.xls' and 'Results5-4.xls' accompanying the documentation. The results spreadsheets have some of the following software listed for comparison:

- DOE-2.1E/NREL
- DOE-2.1E/CIEM
- C2000/EDF
- TRNSYS
- TUD
- HTAL1 & 2
- ESP-r/HOT3000
- CODYRUN

For the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0, the following input files were run:

- Analytical Verification Base Case 100
- Analytical Verification in depth cases 110, 120, 130, 140, 150, 160, 165, 170, 180, 185, 190, 195, 200
- Space Cooling Equipment Performance Base Case 300
- Space Cooling Equipment Performance in depth cases 310, 320, 330, 340, 350, 360, 400, 410, 420, 430, 440, 500, 510, 520, 522, 525, 530, 540, 545
- Space Heating Base Case 100
- Space Heating in depth cases 110, 120, 130, 140, 150, 160, 170, 210, 220, 230

Output data comprising of Cooling Energy Consumption, Evaporator Coil Load, Zone Load and COP, indoor dry bulb temperatures, humidity ratios and other required parameters were compared across software' with results from EnergyGauge Summit 4.0.

In case of the Space Cooling performance test, there were already two sets of example results from software having DOE-2.1E (v120) as their simulation engine. This made the comparison straightforward and the results obtained from the DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 were very close to and in a number of instances exactly as obtained for the other software'. Figure 7, shown below, is a plot for the total cooling electricity consumption for the annual simulation and Figure 8 is a plot showing the total zone loads. These plots reflect the parity in the results.

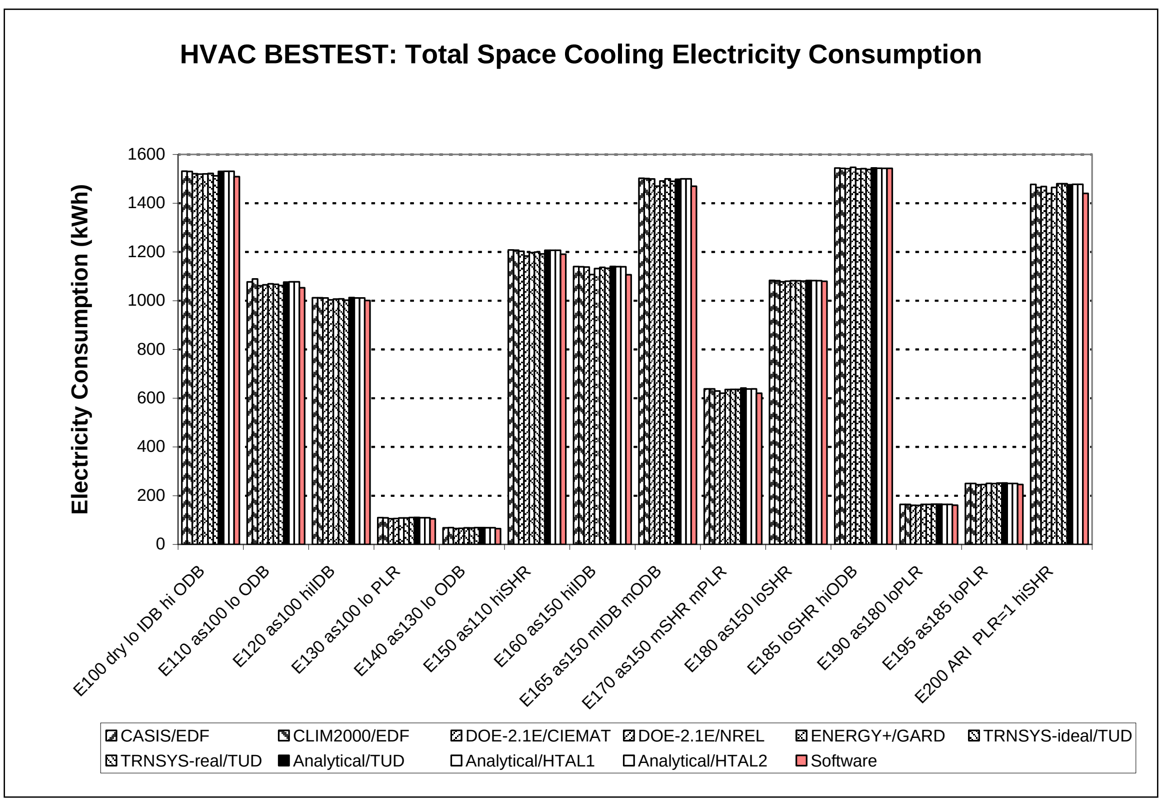

Figure 7: Total Cooling Electricity Consumption comparison results for the HVAC component performance tests

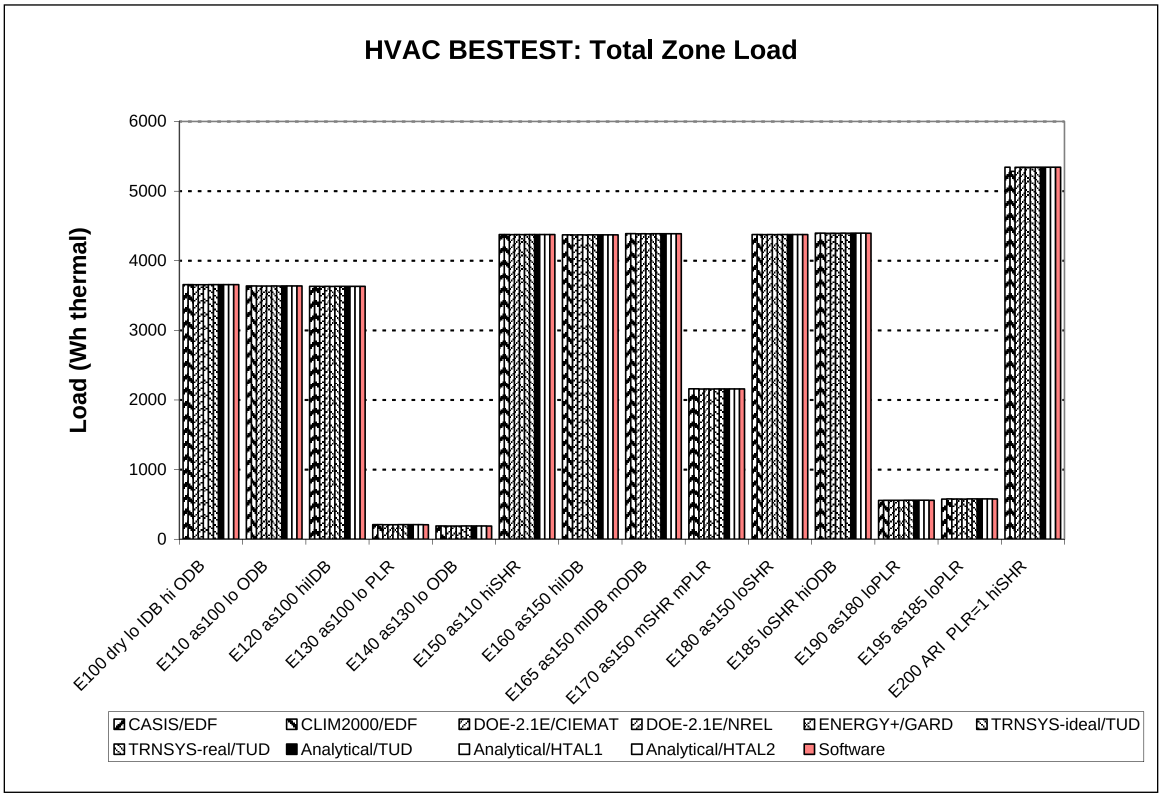

Figure 8: Total zone loads comparison results for the HVAC component performance tests

The Results5-3A.xls, Results5-3B.xls, Results5-4.xls as well as the Sec5-3Aout.xls, Sec5-3Bout.xls, Sec5-4out.xls files have been provided with this report. A few other key comparative results are provided in Appendix A.

5. CONCLUSION

The DOE-2.1E (v120) simulation engine incorporated in EnergyGauge Summit 4.0 was tested using a range of specifications for both envelope and fabric load and HVAC performance as specified in the ASHRAE Standard 140 test suite. The annual heating loads matched up well with the relevant software results provided in the documentation accompanying the Standard 140 whereas the cooling loads were found to be on the higher side especially for low mass buildings for the envelope and fabric load tests. This anomaly was explained by the difference in the outside air film conductance for the simulation engine DOE-2.1E (v120) used by EnergyGauge Summit 4.0. The results for the Space Cooling analytical verification and equipment performance and Space Heating equipment performance tests were found to be comparable to those presented as the reference results obtained from other software using the same standard and specifications for simulation.

As stated earlier, no changes were made to the DOE-2.1E (v120) simulation engine for the purpose of this test or for its incorporation within the EnergyGauge software.

APPENDIX A

HEATING AND COOLING LOAD DIFFERENCES BETWEEN DOE-2.1D AND DOE-2.1E

You will notice a significant difference in loads calculated by 2.1E vs. 2.1D. The heating loads will be 10%-20% lower (depending on building type and climate) and the cooling loads will be 10%-20% higher. The change in loads is due to the following improvements:

a. A new correlation between outside air film conductance and wind speed gives air film conductances that are two to three times lower than in previous versions of DOE-2. This increases the inward-flowing fraction of solar radiation absorbed by walls, roofs and windows and reduces conduction through windows. See "Improved Outside Air Film Conductance Calculations", p.2.98.

b. A revision to the calculation of exterior infrared radiation loss to the sky decreases heat loss from windows and walls relative to 2.1D values. See "Improved Exterior Infrared Radiation Loss Calculation", p.2.97.

c. The wind speed used to calculate outside air film conductance and wind-speed-dependent infiltration is now the weather file wind speed *with corrections for terrain effects, weather station height above ground level, and SPACE height above ground level.* This correction generally gives wind speeds at the building site that are lower than those at the weather station. This results in lower outside air film conductance and lower infiltration rates, both of which tend to decrease heating loads and increase cooling loads. In earlier versions this wind speed correction was applied only to the Sherman-Grimsrud infiltration method. For more details, see "Terrain and Height Modification to Wind Speed", p.2.88.

As evidence that the above improvements are giving accurate loads calculations, Figure A shows that DOE-2.1E predictions are in excellent agreement with measurements of inside air temperature and insolation for three unconditioned test cells. These results are from a recent International Energy Agency study in which the predictions of 25 simulation programs, including DOE-2, were compared with hourly measurements.* The DOE-2.1E temperatures in Figure A are up to 2°C higher than the corresponding DOE-2.1D values (not shown). This is due primarily to the reduced outside air film conductance in 2.1E.

* "Empirical Validation in International Energy Agency Annex 21/Task 12: Final Report", IEA Report No. IEA21RN372/93, U.K. Building Research Establishment and DeMontfort University (Leicester), August 1993. This was a "blind" validation, i.e., the participants did not know what the measured results were when the simulations were done, so it was impossible to adjust a program's input to match the measurements. The DOE-2 numbers in Figure A are from the public release version of DOE-2.1E (Version 001). This validation study also considered comparisons with measurements on *heated* test cells. DOE-2.1E underpredicted the heating energy for these cells because DOE-2 does not accurately model the electric radiators that were used (the radiators, which are 60% radiative and 40% convective, were modeled as baseboards, which are 100% convective in DOE-2).

- 14 - Heating/Cooling Load Differences

Figure 9: Modeling and result differences between DOE-2.1D and DOE-2.1E

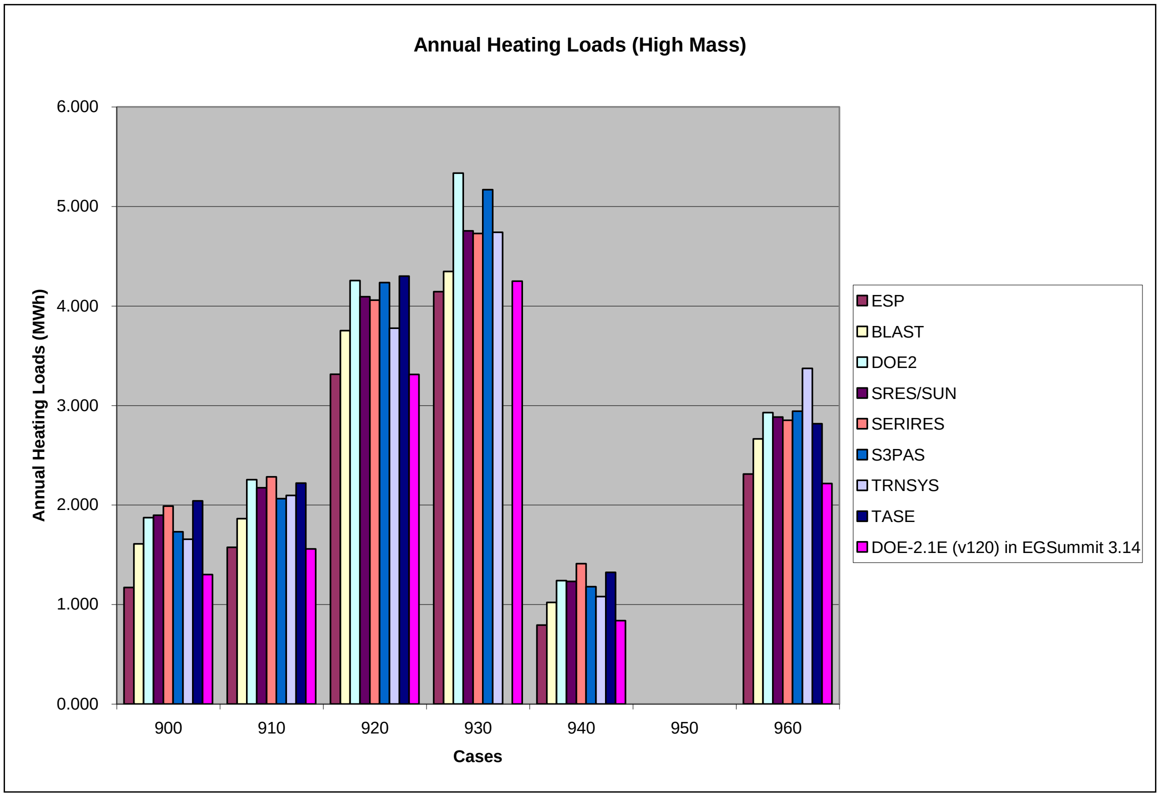

Figure 10: High Mass Annual Heating Loads result comparison

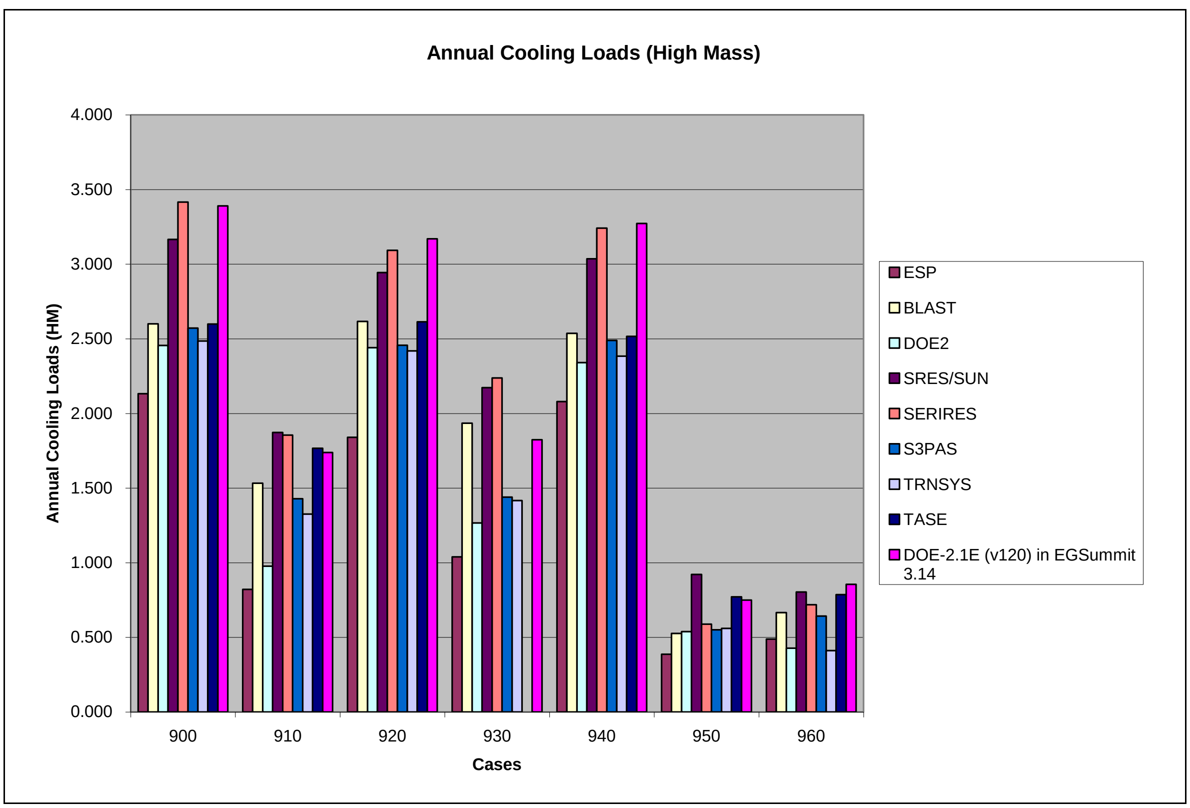

Figure 11: High Mass Annual Cooling Loads result comparison

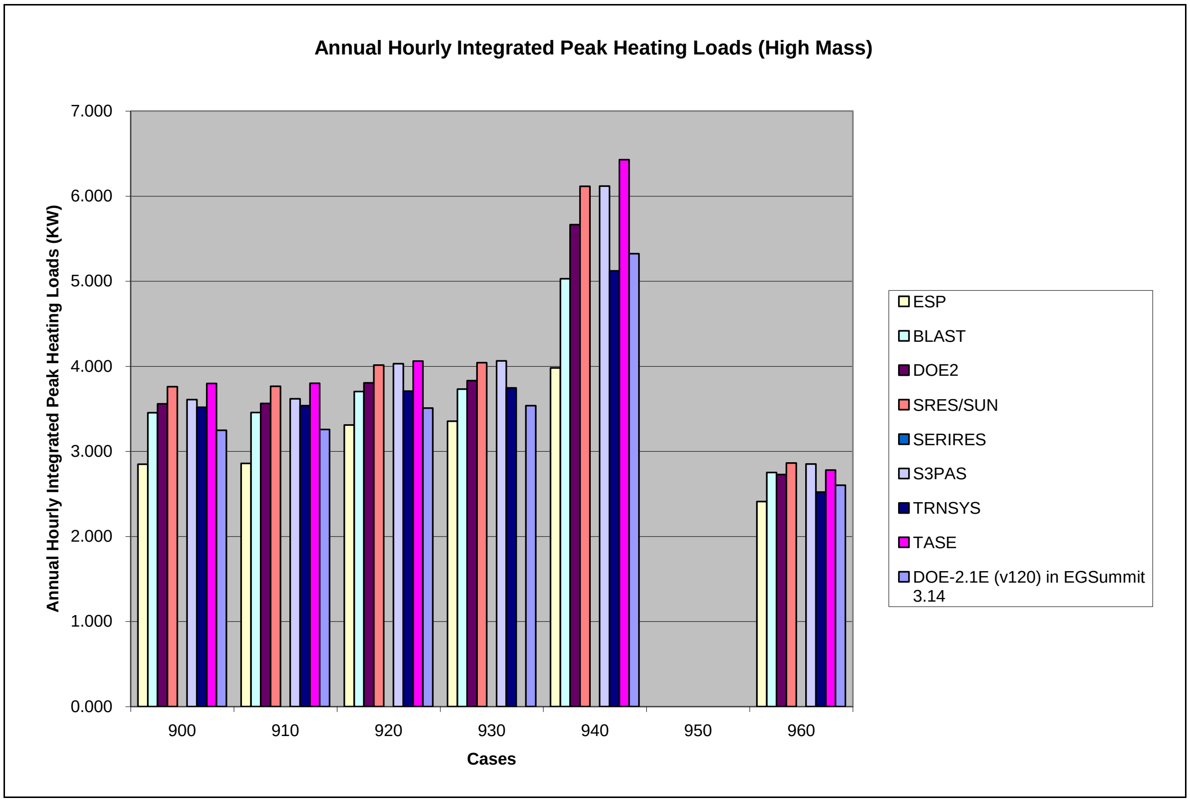

Figure 12: High Mass Annual Integrated Peak Heating Loads result comparison

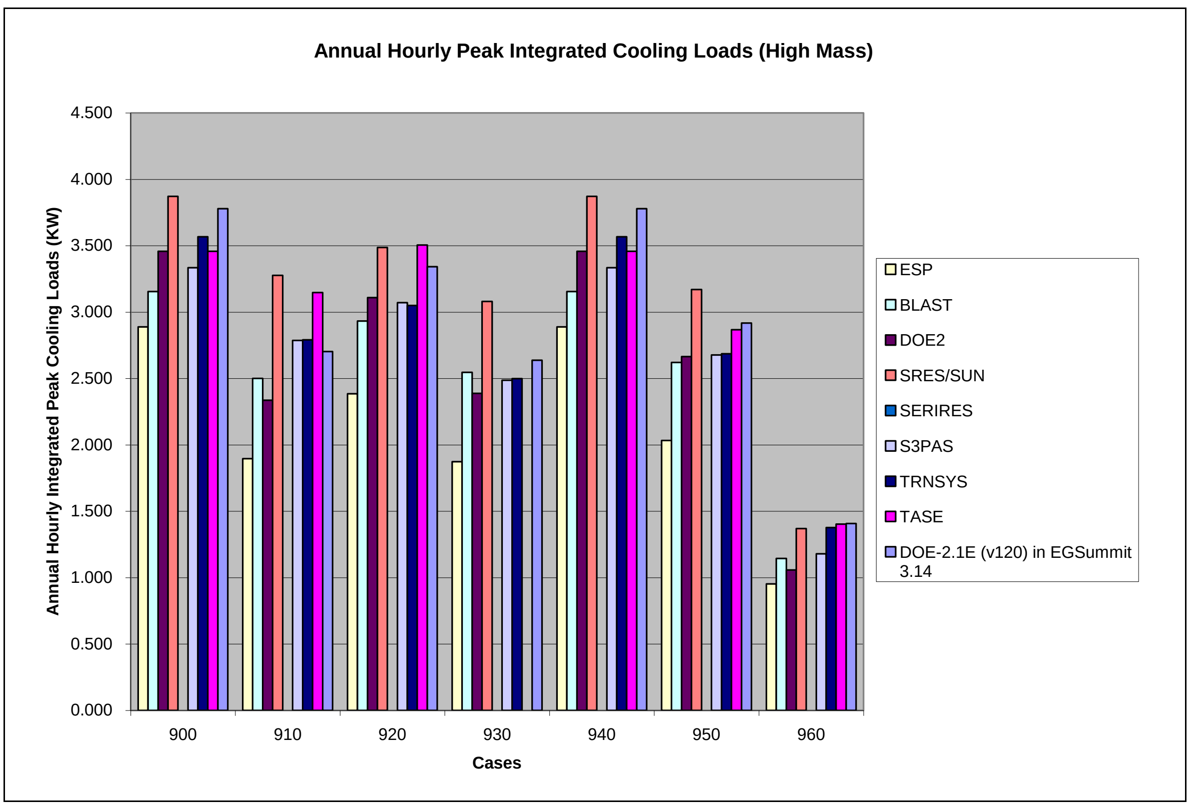

Figure 13: High Mass Annual Integrated Peak Cooling Loads result comparison

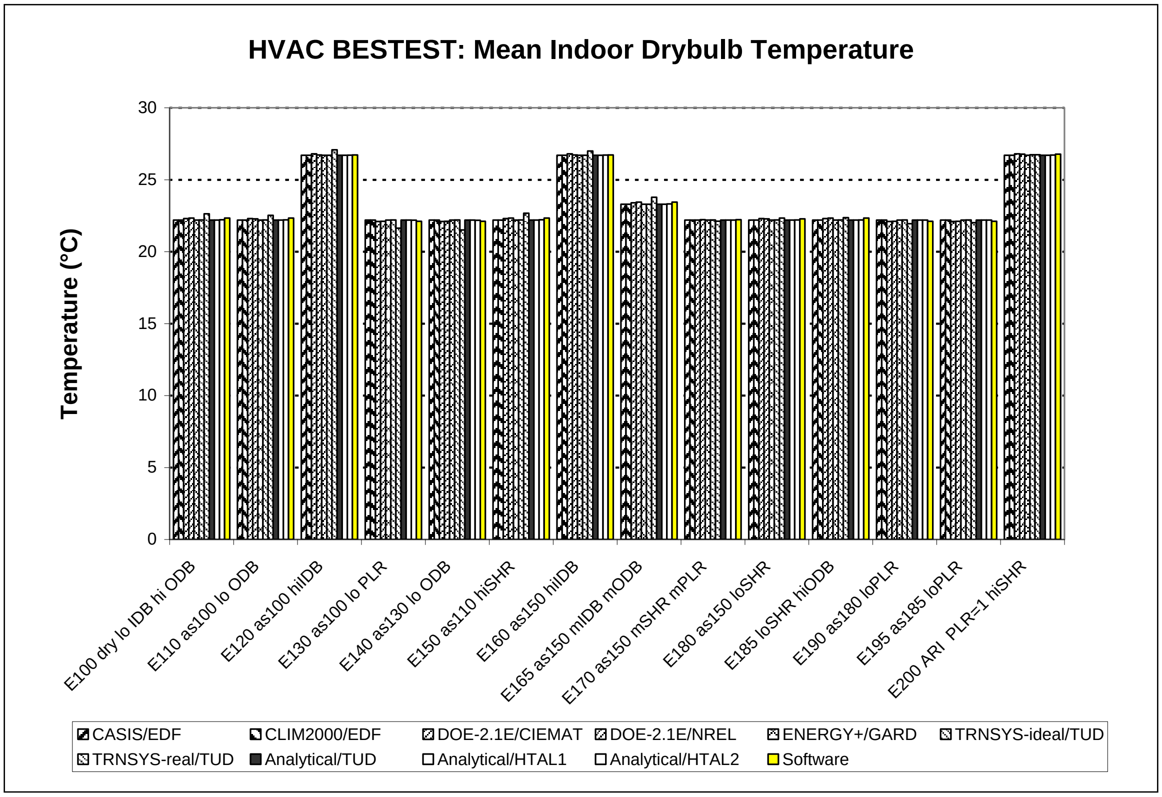

Figure 14: Mean Indoor Dry Bulb result comparison for Space Cooling Analytical Verification

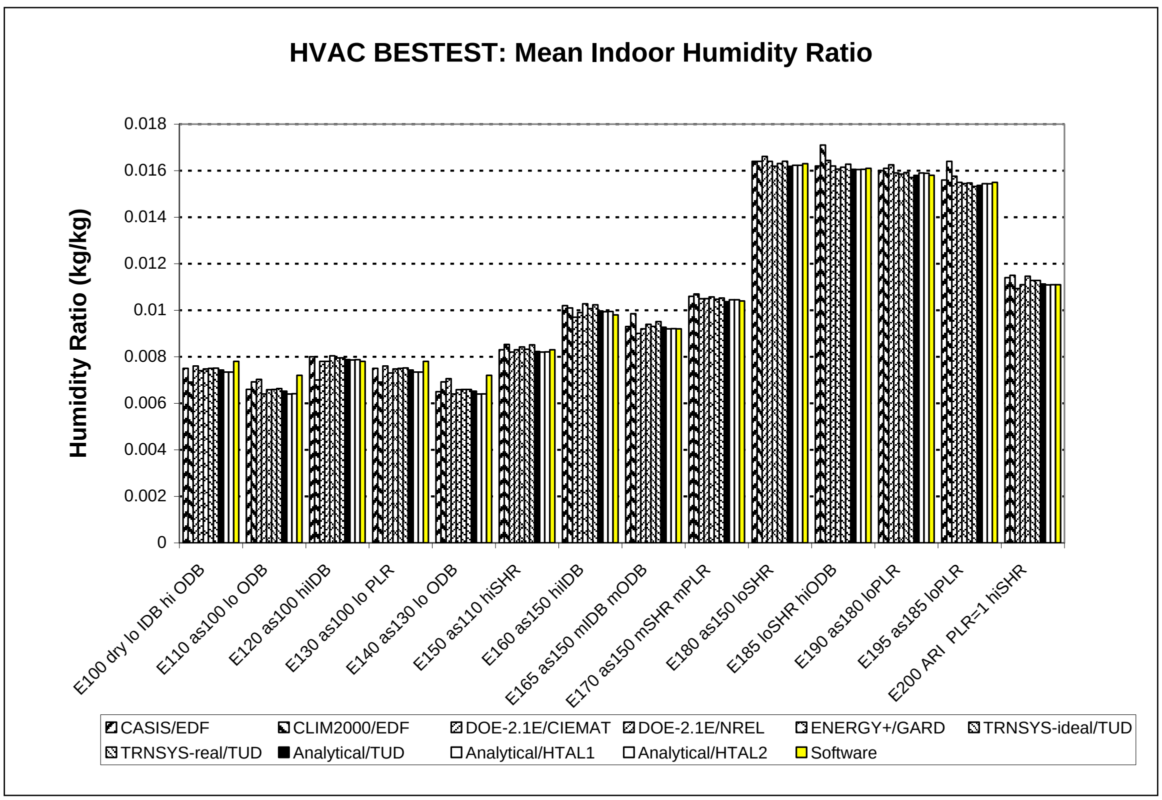

Figure 15: Mean Indoor Humidity Ratio result comparison for Space Cooling Analytical Verification

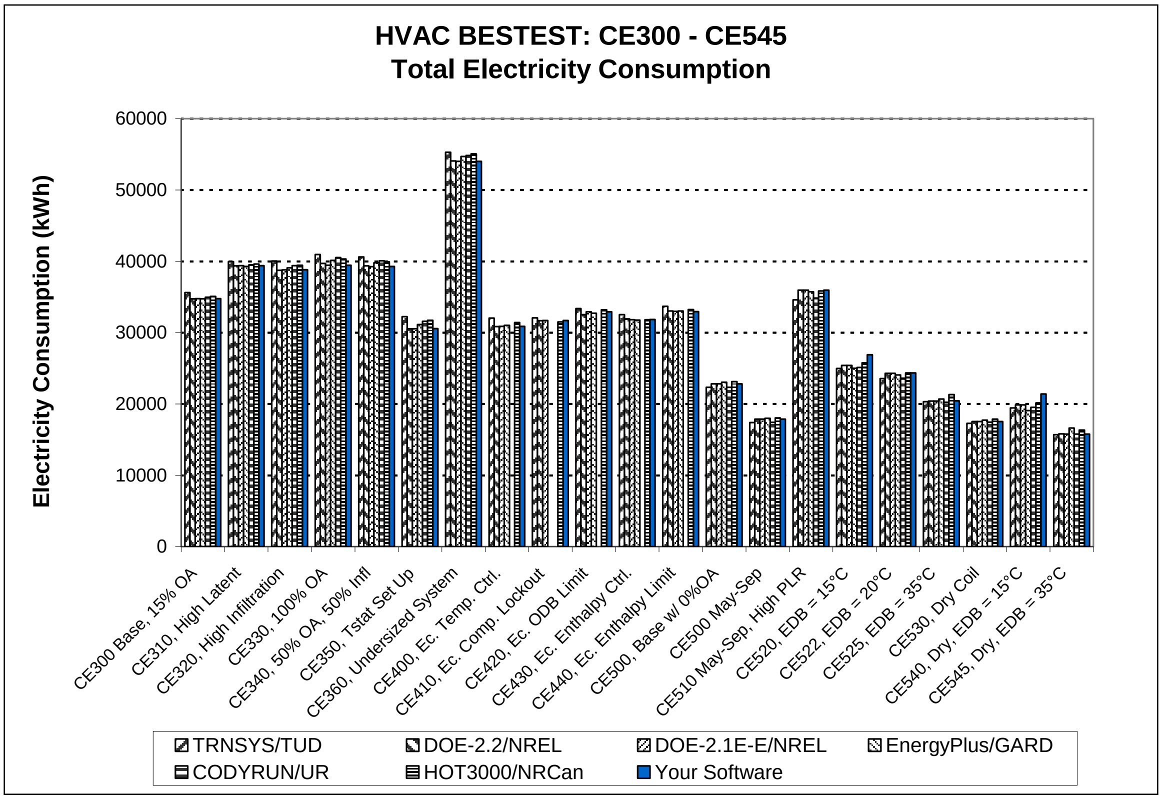

Figure 16: Total Electricity Consumption for Space Cooling Equipment Comparative Tests

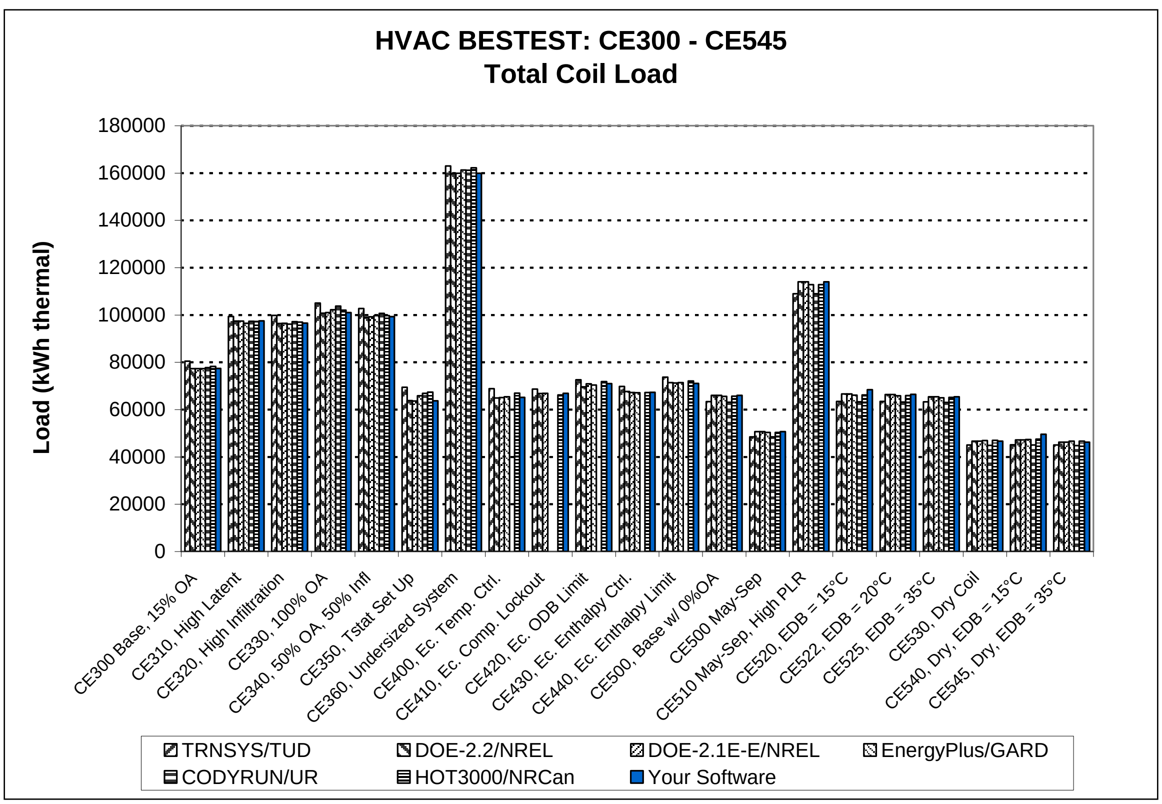

Figure 16: Total Coil Load for Space Cooling Equipment Comparative Tests

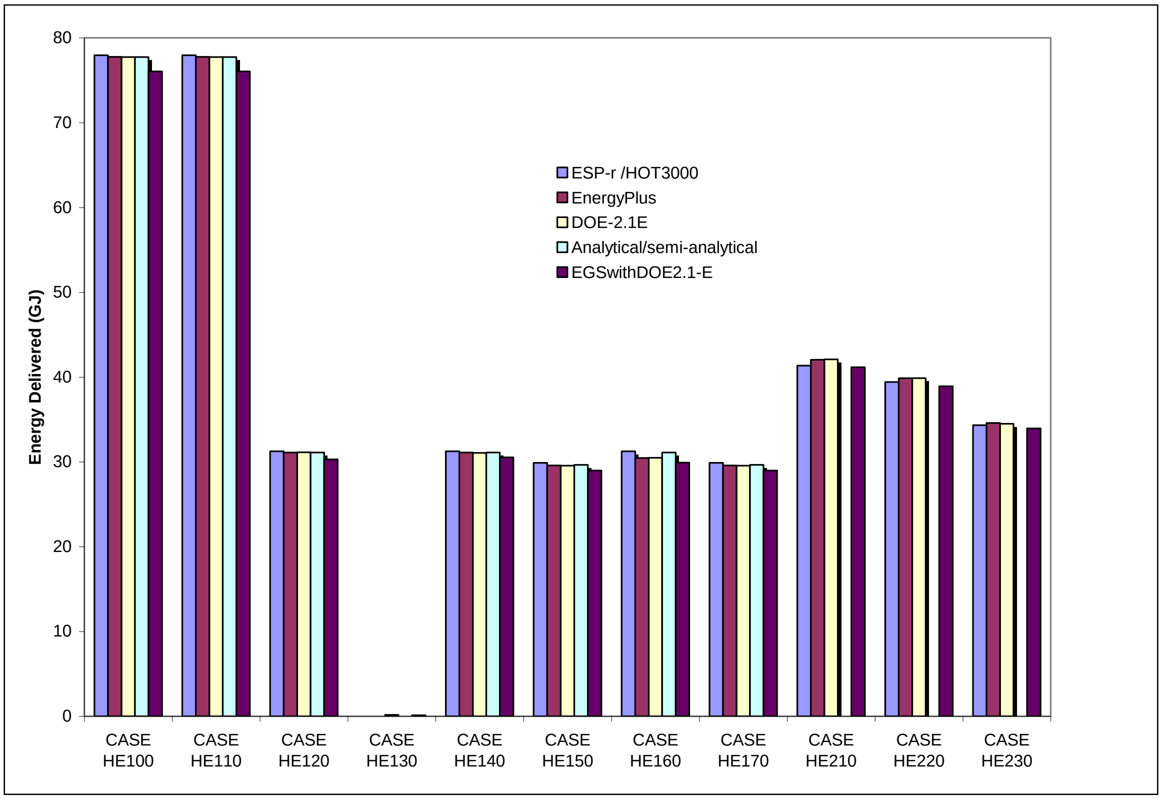

Figure 18: Loads comparison for Space Heating Equipment Comparative Tests