

ASHRAE Standard 140-2011

Test Results Comparison for Section 5.4 - HVAC Equipment Performance Tests HE100-HE230

Results for Autodesk Green Building Studio September 8, 2013
(GBS Sep 2013)

vs.

Informative Annex B16, Section B16.6 Example Results

Prepared By
Autodesk
(Autodesk)

Results Developed
08-Sep-2013

ASHRAE Standard 140-2011
Participating Organizations and Computer Programs for
Quasi-Analytical Solutions and Example Simulation Results
Section 5.4 - HVAC Equipment Performance Tests HE100-HE230

The quasi-analytical solutions and programs used to generate the example simulation results are described below. The first column ("Model"), indicates the proper program name and version number, or indicates a quasi-analytical solution.

The second column ("Authoring Organization") indicates the national research facility, university, or industry organization with expertise in building science that wrote the simulation software or did the quasi-analytical solutions.

The third column ("Implemented By") indicates the national research facility, university, or industry organization with expertise in building science that performed the simulations or did the quasi-analytical solutions.

The entries in the fourth column are the abbreviations for the simulations and quasi-analytical solutions generally used in the tables and charts which follow.

See Standard 140, Annex B17 for further details.

Participating Organizations and Computer Programs

| Model | Authoring Organization | Implemented By | Abbreviation |
|---|--|---------------------------|-----------------------------|
| ESP-r/HOT3000 Tier 1 tests - version 1.1 Tier 2 tests - version 1.7 | CETC/ESRU, ^{a,b} Canada/United Kingdom | CETC, ^a Canada | ESP-r/HOT3000/CETC |
| EnergyPlus 1.0.2.008 | LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-OBT, ^{c,d,e,f,g,h} | GARD Analytics, USA | EnergyPlus/GARD |
| DOE-2.1E version 107 | LANL/LBNL/JJH, ^{i,c,j} USA | CETC, ^a Canada | DOE-2.1E/CETC |
| Analytical/Quasi-Analytical | CETC ^a | CETC ^a | Analytical/Quasi-Analytical |

^aCETC CANMET Energy Technology Centre, Natural Resources Canada, Canada

^bESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

^cLBNL: Lawrence Berkeley National Laboratory, United States

^dUIUC: University of Illinois Urbana/Champaign, United States

^eCERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, United States

^fOSU: Oklahoma State University, United States

^gFSEC: University of Central Florida, Florida Solar Energy Center, United States

^hDOE-OBT: U.S. Department of Energy, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, United States

ⁱLANL: Los Alamos National Laboratory, United States

^jJJH: James J. Hirsch & Associates, United States

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ask Green Building Studio September 8, 2013 (GBS Sep 2013) vs. Annex B16, Section B16.6 Example R
By Autodesk (Autodesk), 08-Sep-2013

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Autodesk Green Building Studio September 8, 2013 (GBS Sep 2013) vs. Annex B16, Section B16.6 Example Results
By Autodesk (Autodesk), 08-Sep-2013**

Note: The statistics in the tables below are based on the Standard 140 informative example results.
These statistics do not have any substantial importance and are not to be interpreted as acceptance criteria.

Table B16.6-1. Total Furnace Load (GJ)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|-----------------------------|-----------------------|--------------------|------------------|-------------------------|-------|---------------------------|----------------------|---------------------------------|--------------------------|----------------------|
| | | | | Min | Max | (Max-Min) /Analytical* | Mean | | | |
| HE100: 100% eff. | 77.94 | 77.75 | 77.76 | 77.75 | 77.94 | 0.2% | 77.74 | 77.76 | 77.76 | |
| HE110: 80% eff. | 77.94 | 77.75 | 77.76 | 77.75 | 77.94 | 0.2% | 77.74 | 77.76 | 77.76 | |
| HE120: 80% eff., PLR=0.4 | 31.25 | 31.10 | 31.13 | 31.10 | 31.25 | 0.5% | 31.10 | 31.16 | 31.16 | |
| HE130: No Load | 0.00 | 0.00 | 0.16 | 0.00 | 0.16 | ---- | 0.00 | 0.00 | 0.00 | |
| HE140: Periodic PLR | 31.26 | 31.10 | 31.12 | 31.10 | 31.26 | 0.5% | 31.10 | 31.14 | 31.14 | |
| HE150: Continuous Circ. Fan | 29.88 | 29.59 | 29.57 | 29.57 | 29.88 | 1.1% | 29.65 | 29.72 | 29.72 | |
| HE160: Cycling Circ. Fan | 31.26 | 30.46 | 30.49 | 30.46 | 31.26 | 2.6% | 31.10 | 30.96 | 30.96 | |
| HE170: Draft Fan | 29.88 | 29.59 | 29.57 | 29.57 | 29.88 | 1.1% | 29.65 | 29.58 | 29.58 | |
| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Min | Max | Mean | (Max-Min) /Mean** | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
| HE210: Realistic Weather | 41.36 | 42.04 | 42.06 | 41.36 | 42.06 | 41.82 | 1.7% | - | 41.83 | 41.83 |
| HE220: Setback Thermostat | 39.41 | 39.87 | 39.76 | 39.41 | 39.87 | 39.68 | 1.2% | - | 39.60 | 39.60 |
| HE230: Undersized Furnace | 34.32 | 34.59 | 34.37 | 34.32 | 34.59 | 34.43 | 0.8% | - | 34.37 | 34.37 |

* Abs[(Max-Min) / (Analytic Solution)]

**Abs[(Max-Min) / (Mean of Example Results)]

Table B16.6-2. Total Furnace Input (GJ)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|-----------------------------|-----------------------|--------------------|------------------|-------------------------|-------|---------------------------|----------------------|---------------------------------|--------------------------|----------------------|
| | | | | Min | Max | (Max-Min) /Analytical* | Mean | | | |
| HE100: 100% eff. | 77.74 | 77.71 | 78.42 | 77.71 | 78.42 | 0.9% | 77.71 | 77.76 | 77.76 | |
| HE110: 80% eff. | 96.92 | 97.22 | 98.02 | 96.92 | 98.02 | 1.1% | 97.22 | 97.20 | 97.20 | |
| HE120: 80% eff., PLR=0.4 | 38.41 | 38.27 | 38.56 | 38.27 | 38.56 | 0.8% | 38.27 | 38.30 | 38.30 | |
| HE130: No Load | 0.00 | 0.00 | 0.14 | 0.00 | 0.14 | ---- | 0.00 | 0.00 | 0.00 | |
| HE140: Periodic PLR | 39.00 | 39.00 | 38.76 | 38.76 | 39.00 | 0.6% | 39.00 | 38.87 | 38.87 | |
| HE150: Continuous Circ. Fan | 37.23 | 36.94 | 36.82 | 36.82 | 37.23 | 1.1% | 37.02 | 36.89 | 36.89 | |
| HE160: Cycling Circ. Fan | 38.12 | 38.12 | 37.96 | 37.96 | 38.12 | 0.4% | 38.09 | 38.05 | 38.05 | |
| HE170: Draft Fan | 37.23 | 36.94 | 36.82 | 36.82 | 37.23 | 1.1% | 37.02 | 36.94 | 36.94 | |
| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Min | Max | Mean | (Max-Min) /Mean** | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
| HE210: Realistic Weather | 50.53 | 52.01 | 52.37 | 50.53 | 52.37 | 51.64 | 3.6% | - | 51.15 | 51.15 |
| HE220: Setback Thermostat | 47.87 | 49.35 | 49.47 | 47.87 | 49.47 | 48.89 | 3.3% | - | 48.30 | 48.30 |
| HE230: Undersized Furnace | 41.37 | 42.55 | 43.22 | 41.37 | 43.22 | 42.38 | 4.4% | - | 42.65 | 42.65 |

* Abs[(Max-Min) / (Analytic Solution)]

**Abs[(Max-Min) / (Mean of Example Results)]

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Autodesk Green Building Studio September 8, 2013 (GBS Sep 2013) vs. Annex B16, Section B16.6 Example Results
By Autodesk (Autodesk), 08-Sep-2013**

Note: The statistics in the tables below are based on the Standard 140 informative example results.
These statistics do not have any substantial importance and are not to be interpreted as acceptance criteria.

Table B16.6-3. Fuel Consumption (m³/s)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|-----------------------------|-----------------------|--------------------|------------------|-------------------------|----------|---------------------------|----------------------|---------------------------------|--------------------------|----------------------|
| | | | | Min | Max | (Max-Min) /Analytical* | | | | |
| HE100: 100% eff. | 0.000263 | 0.000263 | 0.000265 | 0.000263 | 0.000265 | 0.9% | 0.000263 | 0.000263 | 0.000263 | |
| HE110: 80% eff. | 0.000328 | 0.000329 | 0.000332 | 0.000328 | 0.000332 | 1.1% | 0.000329 | 0.000329 | 0.000329 | |
| HE120: 80% eff., PLR=0.4 | 0.000130 | 0.000130 | 0.000131 | 0.000130 | 0.000131 | 0.8% | 0.000130 | 0.000130 | 0.000130 | |
| HE130: No Load | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | --- | 0.000000 | 0.000000 | 0.000000 | |
| HE140: Periodic PLR | 0.000132 | 0.000132 | 0.000131 | 0.000131 | 0.000132 | 0.6% | 0.000132 | 0.000132 | 0.000132 | |
| HE150: Continuous Circ. Fan | 0.000126 | 0.000125 | 0.000125 | 0.000125 | 0.000126 | 1.1% | 0.000125 | 0.000125 | 0.000125 | |
| HE160: Cycling Circ. Fan | 0.000129 | 0.000129 | 0.000129 | 0.000129 | 0.000129 | 0.4% | 0.000129 | 0.000129 | 0.000129 | |
| HE170: Draft Fan | 0.000126 | 0.000125 | 0.000125 | 0.000125 | 0.000126 | 1.1% | 0.000125 | 0.000125 | 0.000125 | |
| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Min | Max | Mean | (Max-Min) /Mean** | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
| HE210: Realistic Weather | 0.000171 | 0.000176 | 0.000177 | 0.000171 | 0.000177 | 0.000175 | 3.5% | - | 0.000173 | 0.000173 |
| HE220: Setback Thermostat | 0.000162 | 0.000167 | 0.000167 | 0.000162 | 0.000167 | 0.000165 | 3.3% | - | 0.000163 | 0.000163 |
| HE230: Undersized Furnace | 0.000140 | 0.000144 | 0.000146 | 0.000140 | 0.000146 | 0.000143 | 4.3% | - | 0.000144 | 0.000144 |

* Abs[(Max-Min) / (Analytic Solution)]

**Abs[(Max-Min) / (Mean of Example Results)]

Table B16.6-4. Fan Energy, both fans (kWh)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|-----------------------------|-----------------------|--------------------|------------------|-------------------------|-------|---------------------------|----------------------|---------------------------------|--------------------------|----------------------|
| | | | | Min | Max | (Max-Min) /Analytical* | | | | |
| HE150: Continuous Circ. Fan | 432.0 | 433.3 | 432.1 | 432.0 | 433.3 | 0.3% | 432.0 | 433.0 | 433.0 | |
| HE160: Cycling Circ. Fan | 170.2 | 172.2 | 172.4 | 170.2 | 172.4 | 1.3% | 172.8 | 171.9 | 171.9 | |
| HE170: Draft Fan | 473.4 | 473.1 | 473.1 | 473.1 | 473.4 | 0.1% | 473.2 | 473.3 | 473.3 | |
| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Min | Max | Mean | (Max-Min) /Mean** | Analytical/ Quasi-Analytical | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
| HE210: Realistic Weather | 281.6 | 291.4 | 298.9 | 281.6 | 298.9 | 290.6 | 6.0% | - | 295.7 | 295.7 |
| HE220: Setback Thermostat | 268.3 | 276.1 | 281.2 | 268.3 | 281.2 | 275.2 | 4.7% | - | 274.3 | 274.3 |
| HE230: Undersized Furnace | 458.3 | 431.4 | 478.4 | 431.4 | 478.4 | 456.0 | 10.3% | - | 450.6 | 450.6 |

* Abs[(Max-Min) / (Analytic Solution)]

**Abs[(Max-Min) / (Mean of Example Results)]

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Autodesk Green Building Studio September 8, 2013 (GBS Sep 2013) vs. Annex B16, Section B16.6 Example Results
By Autodesk (Autodesk), 08-Sep-2013**

Note: The statistics in the tables below are based on the Standard 140 informative example results.
These statistics do not have any substantial importance and are not to be interpreted as acceptance criteria.

Table B16.6-5. Mean Zone Temperature (°C)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|---------------------------|-----------------------|--------------------|------------------|-------------------------|-------|-------|----------------------|--------------------------|----------------------|
| | | | | Min | Max | Mean | (Max-Min) /Mean** | | |
| HE210: Realistic Weather | 20.01 | 20.00 | 19.98 | 19.98 | 20.01 | 20.00 | 0.2% | 19.98 | 19.98 |
| HE220: Setback Thermostat | 18.75 | 18.53 | 18.53 | 18.53 | 18.75 | 18.60 | 1.2% | 18.53 | 18.53 |
| HE230: Undersized Furnace | 15.48 | 15.17 | 15.64 | 15.17 | 15.64 | 15.43 | 3.0% | 15.70 | 15.70 |

**Abs[(Max-Min) / (Mean of Example Results)]

Table B16.6-6. Maximum Zone Temperature (°C)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|---------------------------|-----------------------|--------------------|------------------|-------------------------|-------|-------|---------------------|--------------------------|----------------------|
| | | | | Min | Max | Mean | (Max-Min) /Mean* | | |
| HE210: Realistic Weather | 21.45 | 20.00 | 20.06 | 20.00 | 21.45 | 20.50 | 7.1% | 20.08 | 20.08 |
| HE220: Setback Thermostat | 22.70 | 20.00 | 20.11 | 20.00 | 22.70 | 20.94 | 12.9% | 20.08 | 20.08 |
| HE230: Undersized Furnace | 20.14 | 20.00 | 20.06 | 20.00 | 20.14 | 20.07 | 0.7% | 20.04 | 20.04 |

**Abs[(Max-Min) / (Mean of Example Results)]

Table B16.6-7. Minimum Zone Temperature (°C)

| Cases | ESP-r/HOT3000 CETC | EnergyPlus GARD | DOE-2.1E CETC | Statistics, All Results | | | | GBS Sep 2013 Autodesk | GBS v3.4 Autodesk |
|---------------------------|-----------------------|--------------------|------------------|-------------------------|-------|-------|---------------------|--------------------------|----------------------|
| | | | | Min | Max | Mean | (Max-Min) /Mean* | | |
| HE210: Realistic Weather | 20.00 | 20.00 | 19.89 | 19.89 | 20.00 | 19.96 | 0.6% | 19.88 | 19.88 |
| HE220: Setback Thermostat | 15.00 | 15.00 | 14.94 | 14.94 | 15.00 | 14.98 | 0.4% | 14.93 | 14.93 |
| HE230: Undersized Furnace | 1.45 | 4.48 | 3.22 | 1.45 | 4.48 | 3.05 | 99.3% | 3.73 | 3.73 |

**Abs[(Max-Min) / (Mean of Example Results)]

Figure B16.6-1. Comparison of the Energy Delivered for the Fuel-Fired Furnace Test Cases

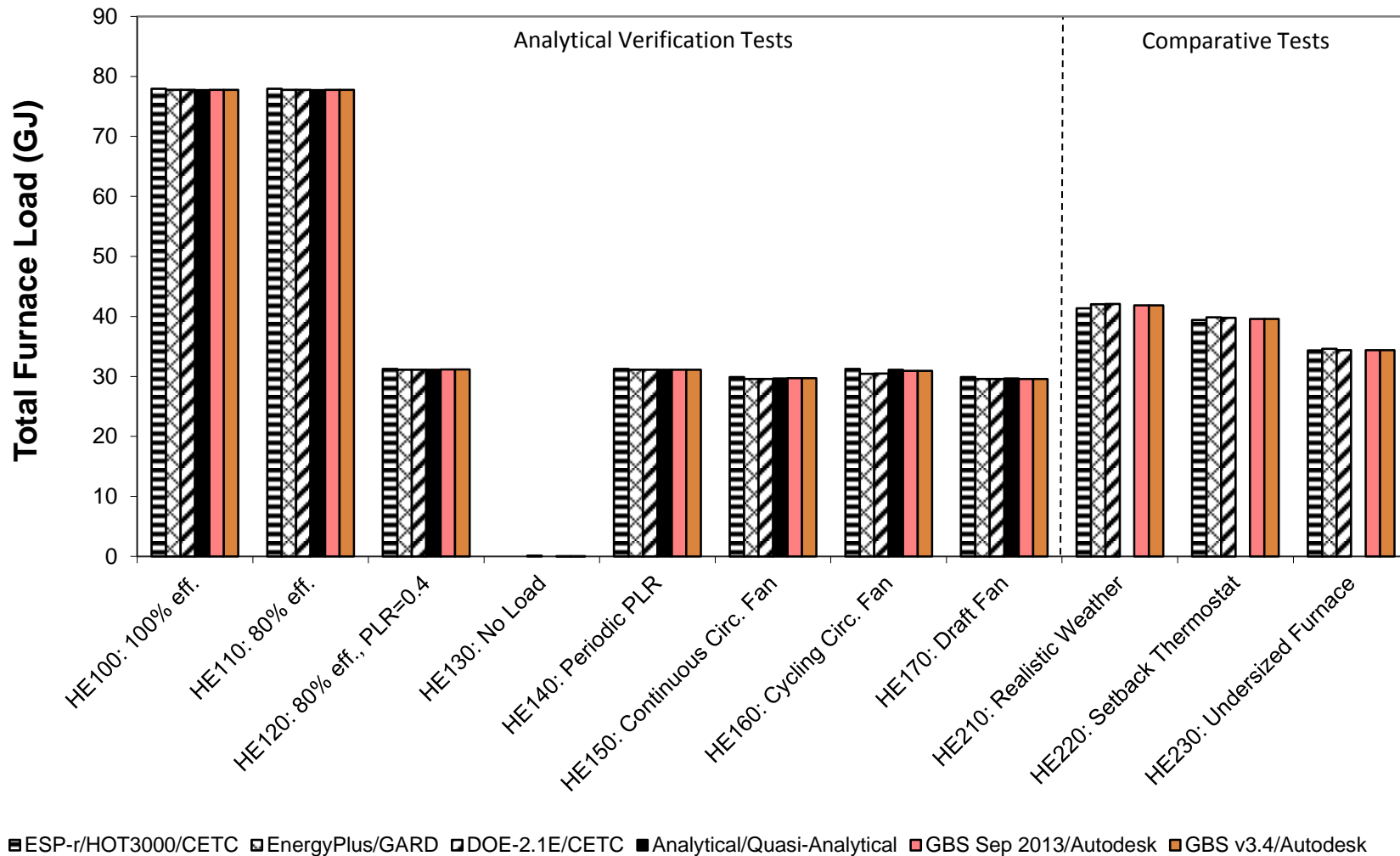


Figure B16.6-2. Comparison of the Energy Consumed for the Fuel-Fired Furnace Test Cases

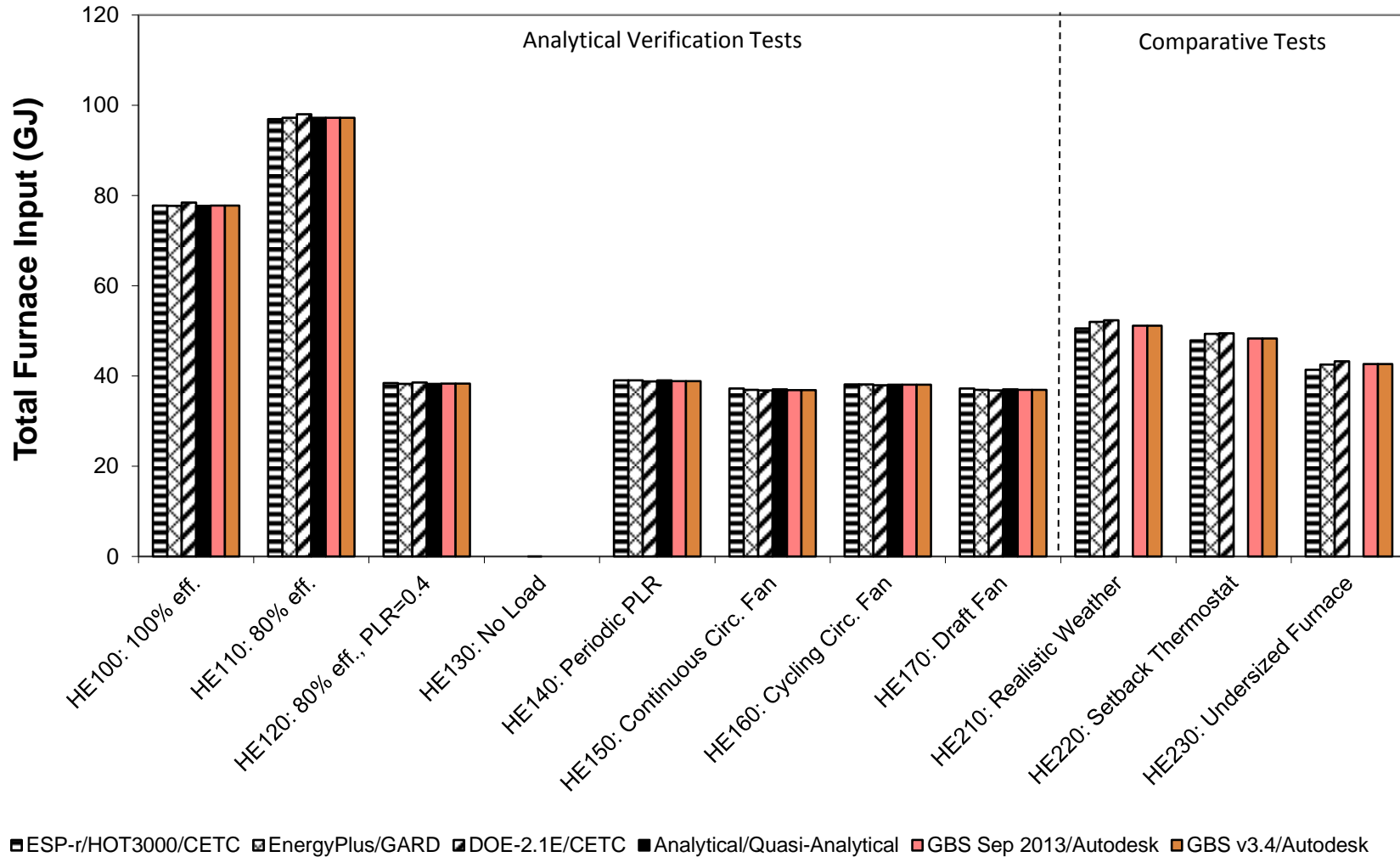


Figure B16.6-4. Comparison of the Fan Energy for the Fuel-Fired Furnace Test Cases

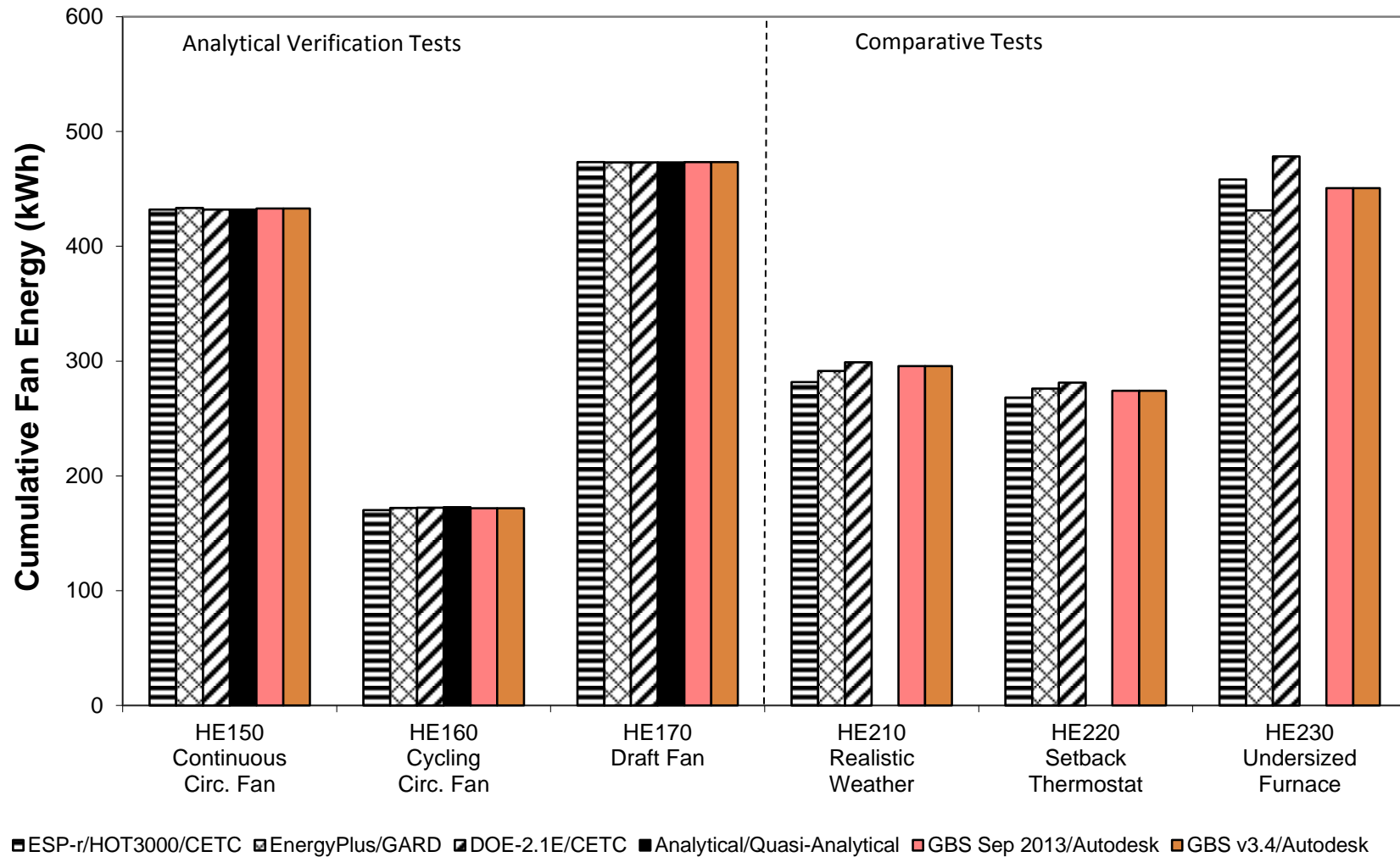


Figure B16.6-5. Comparison of the Mean Zone Temperature for the Fuel-Fired Furnace Comparative Test Cases

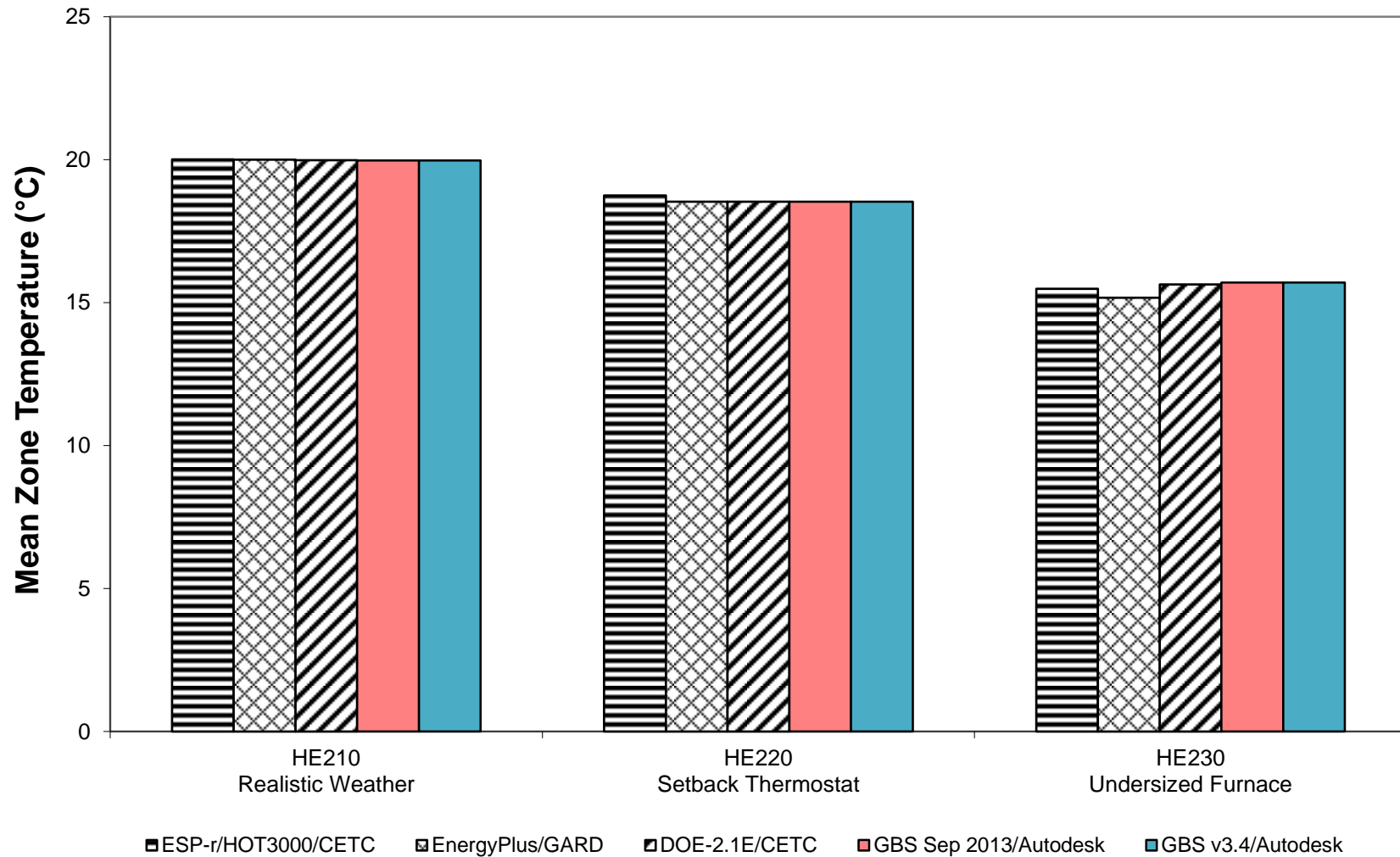
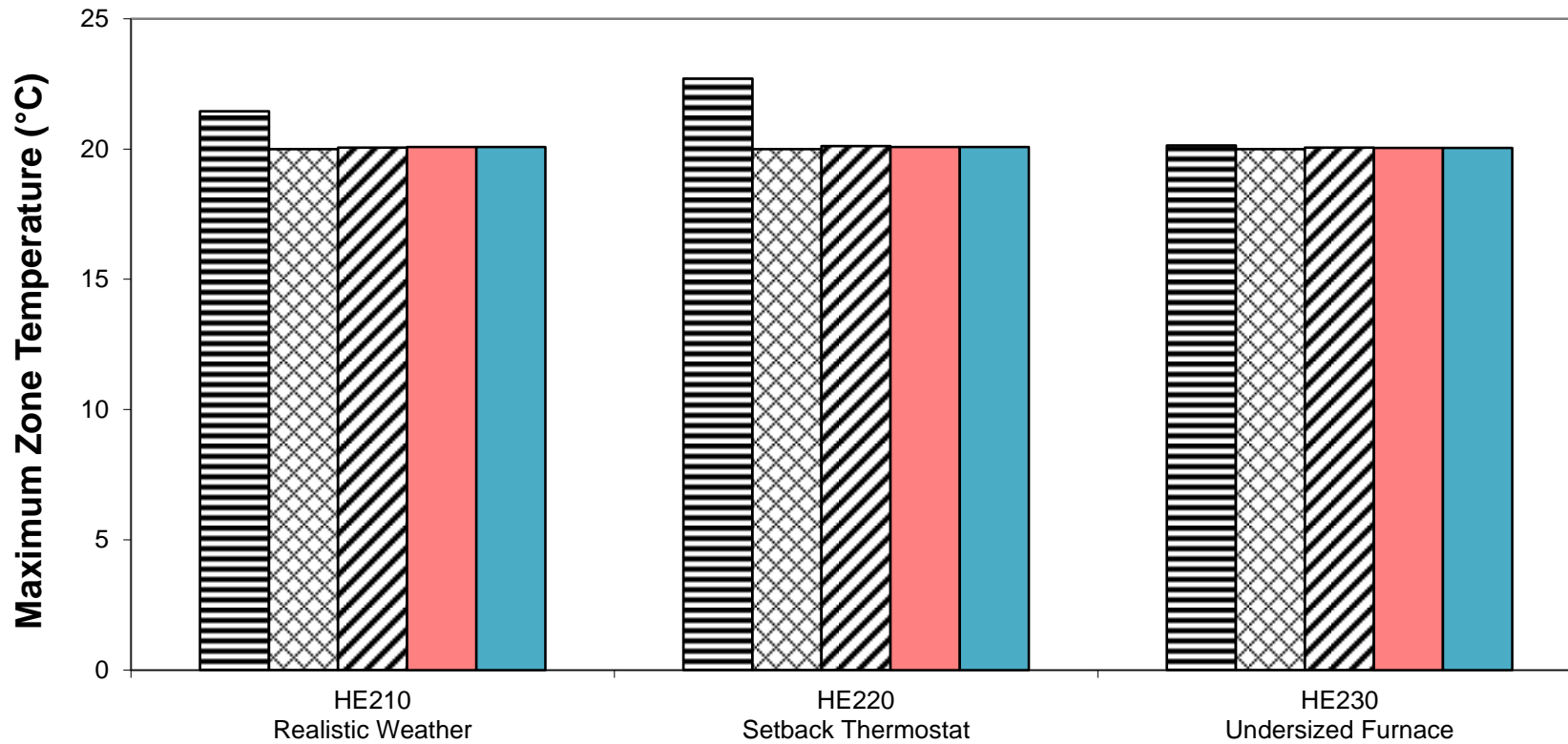


Figure B16.6-6. Comparison of the Maximum Zone Temperature for the Fuel-Fired Furnace Comparative Test Cases



- ESP-r/HOT3000/CETC
- EnergyPlus/GARD
- DOE-2.1E/CETC
- GBS Sep 2013/Autodesk
- GBS v3.4/Autodesk

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

Figure B16.6-7. Comparison of the Minimum Zone Temperature for the Fuel-Fired Furnace Comparative Test Cases

