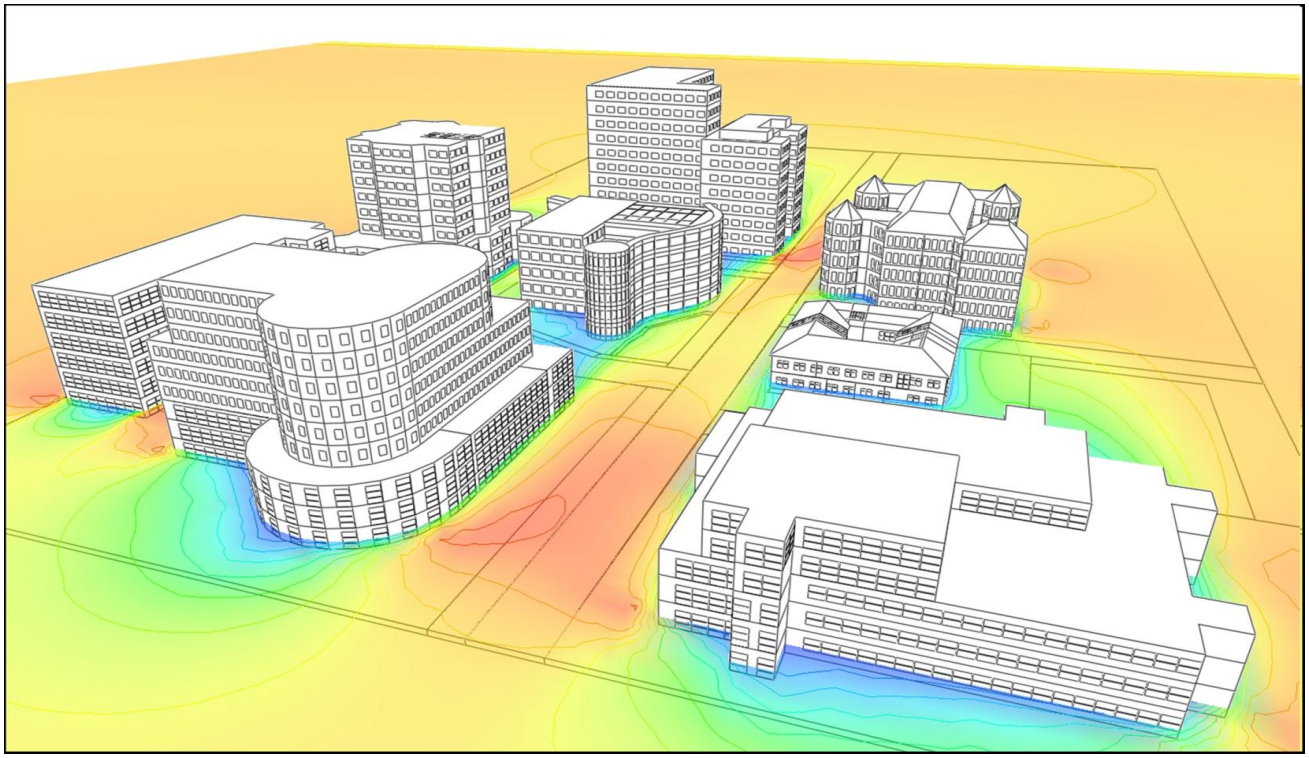
INTEGRATED ENVIRONMENTAL SOLUTIONS

Space-Heating Equipment Performance Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2007

ApacheSim Version <VE>2013
June 2013

Integrated Environmental Solutions
www.iesve.com



Contents

References

[1:ASHRAE 140-2007] ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.
ASHRAE, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329.
www.ashrea.org

[2:ApacheSim] ApacheSim Building Thermal Simulation Program.
Integrated Environmental Solutions (IES) Ltd., Helix Building, Kelvin Campus, West of Scotland Science Park, Glasgow. G20 0SP.
www.iesve.com

[3:Results5-4] Excel workbook, “RESULTS5-4_ies.xls”, supplied by ASHRAE and populated with simulation results from ApacheSim. Contains results/tables/charts for cases HE100 to HE230.

1 Introduction

ANSI/ASHRAE Standard 140-2007, Standard Method of Test (SMOT) for the Evaluation of Building Energy Analysis Computer Programs [1:ASHRAE 140-2007], defines a series of tests for building energy simulation programs. The tests fall into three categories: building envelope and fabric load tests, space-cooling equipment performance tests and space-heating performance tests.

This report covers the space-heating equipment performance tests, described in [1:ASHRAE 140-2007], section 5.4.

The aim of the tests is to identify and diagnose differences in predictions that may be caused by software errors. The ways in which they can be used are listed in [1:ASHRAE 140-2007]:

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

While the text of the Standard emphasizes that all building models are simplifications of reality, and full validation cannot be achieved by a single series of tests, the ASHRAE 140 tests provide a valuable benchmark by which the predictions of a simulation program may be compared with those of its peers, as means to establishing a degree of confidence in the correctness of its algorithms and their implementation.

This report presents the results of the space-heating tests applied to the simulation program ApacheSim [2:ApacheSim].

2 Overview of Tests

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 specification represents a simple unitary fuel-fired furnace with a circulating fan and a draft fan. This case is described in detail in [1:ASHRAE 140-2007], section 5.4.1.

Case HE100 provides the base for a further 10 cases, 7 analytical verification test and 3 comparative tests.

For the analytical verification tests the following parameters are varied,

- efficiency
- weather (outdoor dry-bulb temperature), resulting in different load conditions.
- circulating fan operation
- draft fan operation.

The analytical verification tests are described in detail in [1:ASHRAE 140-2007], section 5.4.2.

For the comparative tests the following parameters are varies,

- weather (realistic temperature conditions are used)
- thermostat control strategy
- furnace size (undersized furnace)

The comparative tests are described in detail in [1:ASHRAE 140-2007], section 5.4.3.

Case	Zone		Weather File	Equipment				
	Outdoor DBT (^oC)	Indoor setpoint Temp. (^oC)		Furnace Capacity (^oC)	Steady-state Efficiency	PLR_f	Circulating Fan (W)	Draft Fan (W)
Analytical Verification Tests								
HE100	-30	20	HE100W	10	100%	1	0	0
HE110	-30	20	HE100W	10	80%	1	0	0
HE120	0	20	HE120W	10	80%	0.4	0	0
HE130	20	20	HE130W	10	80%	0.0	0	0
HE140	-20 to 20	20	HE140W	10	80%	0.0 - 0.8	0	0
HE150	-20 to 20	20	HE140W	10	80%	0.0 - 0.8	200-cont	0
HE160	-20 to 20	20	HE140W	10	80%	0.0 - 0.8	200-cyclic	0
HE170	-20 to 20	20	HE140W	10	80%	0.0 - 0.8	200-cont	50-cyclic
Comparative Tests								
HE210	varying	20	HE210W	10	80%	0.0 – 1.0	200-cyclic	50-cyclic
HE220	varying	15 to 20	HE210W	10	80%	0.0 – 1.0	200-cyclic	50-cyclic
HE230	varying	15 to 20	HE210W	5	80%	0.0 – 1.0	200-cyclic	50-cyclic

Table 2.1 – Space-heating equipment BESTEST cases description.

3 ApacheSim Settings

STANDARD 140 OUTPUT FORM - MODELING NOTES

INSTRUCTIONS: See [1:ASHRAE 140-2007], Annex A2.

SOFTWARE: *ApacheSim*

VERSION: <VE>2013

Simulated Effect:
Solar radiation model.

Optional Settings or Modeling Capabilities:
Off, Anisotropic (default), Isotropic.

Setting or Capability Used:
Anisotropic.

Physical Meaning of Option Used:
Anisotropic short-wave sky model.

Simulated Effect:
Internal Heat Transfer.

Optional Settings or Modeling Capabilities:
CIBSE fixed values (default), Alamdari & Hammond, CIBSE variable values

Setting or Capability Used:
CIBSE fixed values

Physical Meaning of Option Used:
Internal convection coefficients are fixed at values given in CIBSE Guide A. Note: external convective heat transfer is treated using a wind-speed dependent algorithm.

Simulated Effect:
Initial temperature.

Optional Settings or Modeling Capabilities:
Any temperature (default 18°C)

Setting or Capability Used:
18°C

Physical Meaning of Option Used:
Temperature at which building is initialised before simulation. Has minimal effect provided there is sufficient preconditioning.

Simulated Effect:
Time step.

Optional Settings or Modeling Capabilities:
1, 2, 6, 10 or 30 minutes

Setting or Capability Used:
1 minute / 2 minutes

Physical Meaning of Option Used:
Simulation time step. A small time step was used for optimal accuracy.

Simulated Effect:
Reporting interval.

Optional Settings or Modeling Capabilities:
6, 10, 30 or 60 minutes

Setting or Capability Used:
6 minutes

Physical Meaning of Option Used:
Time interval over which simulation results are averaged for output.

Simulated Effect:
Preconditioning period.

Optional Settings or Modeling Capabilities:
Between 0 and 365 days (default 10 days)

Setting or Capability Used:
10 days

Physical Meaning of Option Used:
Number of days simulated in the run-up to the start of the specified simulation period. Has minimal effect, provided the number of days is sufficiently large in relation to the response time of the building.

Simulated Effect:
Direct solar shading and internal solar tracking calculated by the SunCast program.

Optional Settings or Modeling Capabilities:
SunCast shading can be included or not, at the user's option

Setting or Capability Used:
SunCast shading was not used.

Physical Meaning of Option Used:
No solar tracking was employed in the space heating tests. As the model had no shading or glazing, SunCast would not have contributed to the accuracy of the simulation.

Simulated Effect:
Diffuse shading calculated by the SunCast program.

Optional Settings or Modeling Capabilities:
SunCast diffuse shading can be included or not, at the user's option

Setting or Capability Used:
SunCast shading was not used.

Physical Meaning of Option Used:
The effects on external surfaces were not taken into account in the space heating tests. As the model had no shading or glazing, SunCast would not have contributed to the accuracy of the simulation.

Simulated Effect:
Plant Performance.

Optional Settings or Modeling Capabilities:
Apache Systems, Apache HVAC

Setting or Capability Used:
Apache HVAC

Physical Meaning of Option Used:
Apache HVAC is a module within the software that enables detailed plant analysis. This module is required in the tests for analysis of the unitary fuel-fired furnace with circulating fan and draft fan.

4 Notes on ApacheSim Results

The results presented in this report are contained in the Excel Workbook “RESULTS5-4_ies.xls”, [3:Results5-4].

Section 5 presents the ApacheSim results graphically. The charts follow the same style and ordering as those in the ASHRAE standard.

Section 6 gives the numerical values obtained from ApacheSim. In addition, the tables contain a “Within Range” column. This column provides a first indication of values that differ from the values published in the ASHRAE standard.

If the *discrepancy* in the ApacheSim result is less than the *range*, the “Within Range” column contains a “yes”, otherwise it contains a “no”.

The *range* represents the spread of the published results. It is based on the difference between the maximum and minimum of the published results and is reported as a percentage of the mean of the published results (or analytical results if this is available).

The *discrepancy* in the ApacheSim results is calculated from the difference between the Apache result and the mean of the published results (or analytical value if that is known) expressed as a percentage of the mean (or analytical value).

5 Results – Graphical

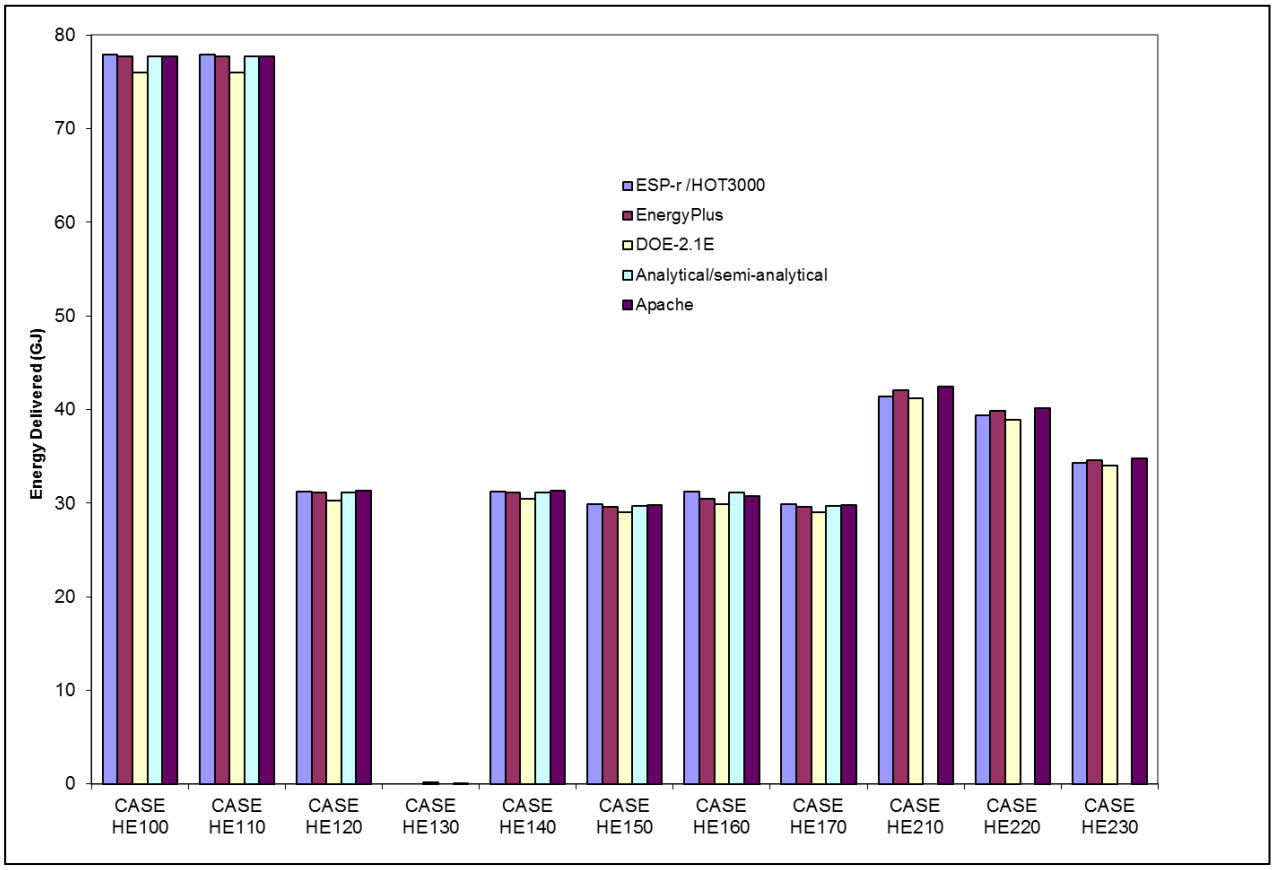


Figure 5.1 – Comparison of the energy delivered for fuel-fired furnace test cases (GJ). HE100 to HE170 are analytical verification tests. HE210, HE220 and HE230 are comparative tests using real weather data.

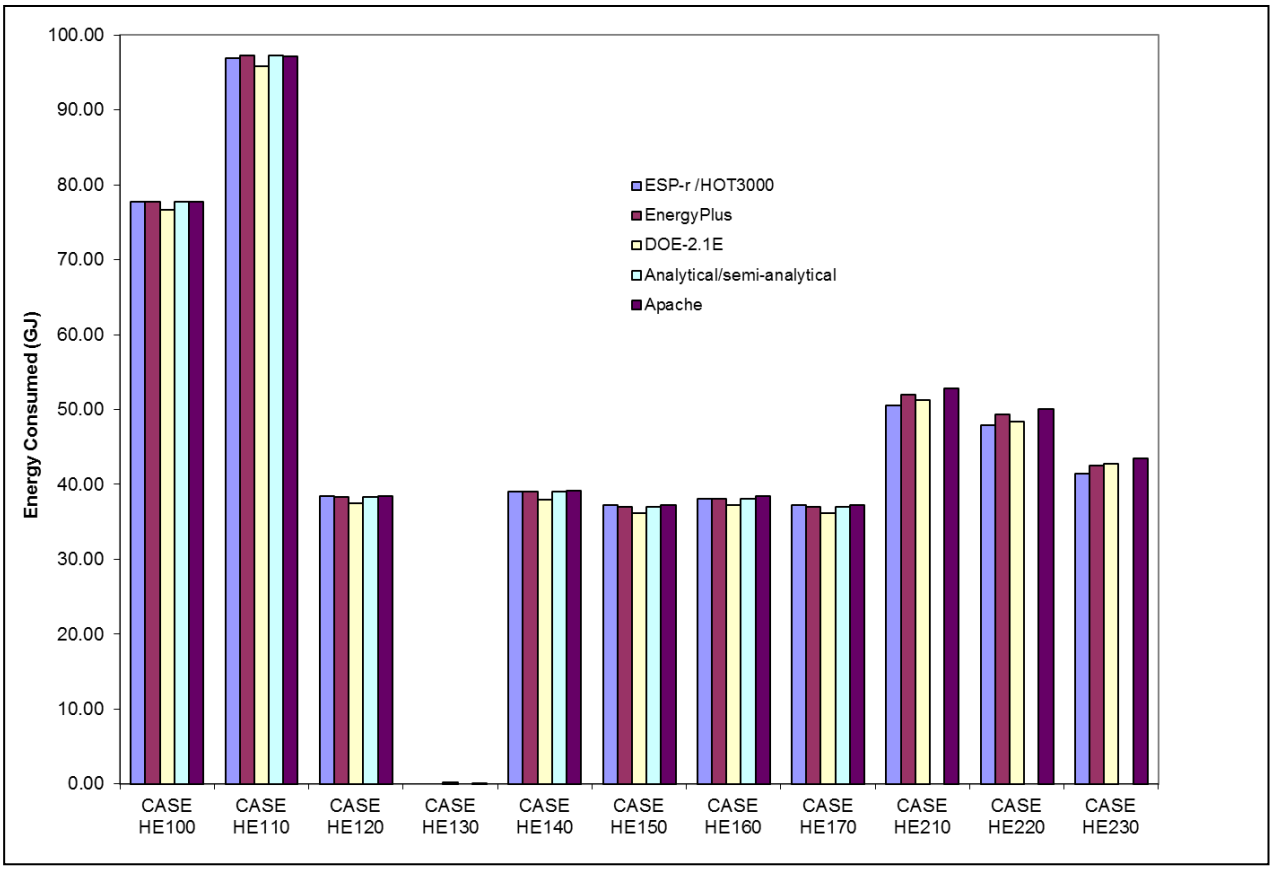


Figure 5.2 – Comparison of the energy consumed for fuel-fired furnace test cases (GJ). HE100 to HE170 are analytical verification tests. HE210, HE220 and HE230 are comparative tests using real weather data.

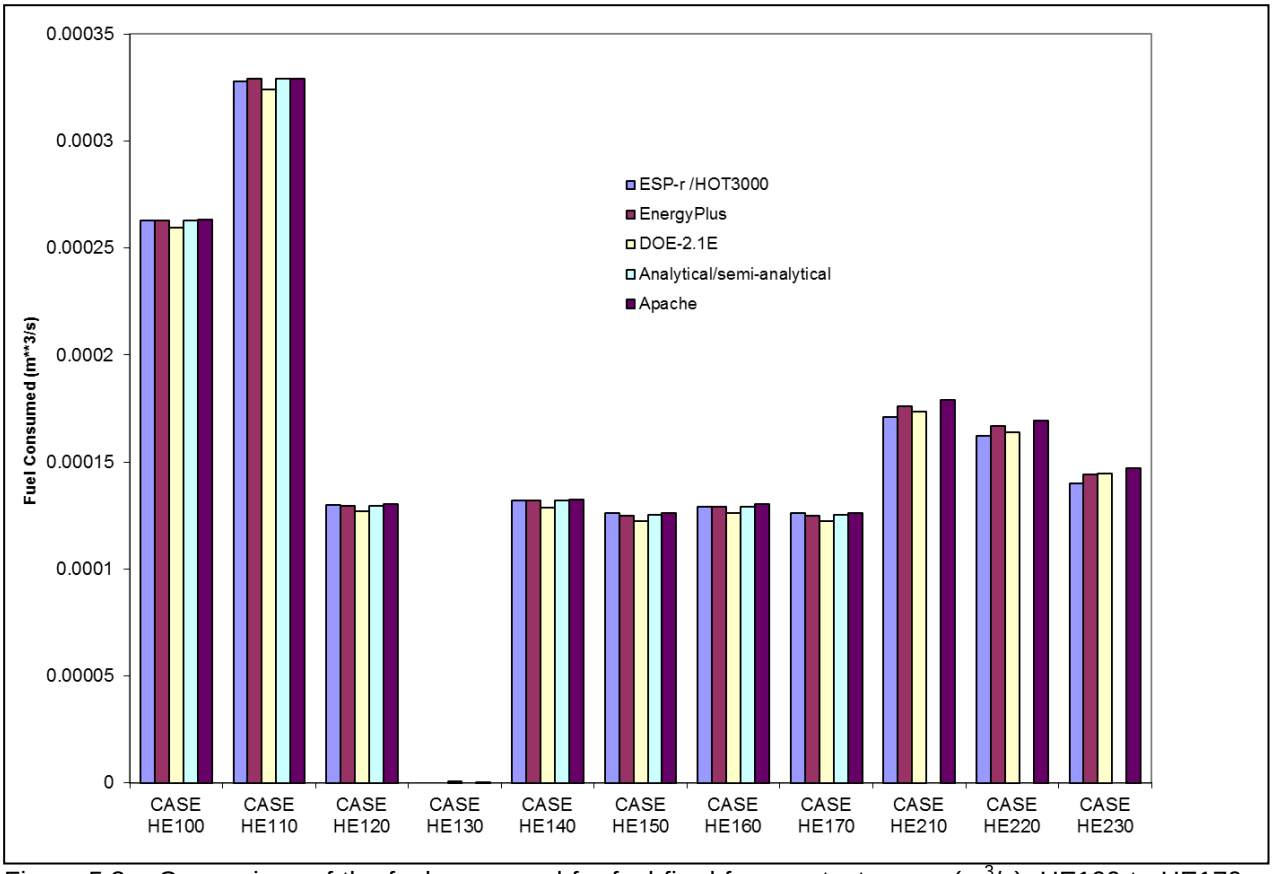


Figure 5.3 – Comparison of the fuel consumed for fuel-fired furnace test cases (m^3/s). HE100 to HE170 are analytical verification tests. HE210, HE220 and HE230 are comparative tests using real weather data.

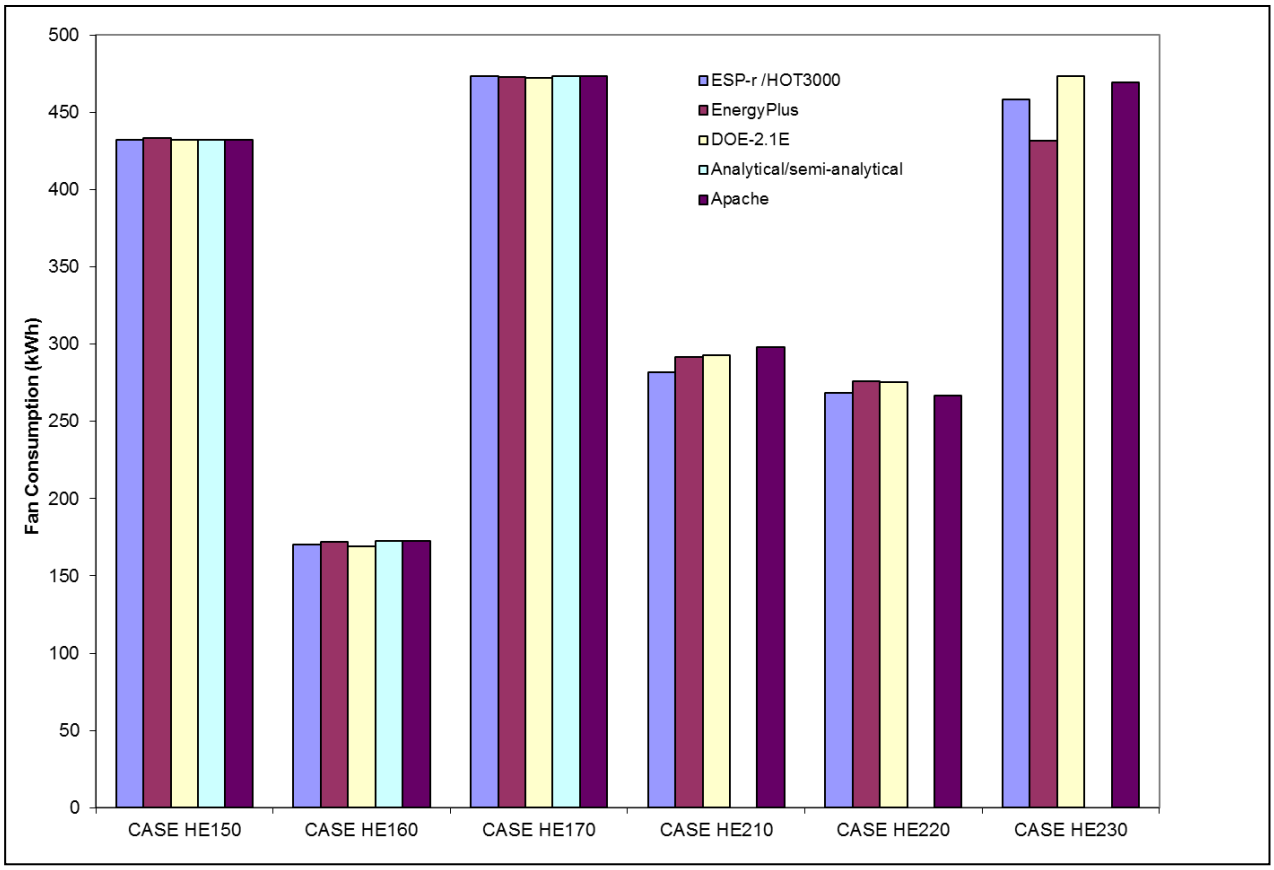


Figure 5.4 – Comparison of the fan energy for fuel-fired furnace test cases (kWh). HE150 to HE170 are analytical verification tests. HE210, HE220 and HE230 are comparative tests using real weather data.

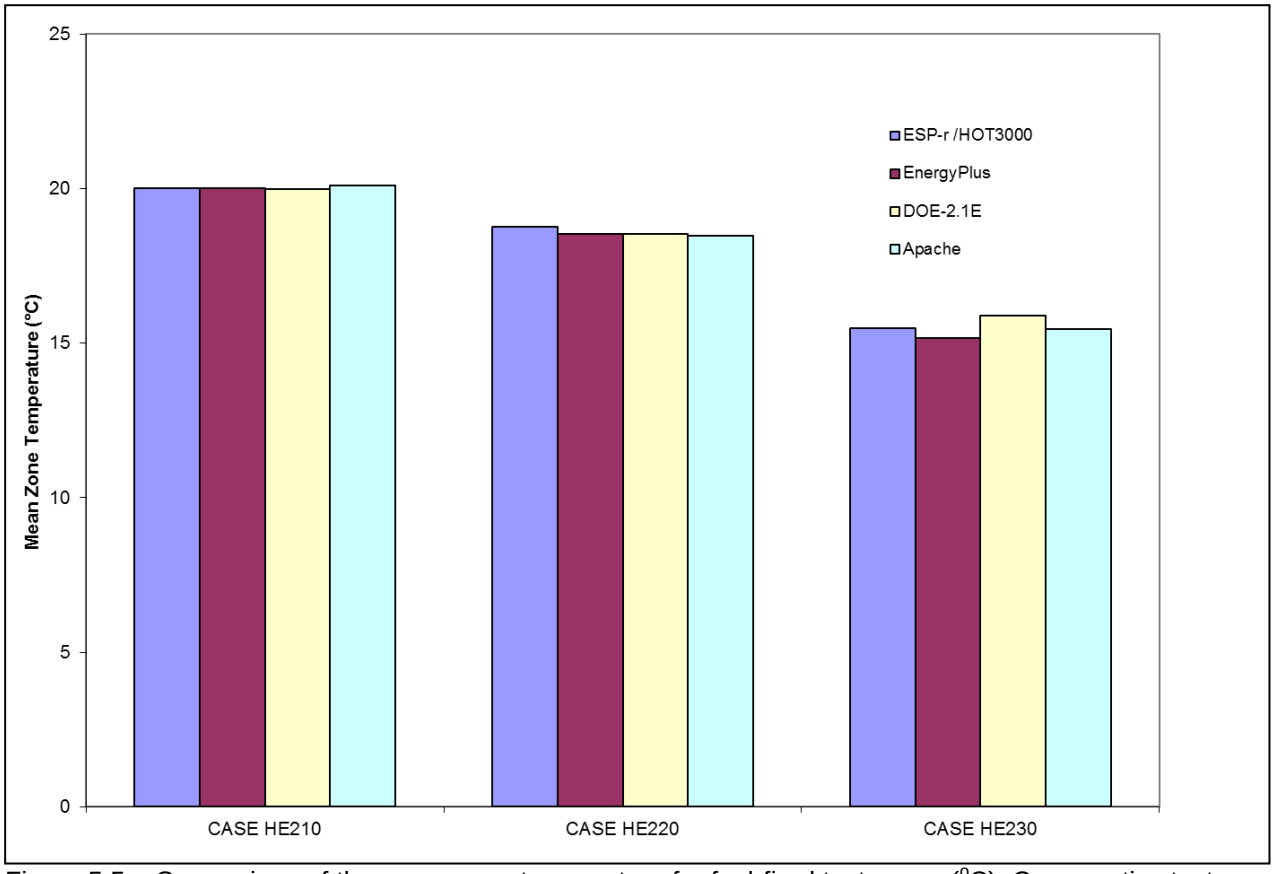


Figure 5.5 – Comparison of the mean zone temperature for fuel-fired test cases (^{o}C). Comparative test cases using real weather data.

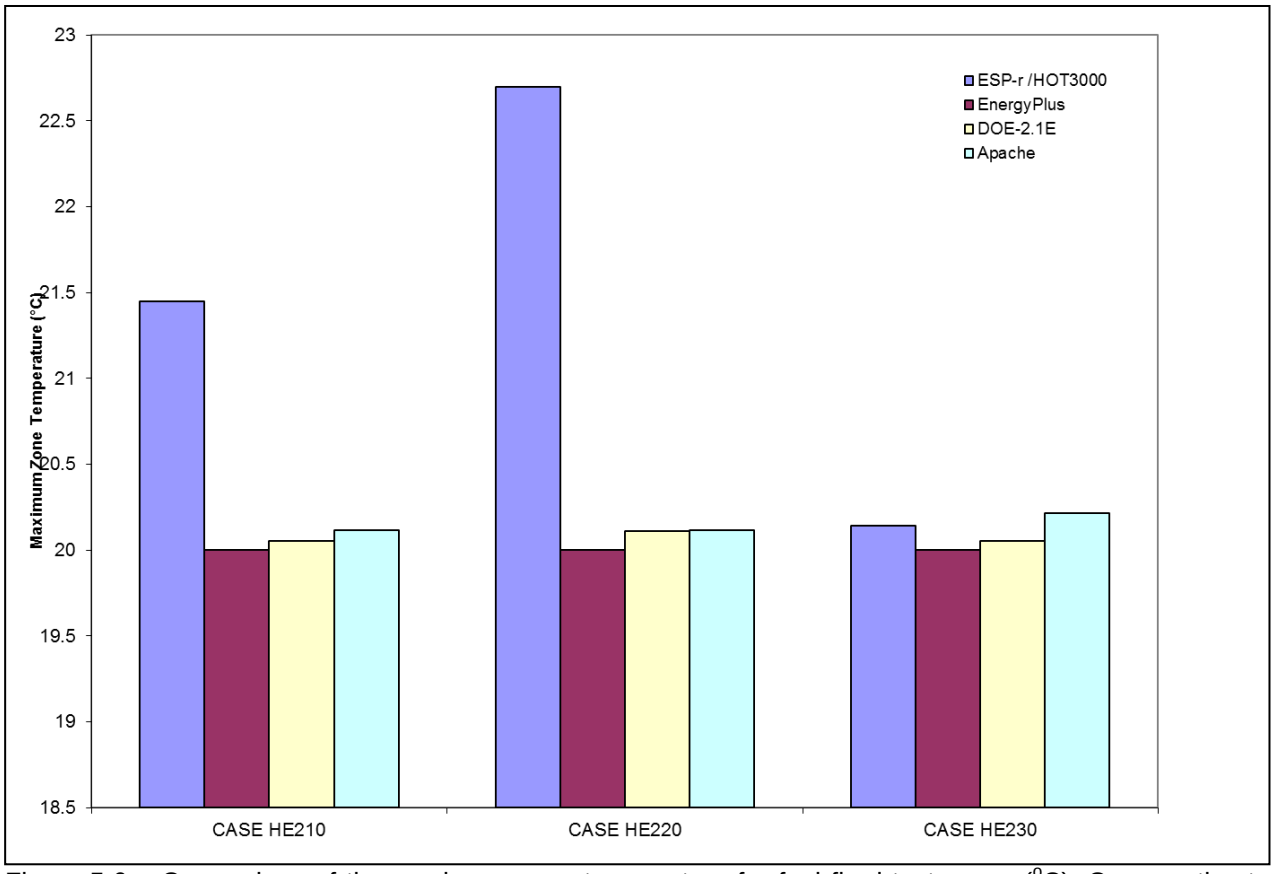


Figure 5.6 – Comparison of the maximum zone temperature for fuel-fired test cases (^{o}C). Comparative test cases using real weather data.

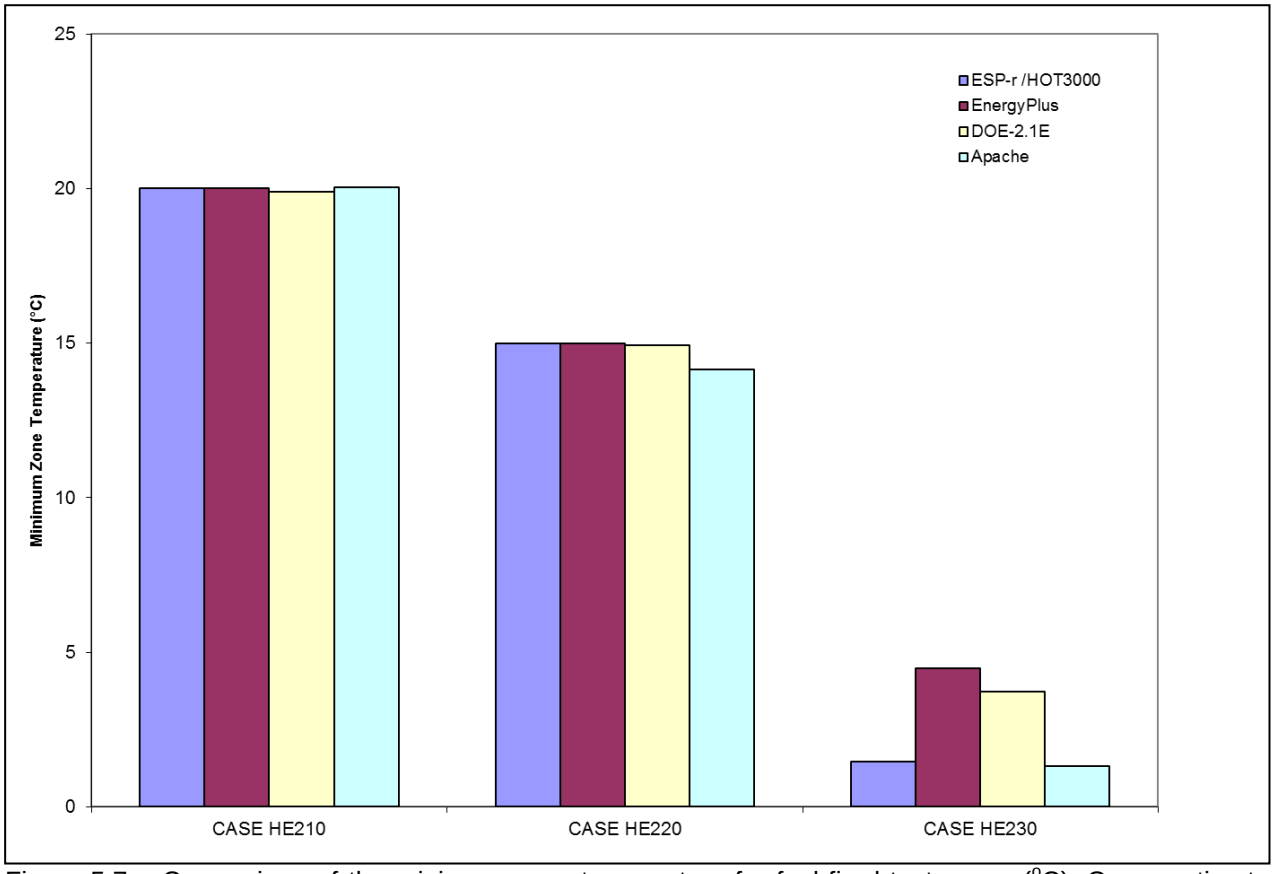


Figure 5.7 – Comparison of the minimum zone temperature for fuel-fired test cases (^{o}C). Comparative test cases using real weather data.

6 Results - Tabulated

TOTAL FURNACE LOAD **GJ**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results			Analytical/semi-analytical				
				Min	Max	(Max-Min) /An	Heat transfer surf method (An)	Infiltration method	Apache (Ap)	|Ap-An| /An	Within Range
CASE HE100	77.94	77.75	76.03	76.03	77.94	2.46%	77.74	77.77	77.76	0.01%	yes
CASE HE110	77.94	77.75	76.03	76.03	77.94	2.46%	77.74	77.77	77.76	0.01%	yes
CASE HE120	31.25	31.1	30.29	30.29	31.25	3.10%	31.1	31.11	31.28	0.55%	yes
CASE HE130	0	0	0.16	0.00	0.16		0	0	0.00		
CASE HE140	31.26	31.1	30.50	30.50	31.26	2.45%	31.1	31.11	31.28	0.55%	yes
CASE HE150	29.88	29.59	28.99	28.99	29.88	2.99%	29.65	29.66	29.80	0.50%	yes
CASE HE160	31.26	30.46	29.93	29.93	31.26	4.29%	31.1	31.11	30.77	1.06%	yes
CASE HE170	29.88	29.59	28.99	28.99	29.88	2.99%	29.65	29.66	29.80	0.50%	yes
CASE HE210	41.36	42.04	41.17	41.17	42.04	2.09%	-	-	42.43	1.98%	yes
CASE HE220	39.41	39.87	38.92	38.92	39.87	2.42%	-	-	40.17	1.97%	yes
CASE HE230	34.32	34.59	34.02	34.02	34.59	1.67%	-	-	34.79	1.41%	yes

Table 6.1 – Total Furnace Load (GJ).

TOTAL FURNACE INPUT **GJ**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results			Analytical/semi-analytical				
				Min	Max	(Max-Min) /An	Heat transfer surf method (An)	Infiltration method	Apache (Ap)	|Ap-An| /An	Within Range
CASE HE100	77.74	77.71	76.62	76.62	77.74	1.43%	77.71	77.71	77.76	0.06%	yes
CASE HE110	96.92	97.22	95.78	95.78	97.22	1.48%	97.22	97.22	97.20	0.02%	yes
CASE HE120	38.41	38.27	37.50	37.50	38.41	2.39%	38.27	38.30	38.49	0.54%	yes
CASE HE130	0.00	0.00	0.14	0.00	0.14		0.00	0.00	0.03		
CASE HE140	39.00	39.00	37.97	37.97	39.00	2.64%	39.00	39.00	39.10	0.24%	yes
CASE HE150	37.23	36.94	36.10	36.10	37.23	3.07%	37.02	37.02	37.20	0.48%	yes
CASE HE160	38.12	38.12	37.25	37.25	38.12	2.29%	38.09	38.12	38.46	0.95%	yes
CASE HE170	37.23	36.94	36.10	36.10	37.23	3.07%	37.02	37.02	37.20	0.48%	yes
CASE HE210	50.53	52.01	51.25	50.53	52.01	2.88%	-	-	52.85	3.09%	no
CASE HE220	47.87	49.35	48.41	47.87	49.35	3.04%	-	-	50.04	2.94%	yes
CASE HE230	41.37	42.55	42.76	41.37	42.76	3.31%	-	-	43.52	3.45%	no

Table 6.2 – Total Furnace Input (GJ).

FUEL CONSUMPTION **m^3/s**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results			Analytical/semi-analytical				
				Min	Max	(Max-Min) /An	Heat transfer surf method (An)	Infiltration method	Apache (Ap)	|Ap-An| /An	Within Range
CASE HE100	0.000263	0.000263	0.000259	0.000259	0.000263	1.40%	0.000263	0.000263	0.000263	0.06%	yes
CASE HE110	0.000328	0.000329	0.000324	0.000324	0.000329	1.48%	0.000329	0.000329	0.000329	0.02%	yes
CASE HE120	0.00013	0.0001295	0.000127	0.000127	0.000130	2.39%	0.0001295	0.0001296	0.000130	0.54%	yes
CASE HE130	0	0	0.000000	0.000000	0.000000		0	0	0.000000		
CASE HE140	0.000132	0.000132	0.000129	0.000129	0.000132	2.64%	0.000132	0.000132	0.000132	0.24%	yes
CASE HE150	0.000126	0.000125	0.000122	0.000122	0.000126	3.07%	0.0001253	0.0001253	0.000126	0.48%	yes
CASE HE160	0.000129	0.000129	0.000126	0.000126	0.000129	2.29%	0.0001289	0.000129	0.000130	0.95%	yes
CASE HE170	0.000126	0.000125	0.000122	0.000122	0.000126	3.07%	0.0001253	0.0001253	0.000126	0.48%	yes
CASE HE210	0.000171	0.000176	0.000173	0.000171	0.000176	2.88%	-	-	0.000179	3.09%	no
CASE HE220	0.000162	0.000167	0.000164	0.000162	0.000167	3.04%	-	-	0.000169	2.94%	yes
CASE HE230	0.00014	0.000144	0.000145	0.000140	0.000145	3.31%	-	-	0.000147	3.45%	no

Table 6.3 – Total Furnace Input (m^3/s).

FAN ENERGY (BOTH FANS) **kWh**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results			Analytical (An)			
				Min	Max	(Max-Min) /An		Apache (Ap)	|Ap-An| /An	Within Range
CASE HE150	432	433.3	432.0	432.0	433.3	0.30%	432	432.00	0.00%	yes
CASE HE160	170.2	172.2	169.2	169.2	172.2	1.74%	172.76	172.80	0.02%	yes
CASE HE170	473.4	473.1	472.2	472.2	473.4	0.26%	473.18	473.16	0.00%	yes
CASE HE210	281.6	291.4	292.7	281.6	292.7	3.86%	-	297.83	3.72%	yes
CASE HE220	268.3	276.1	275.2	268.3	276.1	2.87%	-	266.57	2.07%	yes
CASE HE230	458.3	431.4	473.3	431.4	473.3	9.26%	-	469.52	3.79%	yes

Table 6.4 – Comparison of Fan Energy Consumption (kWh).

MEAN ZONE TEMPERATURE **°C**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results Min	Max	(Max-Min) /Mean	Apache	|Ap-Mean| /Mean	Within Range
CASE HE210	20.01	20	19.99	19.99	20.01	0.11%	20.10	0.48%	no
CASE HE220	18.75	18.53	18.54	18.53	18.75	1.18%	18.47	0.73%	yes
CASE HE230	15.48	15.17	15.88	15.17	15.88	4.56%	15.45	0.41%	yes

Table 6.5 – Comparison of the Mean Temperature for the Comparative Test Cases (^{o}C).

MAXIMUM ZONE TEMPERATURE **°C**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results Min	Max	(Max-Min) /Mean	Apache	|Ap-Mean| /Mean	Within Range
CASE HE210	21.45	20	20.06	20.00	21.45	7.00%	20.12	1.87%	yes
CASE HE220	22.7	20	20.11	20.00	22.70	12.65%	20.12	3.91%	yes
CASE HE230	20.14	20	20.06	20.00	20.14	0.70%	20.22	0.76%	no

Table 6.6 – Comparison of the Maximum Temperature for the Comparative Test Cases (^{o}C).

MINIMUM ZONE TEMPERATURE **°C**

Cases	ESP-r /HOT3000	EnergyPlus	DOE-2.1E	Statistics, All Results Min	Max	(Max-Min) /Mean	Apache	|Ap-Mean| /Mean	Within Range
CASE HE210	20	20	19.89	19.89	20.00	0.56%	20.05	0.43%	yes
CASE HE220	15	15	14.94	14.94	15.00	0.37%	14.15	5.52%	no
CASE HE230	1.45	4.48	3.72	1.45	4.48	102.19%	1.30	59.45%	yes

Table 6.7 – Comparison of the Minimum Temperature for the Comparative Test Cases (^{o}C).