ANSI/ASHRAE Standard 140-2004 Building Thermal Envelope and Fabric Load Tests

DesignBuilder Version 1.2.0 (incorporating EnergyPlus version 1.3.0) - June 2006

1.0 Purpose

The ANSI/ASHRAE Standard 140-2004[1] specifies test procedures that can be applied to evaluate the range of applicability and capability of software designed to calculate the thermal performance of buildings and their environmental control systems. The tests are based on the principle of comparing the performance of one program against the performance of other programs and while the tests are not intended to evaluate all aspects of the software, they are designed to indicate any serious flaws or limitations. Interested readers are advised to refer to the standard itself for more information.

The tests as applied to DesignBuilder have three main objectives:

- To indicate the relative performance of DesignBuilder compared with various other state-of-the-art building energy computer programs.
- To compare the results from EnergyPlus (v 1.3.0) run from within DesignBuilder with the results taken from the GARD Analytics report[2] on EnergyPlus (v 1.3.0) run in standalone mode.
- To allow future versions of DesignBuilder to be compared with previous versions as part of the DesignBuilder Quality Assurance procedure.

2.0 Building Thermal Envelope and Fabric Load Test Cases

The thermal envelope and fabric load test cases are divided into three main groups. The first group is designed to test the software using a low mass configuration, the second using high mass and the third group tests both low and high mass configurations under free float conditions.

The following test cases were performed as specified in the standard:

- Base test case 600 (Section 5.2.1 of Standard)
- Basic tests (Section 5.2.2 of Standard)

  Low mass test cases 610-650.
  High mass test cases 900-960
  Free-float test cases 600FF, 650FF, 900FF and 950FF

Modelling requirements specific to DesignBuilder are detailed in Section 2.5.

2.1 Common Input Information

This section describes input data that is common to all test cases.

2.1.1 Window Properties

Property	**Value**
Extinction coefficient	0.0196/mm
Number of panes	2
Pane thickness	3.175 mm
Air-gap thickness	13 mm
Index of refraction	1.526
Normal direct-beam transmittance through one pane	0.86156
Thermal conductivity of glass	1.06 W/mK
Conductance of each glass pane	333 W/m^2K
Combined radiative and convective coefficient of air gap	6.297 W/m^2K
Exterior combined surface coefficient	21.00 W/m^2K
Interior combined surface coefficient	8.29 W/m^2K
U-value from interior air to ambient air	3.0 W/m^2K
Hemispherical infrared emittance of ordinary uncoated glass	0.9
Density of glass	2500 kg/m^3
Specific heat of glass	750 J/kgK
Interior shade devices	None
Double-pane shading coefficient at normal incidence	0.907
Double-pane solar heat gain coefficient at normal incidence	0.789

EnergyPlus uses the Windows 5 format for the specification of window properties and additional glass properties are required for the inside and outside surfaces. These additional properties have been obtained from the GARD Analytics report[2]:

Thermal Properties

Property	Value
Thickness	3.175 mm
Conductivity	1.060 W/mK

Solar Properties

Property	Value
Solar transmittance	0.86156
Outside solar reflectance	0.07846
Inside solar reflectance	0.07846

Visible Properties

Property	Value
Visible transmittance	0.91325
Outside visible reflectance	0.08200
Inside visible reflectance	0.08200

Infra-Red Properties

Property	Value
Infra-red transmittance	0.00000
Outside infra-red reflectance	0.84000
Inside infra-red reflectance	0.84000

2.1.2 Weather

The weather file used is the DRYCOLD.TMY file supplied with the ASHRAE Standard[1].

2.1.3 Infiltration

The infiltration rate used for all test cases considered is 0.5 a.c./hr unless otherwise stated.

2.1.4 Internally Generated Heat

Internal heat gains generated by lights, occupants, equipment, etc.are set at 200W. Heat gains have no latent content and have a 60% radiant fraction.

2.1.5 Mechanical System

The mechanical system for each test case for which heating or cooling is specified has the following properties unless otherwise stated:

- 100% convective air system
- Thermostat senses air temperature only
- No latent load
- Thermostat is non-proportional
- Thermostat has dual setpoint with deadband, heating < 20C, cooling > 27C

2.1.6 Ground Temperature

The soil temperature is a constant 10C.

2.2 Low Mass Test Cases

The low mass test case constructions are detailed below:

Low Mass Wall Construction (inside to outside)

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Plasterboard	0.160	0.012	13.333	0.075	950.000	840.000
Fibreglass Quilt	0.040	0.066	0.606	1.650	12.000	840.000
Wood Siding	0.140	0.009	15.556	0.064	530.000	900.000
Ext.Surface Coeff.			29.300	0.034		
Total air-air			0.514	1.944		
Total surf-surf			0.559	1.789		

Low Mass Floor Construction (inside to outside)

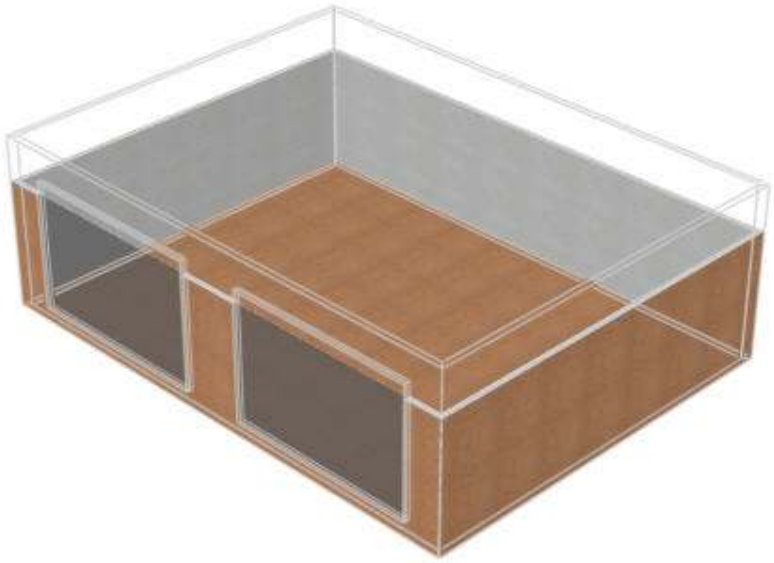
Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Timber Flooring	0.140	0.025	5.600	0.179	650.000	1200.000
Insulation	0.040	1.003	0.040	25.075	12.000	840.000
Total air-air			0.039	25.374		
Total surf-surf			0.040	25.254		

Low Mass Roof Construction (inside to outside)

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Plasterboard	0.160	0.010	16.000	0.063	950.000	840.000
Fibreglass Quilt	0.040	0.1118	0.358	2.794	12.000	840.000
Roof Deck	0.140	0.019	7.368	0.136	530.000	900.000
Ext.Surface Coeff.			29.300	0.034		
Total air-air			0.318	3.147		
Total surf-surf			0.334	2.992		

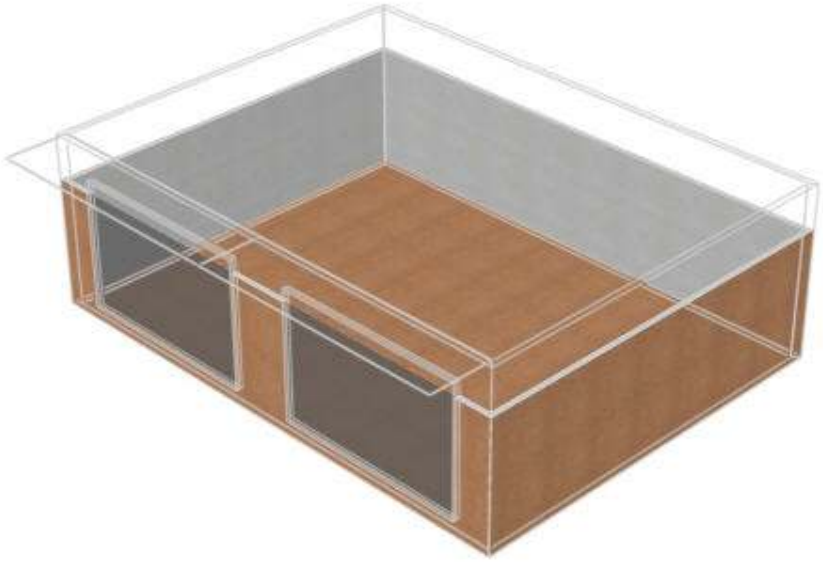
2.2.1 Low Mass Basic Test Case 600

Test case 600 comprises a single rectangular lightweight zone the dimensions of which are 8m x 6m x 2.7m. The zone is not partitioned and is fitted with two 6 m^2 windows in the south facing wall:



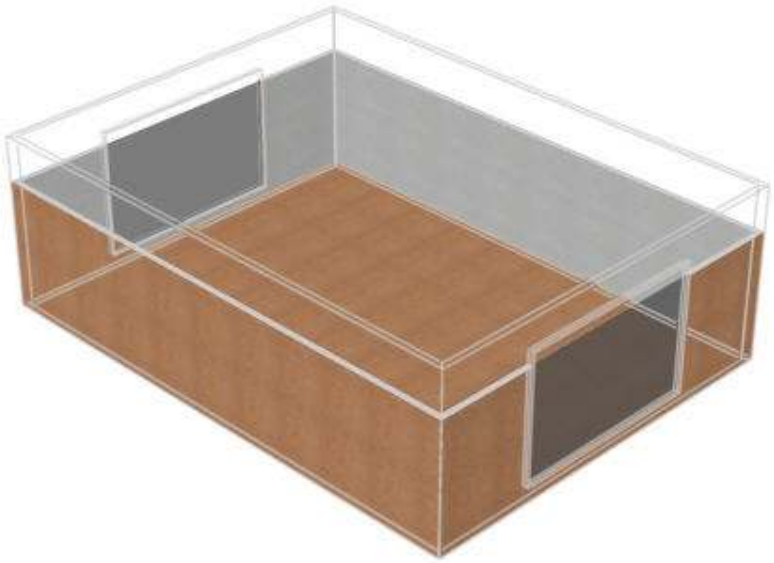
2.2.2 Low Mass with South Shading – Test Case 610

Test case 610 is the same as test case 600 with the addition of a 1m horizontal overhang that runs across the entire length of the south-facing wall at roof level:



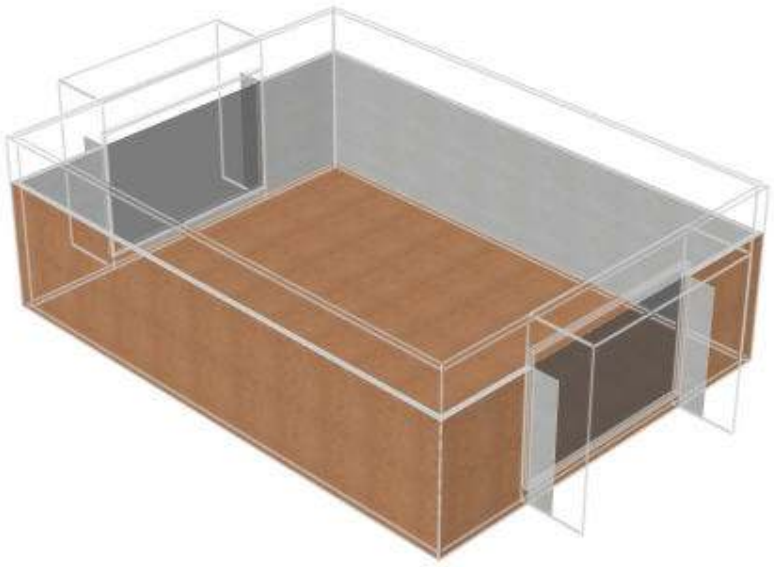
2.2.3 Low Mass with East-West Window Orientation – Test Case 620

Test case 620 is the same as test case 600 except that the south-facing windows are removed and 6m^2 of window area is added to the east and west facades:



2.2.4 Low Mass with East-West Shading – Test Case 630

Test case 630 is the same as test case 620 with the addition of shading overhangs and side fins around the east and west-facing windows. A 1m overhang is located at roof level and extends across the 3m width of each window. A 1m deep side fin is located at the side edges of each window running from the roof level down to the ground:



2.2.5 Low Mass with Thermostat Setback – Test Case 640

Test case 640 is the same as test case 600 except that the following setpoint schedule is used:

- 2300-0700 hours: heating ON if inside temperature < 10C
- 0700-2300 hours: heating ON if inside temperature < 20C
- 0000-2300 hours: cooling ON if inside temperature > 27C
- Otherwise heating and cooling is OFF

2.2.6 Low Mass with Night Ventilation – Test Case 650

Test case 650 is the same as test case 600 except that the following nighttime ventilation schedule and heating/cooling setpoint schedules are used:

- 1800-0700 hours: ventilation fan is ON
- 0700-1800 hours: ventilation fan is OFF
- 0000-2300 hours: heating is OFF
- 0070-1800 hours: cooling ON if inside temperature > 27C, otherwise cooling is OFF
- 1800-0700 cooling is OFF

The ventilation fan capacity is 13.14 ac/hr and there is no heat exchange from the fan to the supply air.

2.3 High Mass Test Cases

The high mass test case constructions are detailed below:

High Mass Wall Construction (inside to outside)

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Concrete Block	0.510	0.1000	5.100	0.196	1400.00	1000.00
Foam Insulation	0.040	0.0615	0.651	1.537	10.00	1400.00
Wood Siding	0.140	0.0090	15.556	0.064	530.00	900.00
Ext.Surface Coeff.			29.300	0.034		
Total air-air			0.512	1.952		
Total surf-surf			0.556	1.797		

High Mass Floor Construction (inside to outside)

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Concrete Slab	1.130	0.080	14.125	0.071	1400.00	1000.00
Insulation	0.040	1.007	0.040	25.175		
Total air-air			0.039	25.366		
Total surf-surf			0.040	25.246		

High Mass Roof Construction (inside to outside)

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Int.Surface Coeff.			8.290	0.121		
Plasterboard	0.160	0.010	16.000	0.063	950.000	840.000
Fibreglass Quilt	0.040	0.1118	0.358	2.794	12.000	840.000
Roof Deck	0.140	0.019	7.368	0.136	530.000	900.000
Ext.Surface Coeff.			29.300	0.034		
Total air-air			0.318	3.147		
Total surf-surf			0.334	2.992		

2.3.1 High Mass Basic Test Case 900

The basic high mass test case uses the same building model as the low mass basic test case 600 except the construction of the walls and floor are modified to incorporate the higher mass materials.

2.3.2 High Mass with South Shading – Test Case 910

Test case 910 is the same as the low mass test case 610 except for the high mass construction specified for the walls and floor.

2.3.3 High Mass with East-West Window Orientation – Test Case 920

Test case 920 is the same as the low mass test case 620 except for the high mass construction specified for the walls and floor.

2.3.4 High Mass with East-West Shading – Test Case 930

Test case 930 is the same as the low mass test case 630 except for the high mass construction specified for the walls and floor.

2.3.5 High Mass with Thermostat Setback – Test Case 940

Test case 940 is the same as the low mass test case 640 except for the high mass construction specified for the walls and floor.

2.3.6 High Mass with Night Ventilation – Test Case 950

Test case 950 is the same as the low mass test case 650 except for the high mass construction specified for the walls and floor.

2.3.7 Sunspace – Test Case 960

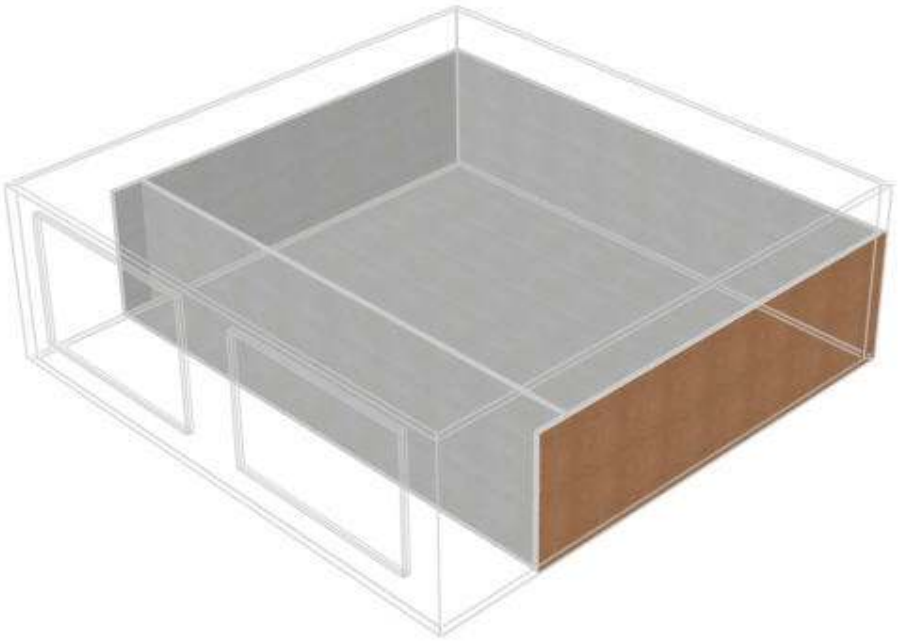
Test case 960 comprises two rectangular zones separated by a common wall. The northern zone is of lightweight construction and the southern zone of heavyweight construction.

Common Wall Construction

Element	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/kgK)
Common Wall	0.510	0.200	2.55	0.392	1400	1000

The north zone has the same dimensions and construction as the building model used for test case 600 except that the south-facing wall with windows is replaced with a partition wall adjacent to the south zone. Infiltration to the north zone is 0.5 ac/hr and the internal heat gain is 200 W as specified in Section 2.1.4. Control of heating and cooling is the same as that specified for test case 600.

The south zone is 2m x 8m x 2.7m. The north wall of the south zone is the common wall and the south wall has two $6m^2$ windows that are the same as the windows specified for test case 900 except that the lower edges of the windows are located 0.5m from the ground. Infiltration to the south zone is 0.5 ac/hr. The south zone has no heating or cooling.



2.4 Free Float Test Cases

There are four free float test cases incorporating both lightweight and heavyweight constructions.

2.4.1 Low Mass with Free Floating Temperature – Test Case 600FF

Test case 600FF is the same as test case 600 except that there is no mechanical heating or cooling.

2.4.2 Low Mass with Night Ventilation and Free Floating Temperature – Test Case 650FF

Test case 650FF is the same as test case 650 except that there is no mechanical heating or cooling.

2.4.3 High Mass with Free Floating Temperature – Test Case 900FF

Test case 900FF is the same as test case 900 except that there is no mechanical heating or cooling.

2.4.4 High Mass with Night Ventilation and Free Floating Temperature – Test Case 950FF

Test case 950FF is the same as test case 950 except that there is no mechanical heating or cooling.

2.5 Modelling Notes

Model geometry is defined in DesignBuilder by drawing the external dimensions of a building rather than the internal dimensions of the contained zones and this is accounted for in the specification of the test case geometry. Also, due to the fact that different programs have different input requirements there are some items of data provided by the standard that are not required by DesignBuilder. This section details various modelling considerations that are specific to DesignBuilder in preparation of the test case input data. Some of the input data that is specific to EnergyPlus has been extracted from the GARD Analytics report[2].

2.5.1 Geometry

DesignBuilder geometry is based on the concept of blocks. A building block represents the outer shell of the model or part of the model and comprises a set of building elements, which includes external walls, roof, and floor slab. A vertically extruded block is created in DesignBuilder by drawing the external perimeter of the outer wall. The resulting internal zone perimeter is the same as the external block perimeter but shrunk by the defined thickness of the external wall. The user-defined block wall thickness only affects the resulting zone dimensions and has no effect on the thermal properties of the walls. The resulting zone upper and lower surfaces correspond identically with the upper and lower block surfaces.

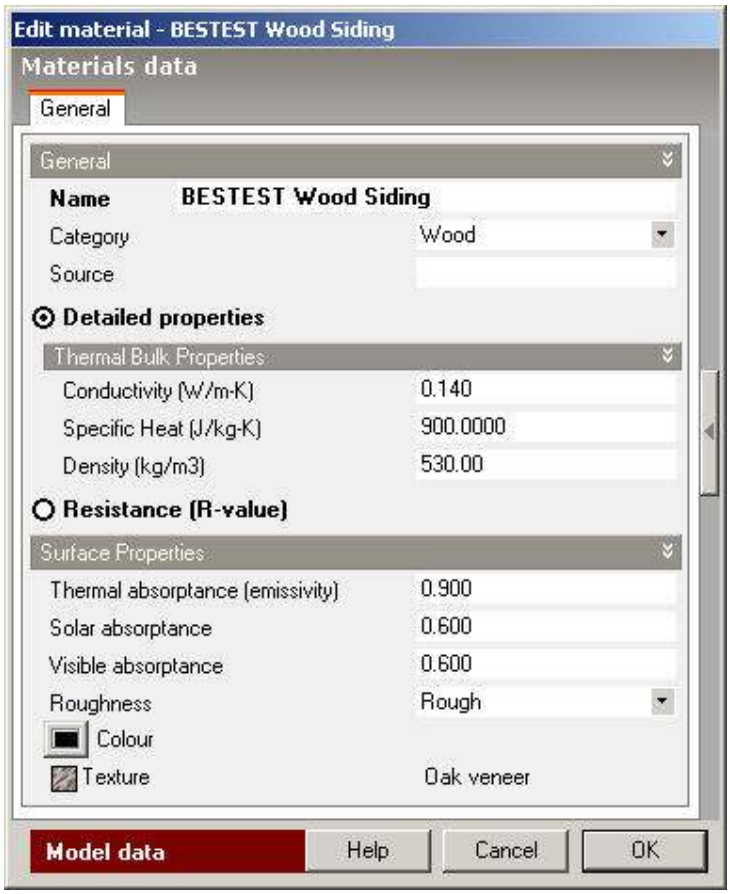
For simplicity, in order to arrive at the correct zone geometry for the tests, the wall thickness was set at 0.1m and 0.2m added on to the specified plan zone dimensions. For example, the base test case 600 has the specified dimensions of 8m x 6m x 2.7m and in DesignBuilder the block dimensions are 8.2m x 6.2m x 2.7m.

2.5.2 Material Specification

Materials for walls floors and roofs were specified using the ‘Detailed’ material description except for floor insulation, which was defined through specification of ground materials using the ‘Resistance’ option.

Both low and high mass test cases incorporate floor constructions that include a thick layer of insulation to effectively decouple the floor from the ground. The ASHRAE standard[1] incorporates this specification in recognition of the fact that the state-of-the-art in ground modelling is not good.

Ground thermal properties are always included with ground floor constructions in DesignBuilder and are specified as a separate construction. In order to arrive at the floor specifications provided by the standard, the ground construction materials were defined to have the same thermal properties as the insulating layers and then the floor constructions were defined excluding these layers.



2.5.3 HVAC System

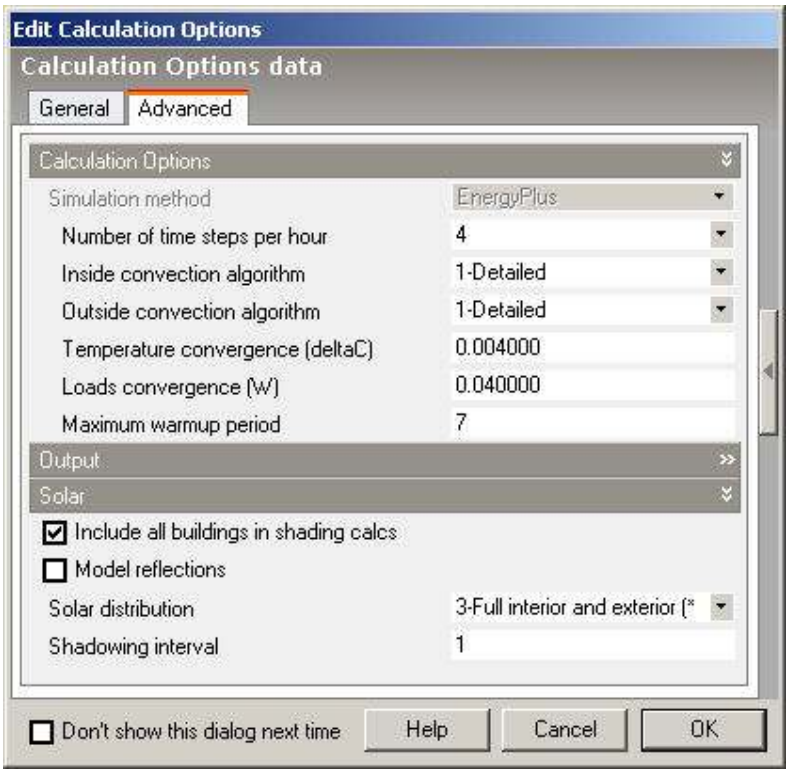
The 'Simple' HVAC system option was selected from the DesignBuilder 'Model Options' which uses the 100% convective PURCHASED AIR system in EnergyPlus. At the Zone level, the plant capacities were set to 1000kW for both heating and cooling to simulate infinite capacity. System efficiencies (COP) for both heating and cooling were set to 1.0.

2.5.4 Surface heat transfer coefficients

EnergyPlus automatically calculates surface heat transfer coefficients. The ASHRAE standard[1] specifies that where a program automatically calculates these coefficients, then they should be derived by the program rather than taken from the standard.

2.5.5 Calculation Options

This section details specifications for the simulation.



a) Convergence

The convergence variables were set as follows:

- Loads Convergence=0.0040
- Temperature Convergence=0.040

b) Solar Distribution

In order to calculate the correct solar distribution for the window overhang test cases, the solar distribution option was set to 'Full interior and exterior'.

c) Time Steps

The number of time steps per hour was set to 4.

d) Convection Algorithms

The inside and outside convection algorithms were set to 'Detailed'.

2.5.6 Weather

The weather file to be used for all test case simulations is provided with the ASHRAE standard[1] in the form of a TMY format file. This file was first translated to the EnergyPlus EPW format using the conversion utility incorporated within DesignBuilder.

3.0 Results and Discussion

The test results are presented in Appendix I as tables and in Appendix II in the form of charts. Details of the programs for which results are provided with the ASHRAE standard[1] are given in the table below.

Program	Developer	Implemented by
BLAST-3.0 level 193 v1	CERL, U.S.	NREL, U.S. Politecnico, Torino, Italy
DOE2.ID 14	LANL/LBL, U.S.	NREL, U.S.
ESP-RV8	Strathclyde University, U.K.	De Montfort University, U.K.
SERIRES/SUNCODE 5.7	NREL/Ecotope, U.S.	NREL, U.S.
SERIRES 1.2	NREL, U.S. BRE, U.K.	BRE, U.K.
S3PAS	University of Sevilla, Spain	University of Sevilla, Spain
TASE	Tampere University, Finland	Tampere University, Finland
TRNSYS 13.1	LANL/LBL U.S.	GARD Analytics, U.S. using NREL input files

Test results for EnergyPlus have been extracted from the report provided by GARD Analytics[2]. EnergyPlus has been developed by the U.S. Department of Energy.

One of the main purposes of the tests as applied to DesignBuilder was to check the results from DesignBuilder against the results from EnergyPlus run in standalone mode. For all 67 comparisons comprising annual heating and cooling, peak heating and cooling and free float temperatures, the results from EnergyPlus (standalone) and DesignBuilder are identical.

The charts in Appendix II display comparative results for annual heating, annual cooling, peak heating and peak cooling. For the 52 individual comparisons performed, all results for EnergyPlus (standalone) and DesignBuilder are within the range of results from other programs with the following exceptions:

Test	**Output**	**Range from Other Programs**	**EnergyPlus/ DesignBuilder**
630	Annual Heating	5.05 to 6.47	4.95
640	Peak Heating	5.23 to 5.91	7.34
910	Annual Heating	1.58 to 2.82	1.52
920	Annual Heating	3.31 to 4.25	3.20
930	Annual Heating	4.14 to 5.34	4.05

For the free floating test cases shown in Appendix III, where an additional 15 comparisons were made, all results for EnergyPlus (standalone) and DesignBuilder are again within the range of results from other programs with the following exceptions:

Test	Output	Range from Other Programs	EnergyPlus/ DesignBuilder
600FF	Maximum Zone Temperature	64.9 to 69.5	64.6
650FF	Maximum Zone Temperature	63.2 to 68.2	62.8
650FF	Minimum Zone Temperature	-23.0 to-21.0	-23.1
950FF	Minimum Zone Temperature	-20.2 to -17.8	-20.4
960FF	Maximum Zone Temperature	48.9 to 51.0	51.7

The charts in Appendix IV display comparative sensitivity of the various programs to changes in building specification including increased mass, different window orientation, windows with and without shading, etc. Sensitivity comparisons indicate a significant difference between EnergyPlus/DesignBuilder results and the other program results for the test cases indicated in the table below.

Test	Output	Range from Other Programs	EnergyPlus/ DesignBuilder
640-600	Peak Heating	1.55 to 2.60	3.5
650-600	Annual Cooling	-1.42 to –1.24	-1.65
920-900	Annual Cooling	-0.356-0.018	0.086

GARD Analytics[2] has indicated that further testing will be conducted on EnergyPlus to determine the reasons for the difference in results for all test cases showing a departure from the range of other program results.

4.0 Conclusion

DesignBuilder Version 1.2.0 was used to simulate a number of building test cases specified within the ANSI/ASHRAE Standard 140-2004 'Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs'. The test cases incorporated both low and high mass constructions, windows of differing orientations, windows with and without external shading, heating with and without night setback, cooling with and without night ventilation and free floating temperature conditions. Annual and peak heating and cooling energy requirements were predicted for thirteen different test cases using DesignBuilder and the results were compared with the results for EnergyPlus Version 1.3.0 run in standalone mode together with results from eight other building energy simulation programs. The maxim, minimum and average free-floating temperatures were also compared for four additional test cases. All results for DesignBuilder were found to be identical to the results extracted from the GARD Analytics report[2] for EnergyPlus run in standalone mode. For further information regarding the standalone EnergyPlus tests, interested readers are advised to refer to the GARD Analytics report[2].

5.0 References

1 ANSI/ASHRAE 2004. Standard 140-2004, Standard Method of Test for the evaluation of Building Energy Analysis Computer Programs.

2. EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2004 – GARD Analytics, February 2006

Appendix I

Comparison Tables

Low Mass Heating and Cooling

Test Case	600	610	620	630	640	650
Annual Heating (MWh)						
Minimum	4.298	4.355	4.613	5.050	2.751	0.000
Maximum	5.709	5.786	5.944	6.469	3.803	0.000
Average	5.08	5.140	5.410	5.810	3.217	0.000
EnergyPlus	4.498	4.530	4.651	4.951	2.914	0.000
DesignBuilder	4.498	4.530	4.651	4.951	2.914	0.000
Difference, %	-11.5%	-11.9%	-14.0%	-14.8%	-9.4%	0.000%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	NO	YES	YES
Annual Cooling (MWh)						
Minimum	6.137	3.915	3.417	2.129	5.952	4.816
Maximum	7.964	5.778	5.004	3.701	7.811	6.545
Average	6.900	4.935	4.250	2.901	6.663	5.546
EnergyPlus	6.918	4.900	4.351	2.933	6.619	5.395
DesignBuilder	6.918	4.900	4.351	2.933	6.619	5.395
Difference, %	0.26%	-0.71%	2.38%	1.1%	-0.07%	-2.7%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	YES	YES
Peak Heating (kW)						
Minimum	3.437	3.437	3.591	3.592	5.232	0.000
Maximum	4.258	4.258	4.277	4.280	6.530	0.000
Average	3.943	3.941	4.026	4.023	5.908	0.000
EnergyPlus	3.834	3.821	3.831	3.805	7.312	0.000
DesignBuilder	3.834	3.821	3.831	3.805	7.312	0.000
Difference, %	-2.76%	-3.04%	-4.8%	-5.42%	23.8%	0.000%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	NO	YES
Peak Cooling (kW)						
Minimum	5.965	5.669	3.634	3.072	5.892	5.831
Maximum	6.827	6.371	4.593	4.116	6.776	6.671
Average	6.386	6.020	4.206	3.629	6.331	6.238
EnergyPlus	6.629	6.271	4.008	3.459	6.561	6.417
DesignBuilder	6.629	6.271	4.008	3.459	6.561	6.417
Difference, %	3.80%	4.17%	-4.7%	-4.68%	3.63%	2.87%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	YES	YES

High Mass Heating and Cooling

Test Case	900	910	920	930	940	960	950
Annual Heating (MWh)							
Minimum	1.170	1.575	3.313	4.143	0.793	2.311	0.000
Maximum	1.988	2.282	4.300	5.335	1.411	2.943	0.000
Average	1.711	2.030	4.255	3.951	1.146	2.763	0.000
EnergyPlus	1.245	1.519	3.204	3.901	0.818	2.343	0.000
DesignBuilder	1.245	1.519	3.204	3.901	0.818	2.343	0.000
Difference, %	-27.2%	-25.2%	-24.7%	-1.21%	-28.6%	-15.2%	0.000
EnergyPlus/DesignBuilder within Range	YES	NO	NO	NO	YES	YES	YES
Annual Cooling (MWh)							
Minimum	2.132	0.821	1.840	1.039	2.079	0.411	0.387
Maximum	3.415	1.872	3.092	2.238	3.241	0.803	0.921
Average	2.723	1.414	2.565	1.681	2.620	0.624	0.585
EnergyPlus	2.578	1.278	2.639	1.719	2.498	0.693	0.544
DesignBuilder	2.578	1.278	2.639	1.719	2.498	0.693	0.544
Difference, %	-5.3%	-9.62%	2.88%	2.26%	-4.6%	11.1%	-7.0%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	YES	YES	YES
Peak Heating (kW)							
Minimum	2.850	2.858	3.308	3.355	3.980	2.410	0.000
Maximum	3.760	3.764	4.029	4.064	6.117	2.863	0.000
Average	3,445	3.452	3.772	3.805	5.381	2.720	0.000
EnergyPlus	3.239	3.237	3.555	3.575	5.813	2.704	0.000
DesignBuilder	3.239	3.237	3.555	3.575	5.813	2.704	0.000
Difference, %	-6.0%	-6.2%	-5.7%	-6.0%	8.0%	-0.6%	0.000
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	YES	YES	YES
Peak Cooling (kW)							
Minimum	2.888	1.896	2.385	1.873	2.888	0.953	2.033
Maximum	3.871	3.277	3.487	3.080	3.871	1.370	3.170
Average	3.341	2.560	2.997	2.475	3.841	1.141	2.633
EnergyPlus	3.279	2.597	2.853	2.354	3.279	1.187	2.445
DesignBuilder	3.279	2.597	2.853	2.354	3.279	1.187	2.445
Difference, %	-1.85%	1.44%	-4.8%	-5.0%	-0.15%	4.03%	-7.1%
EnergyPlus/DesignBuilder within Range	YES	YES	YES	YES	YES	YES	YES

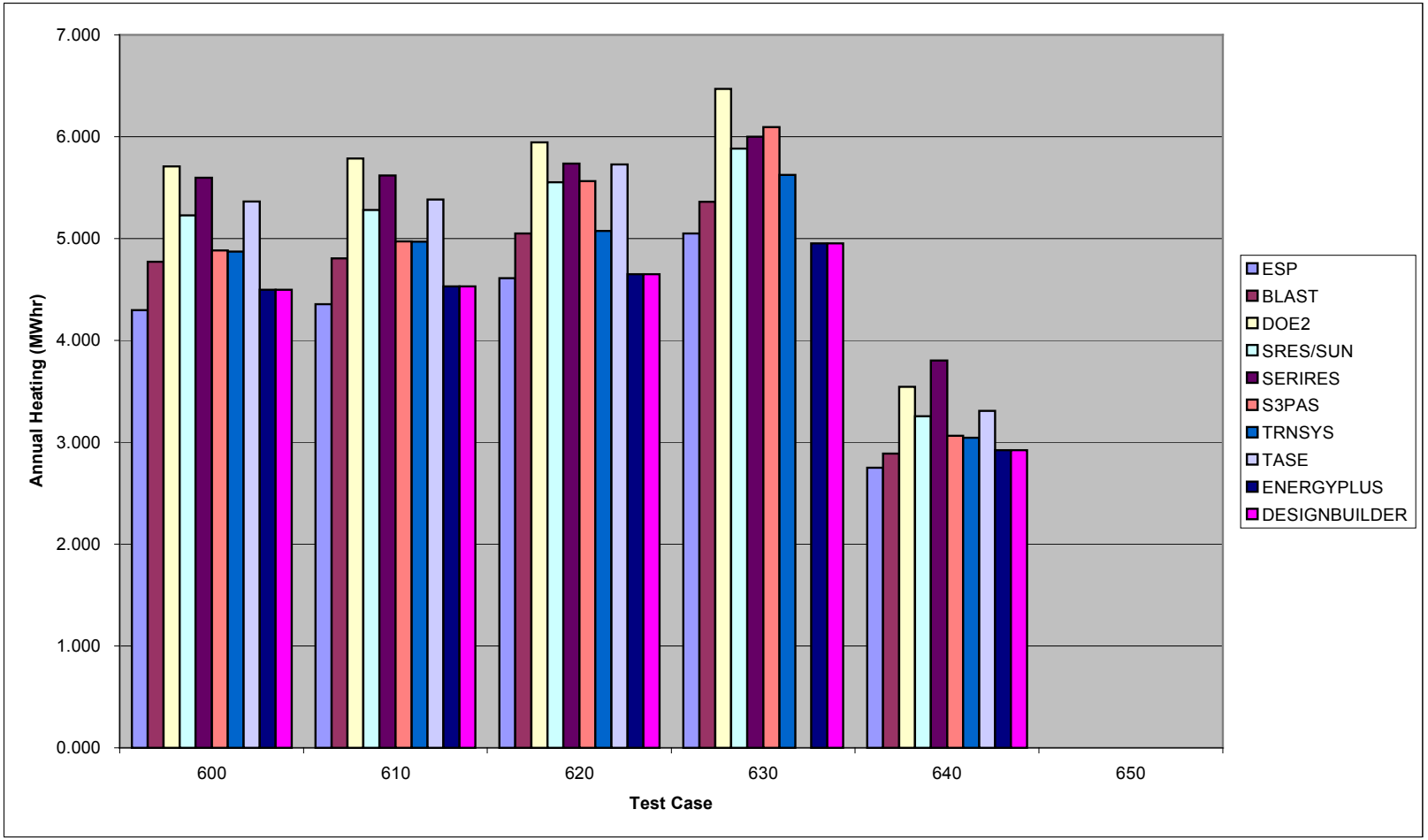
Free Floating Temperature

Test Case	600FF	900FF	650FF	950FF	960
Maximum Annual Hourly Temperature (C)					
Minimum	64.9	41.8	63.2	35.5	48.9
Maximum	69.5	44.8	68.2	38.5	51.0
Average	66.6	43.1	65.0	36.4	49.6
EnergyPlus	64.6	43.3	62.8	36.8	51.72
DesignBuilder	64.6	43.3	62.8	36.8	51.72
Difference, %	-3.0%	0.46%	-3.4%	2.8%	16.3%
EnergyPlus/DesignBuilder within Range	NO	YES	NO	YES	NO
Minimum Annual Hourly Temperature (C)					
Minimum	-18.8	-4.5	-23.0	-20.2	1.4
Maximum	-15.6	-1.6	-21.6	-18.6	3.9
Average	-17.4	-3.5	-22.6	-19.6	2.5
EnergyPlus	-17.7	-2.6	-23.1	-20.4	2.1
DesignBuilder	-17.7	-2.6	-23.1	-20.4	2.1
Difference, %	1.72%	-25.7%	2.21%	4.1%	-.16.0%
EnergyPlus/DesignBuilder within Range	YES	YES	NO	NO	YES
Average Annual Hourly Temperature (C)					
Minimum	24.6	24.6	18.2	14.1	27.5
Maximum	25.9	25.9	19.6	15.0	28.5
Average	25.3	25.4	18.8	14.3	28.1
EnergyPlus	25.8	26.1	18.5	14.5	28.8
DesignBuilder	25.8	26.1	18.5	14.5	28.8
Difference, %	1.98%	2.75%	-1.6%	1.4%	2.5%
EnergyPlus/DesignBuilder within Range	YES	NO	YES	YES	NO

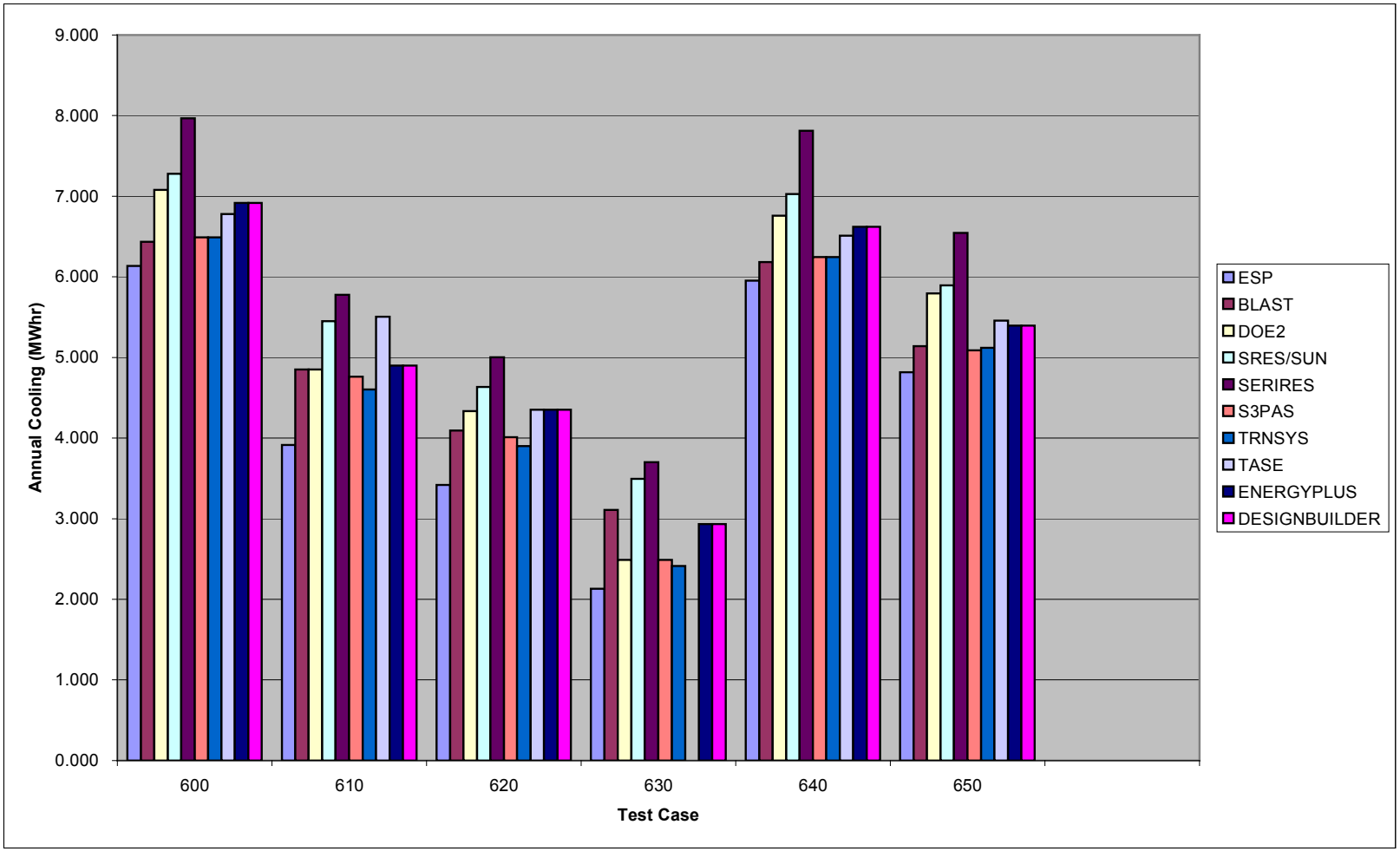
Appendix II

Heating and Cooling Comparison Charts

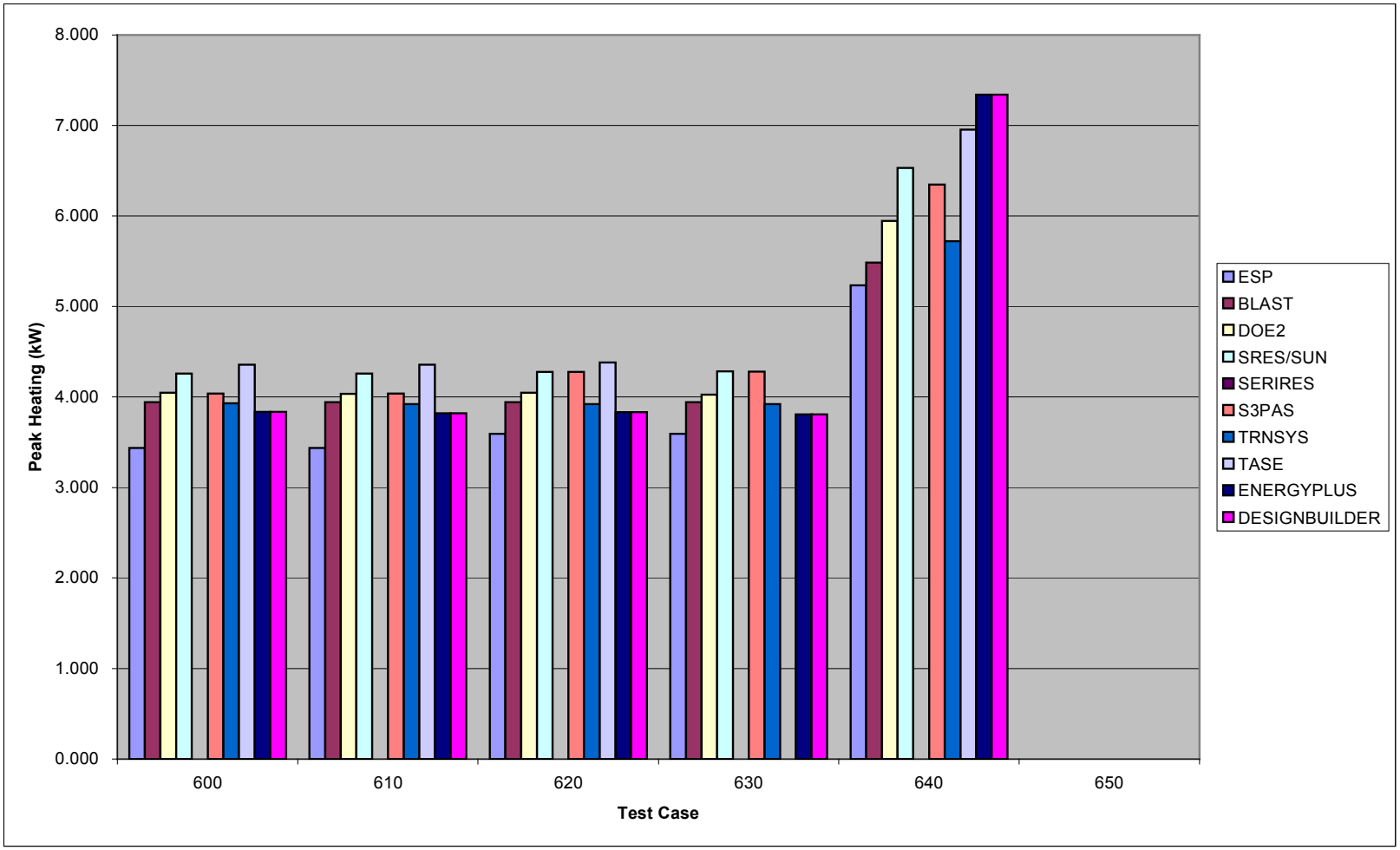
Low Mass Annual Heating



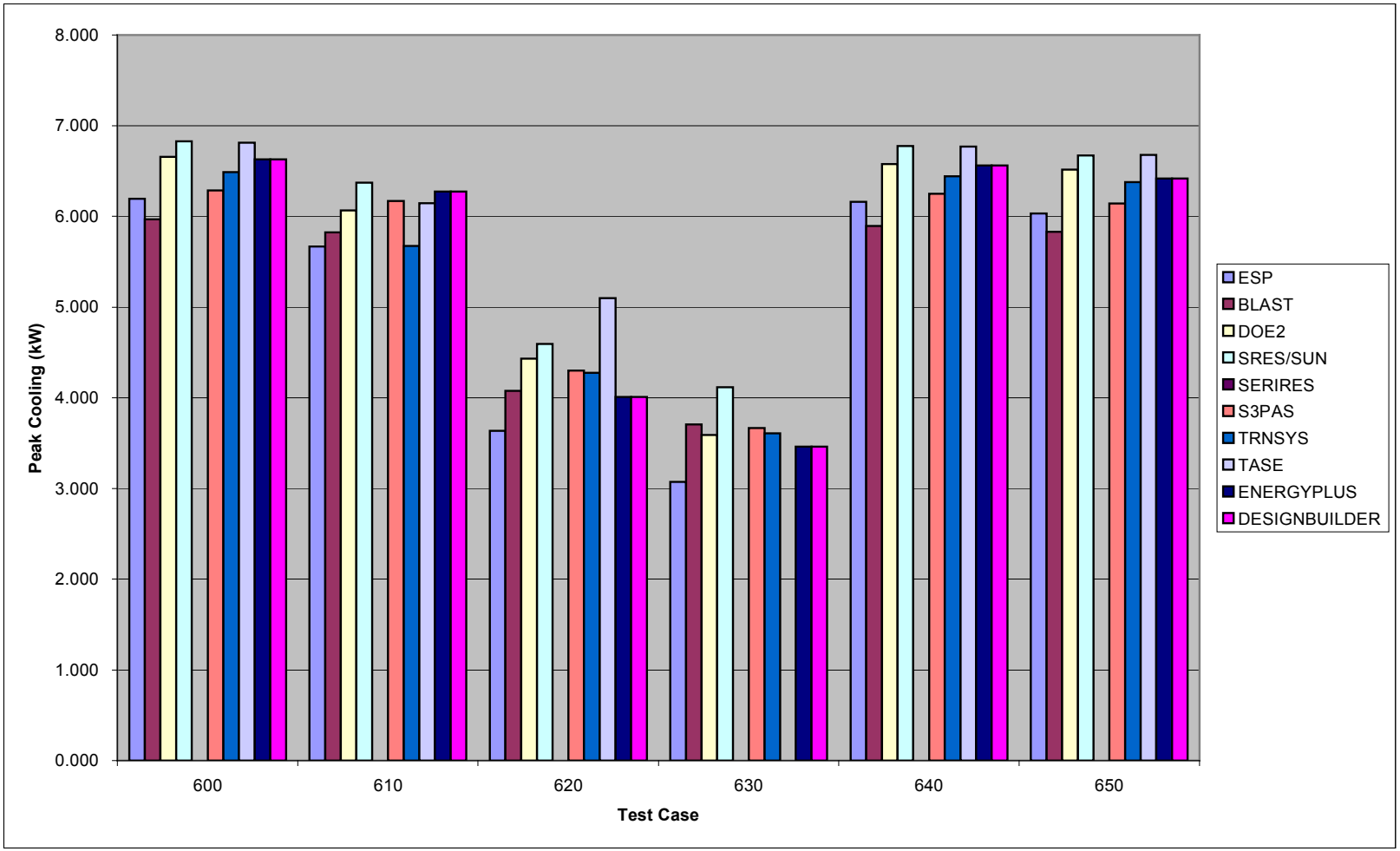
Low Mass Annual Cooling



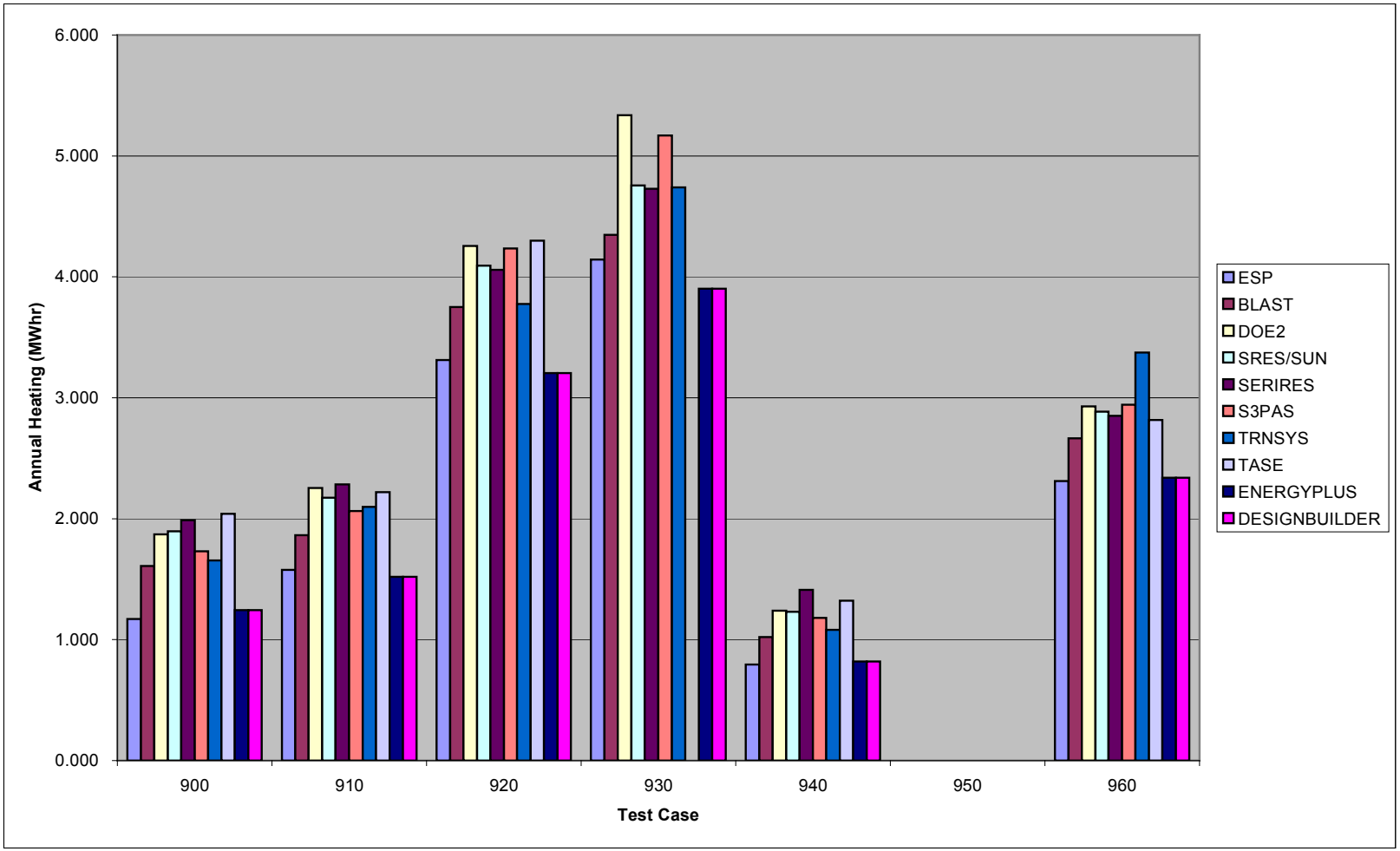
Low Mass Peak Heating



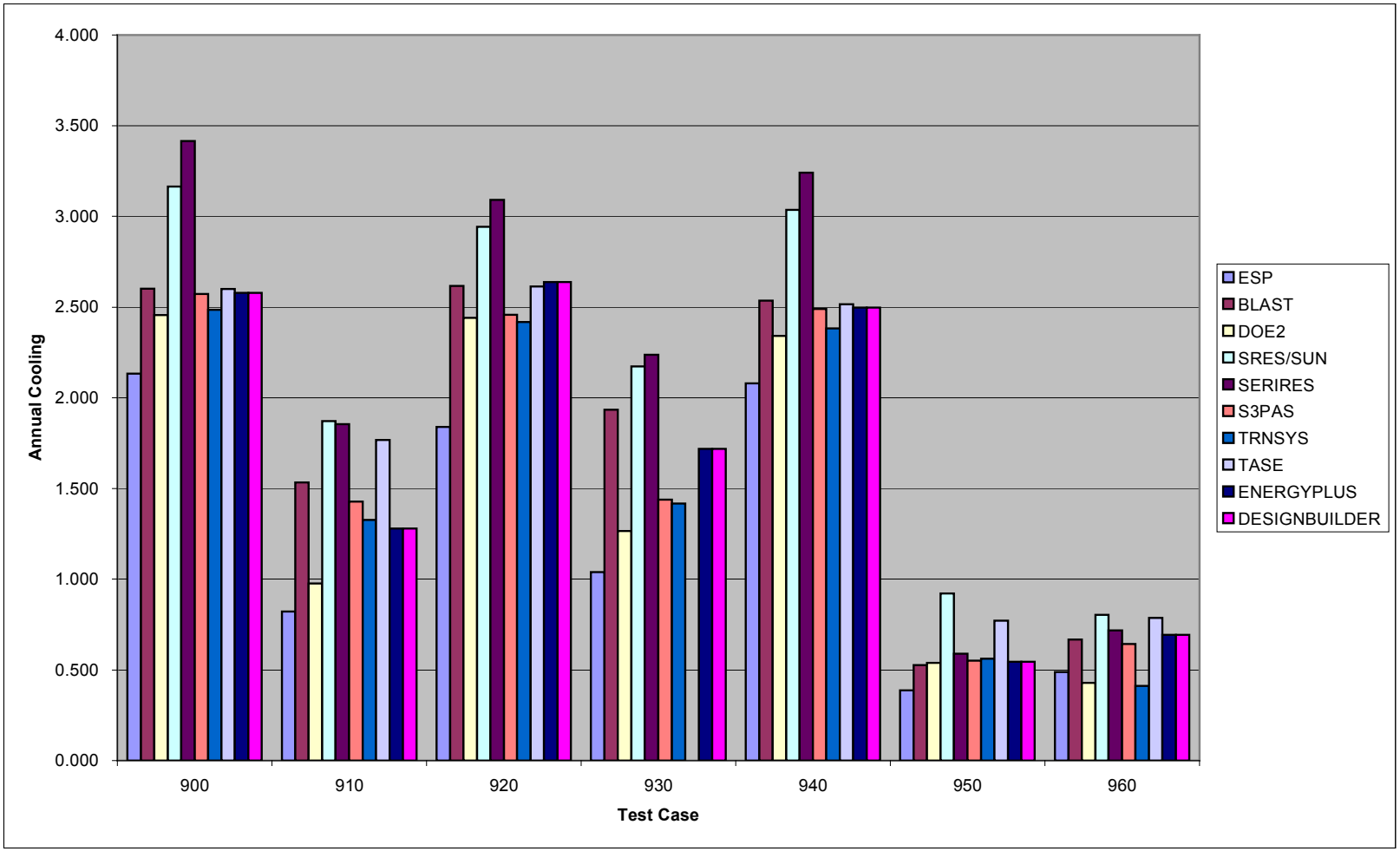
Low Mass Peak Cooling



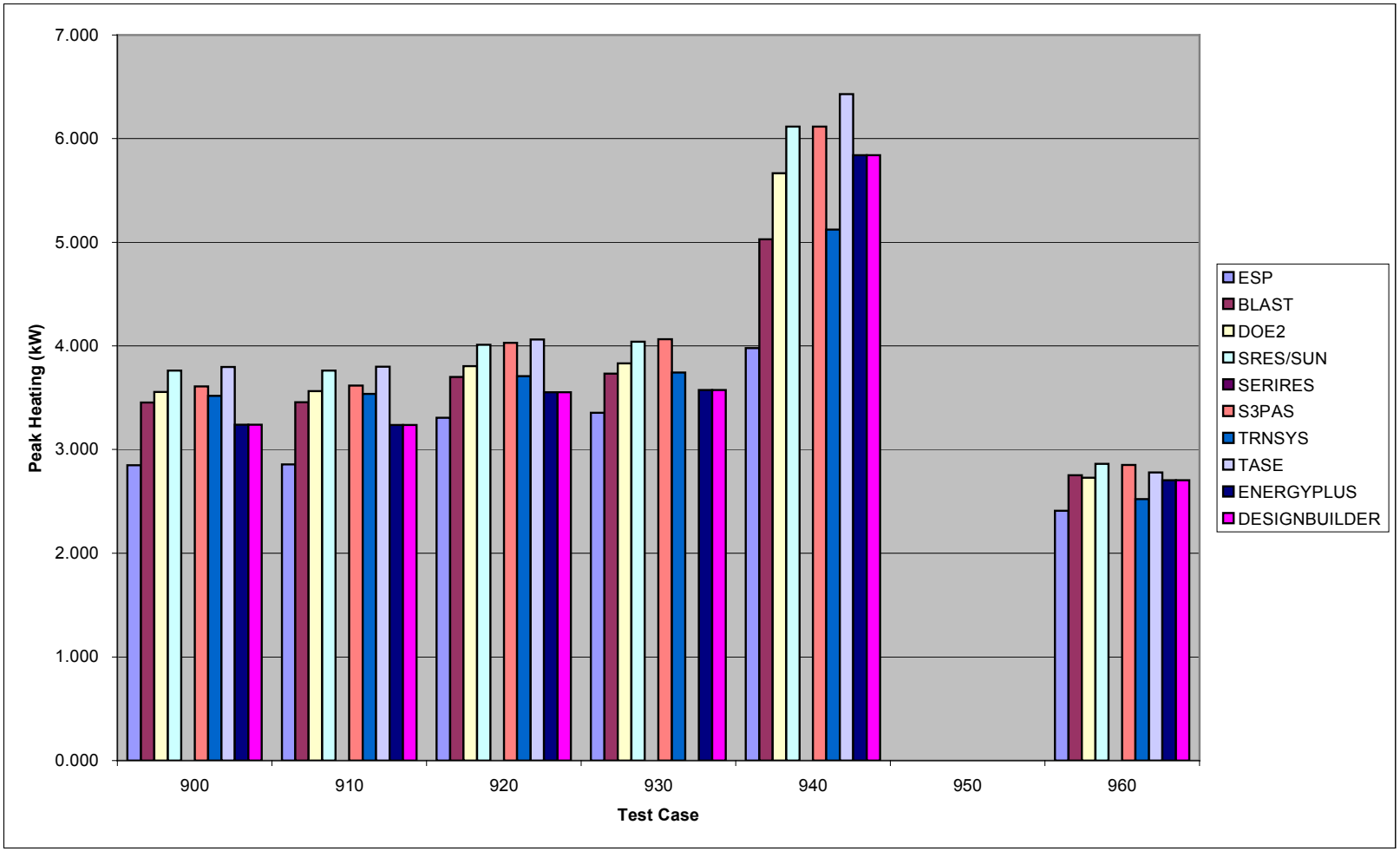
High Mass Annual Heating



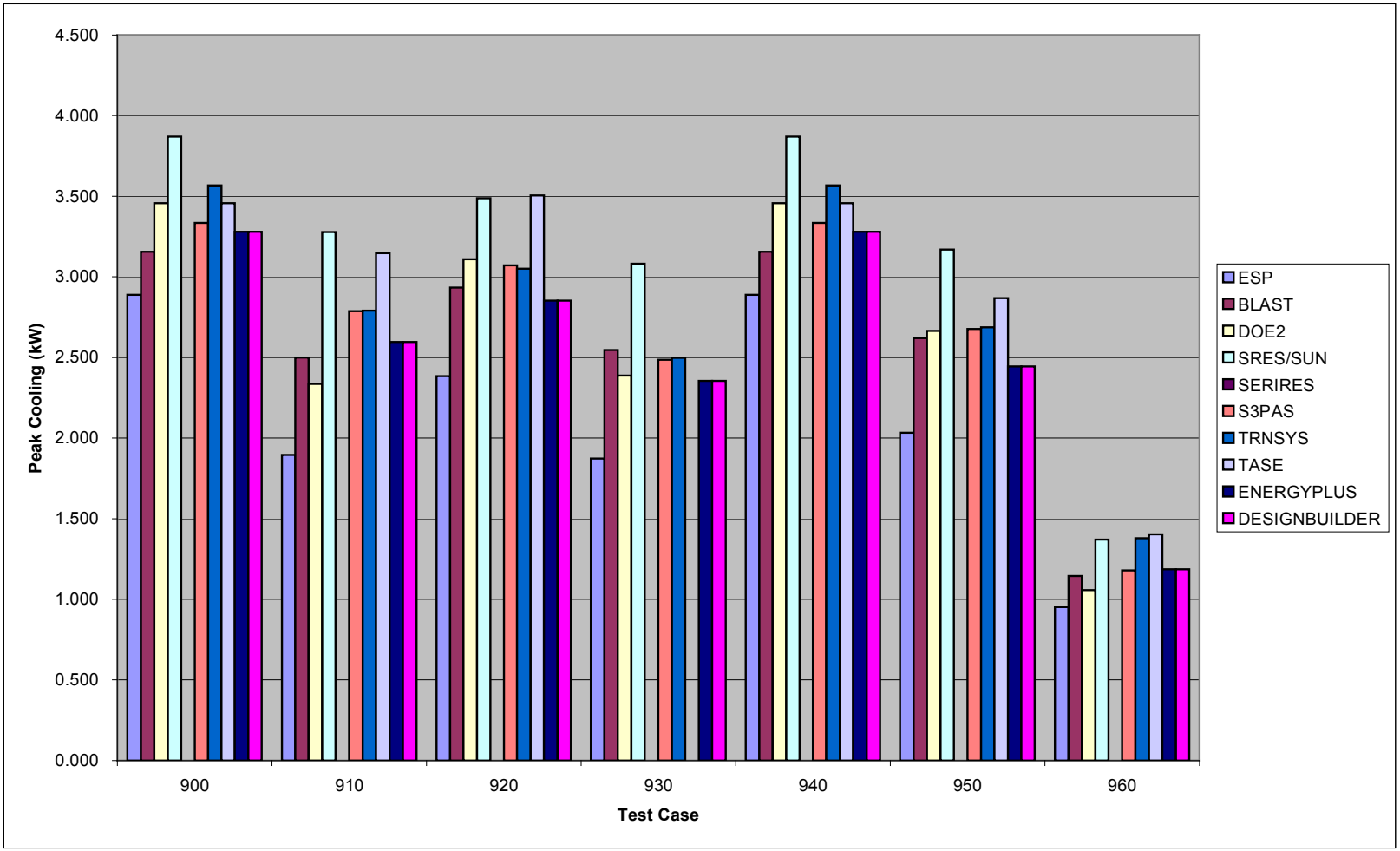
High Mass Annual Cooling



High Mass Peak Heating



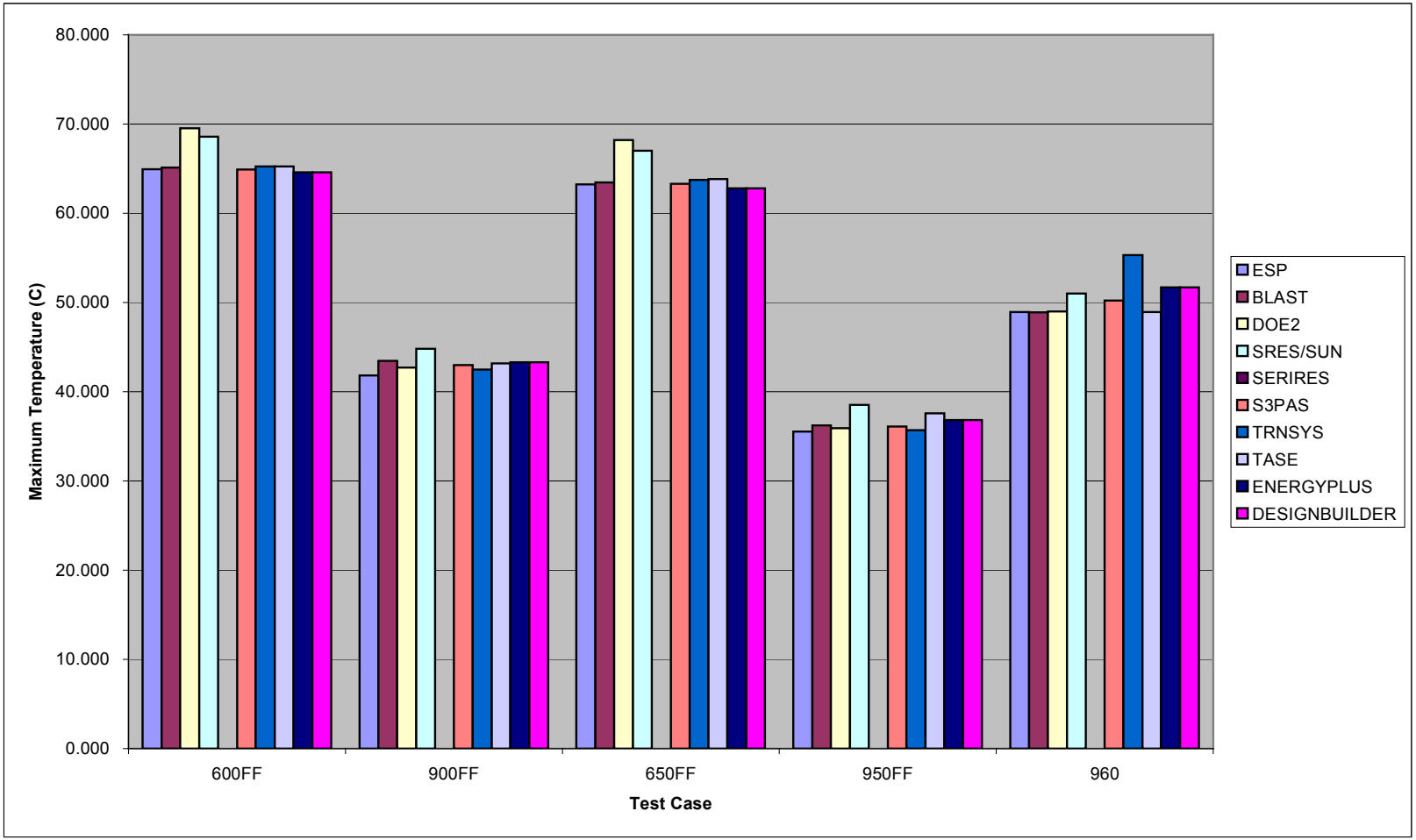
High Mass Peak Cooling



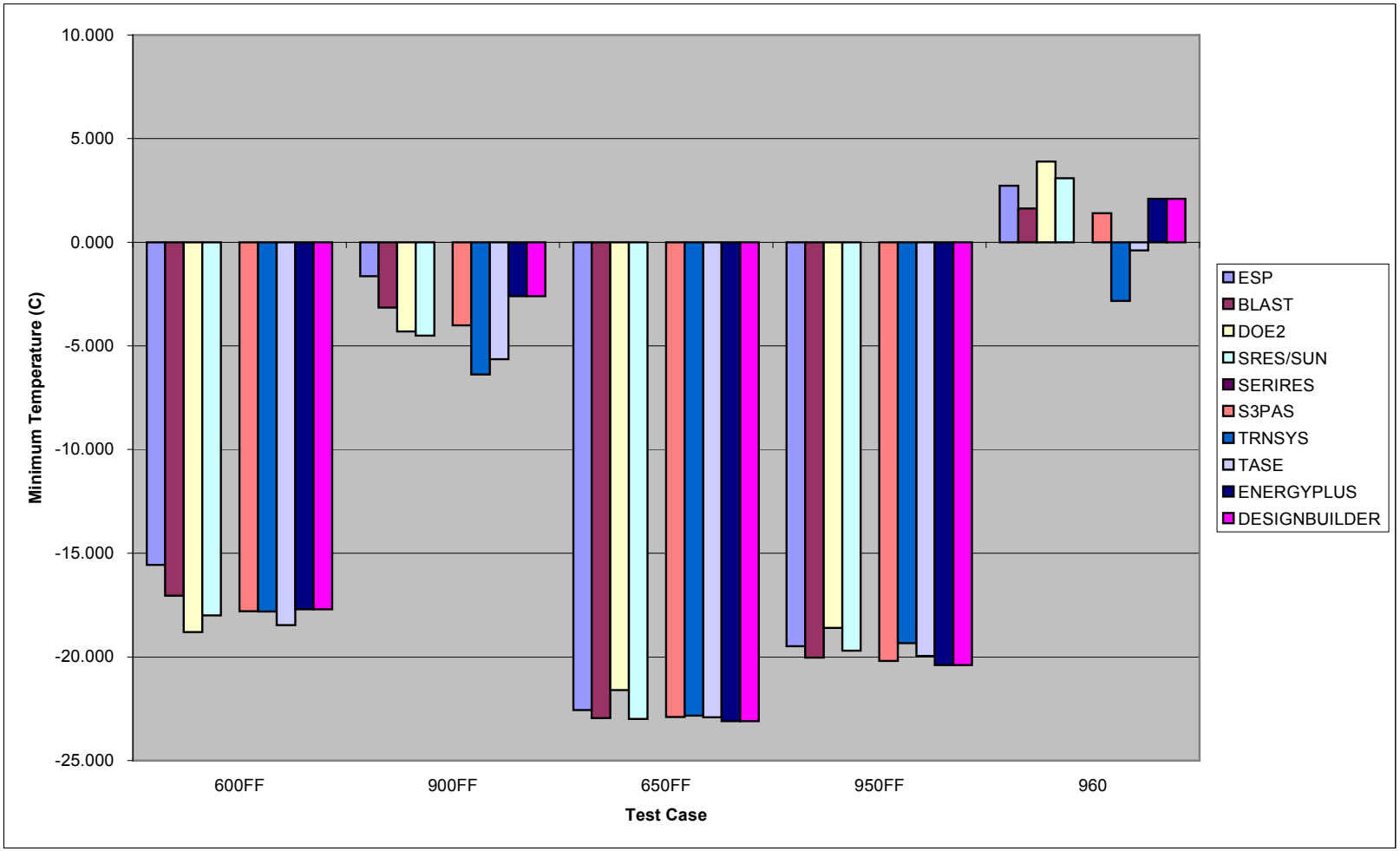
Appendix III

Free Floating Temperature Charts

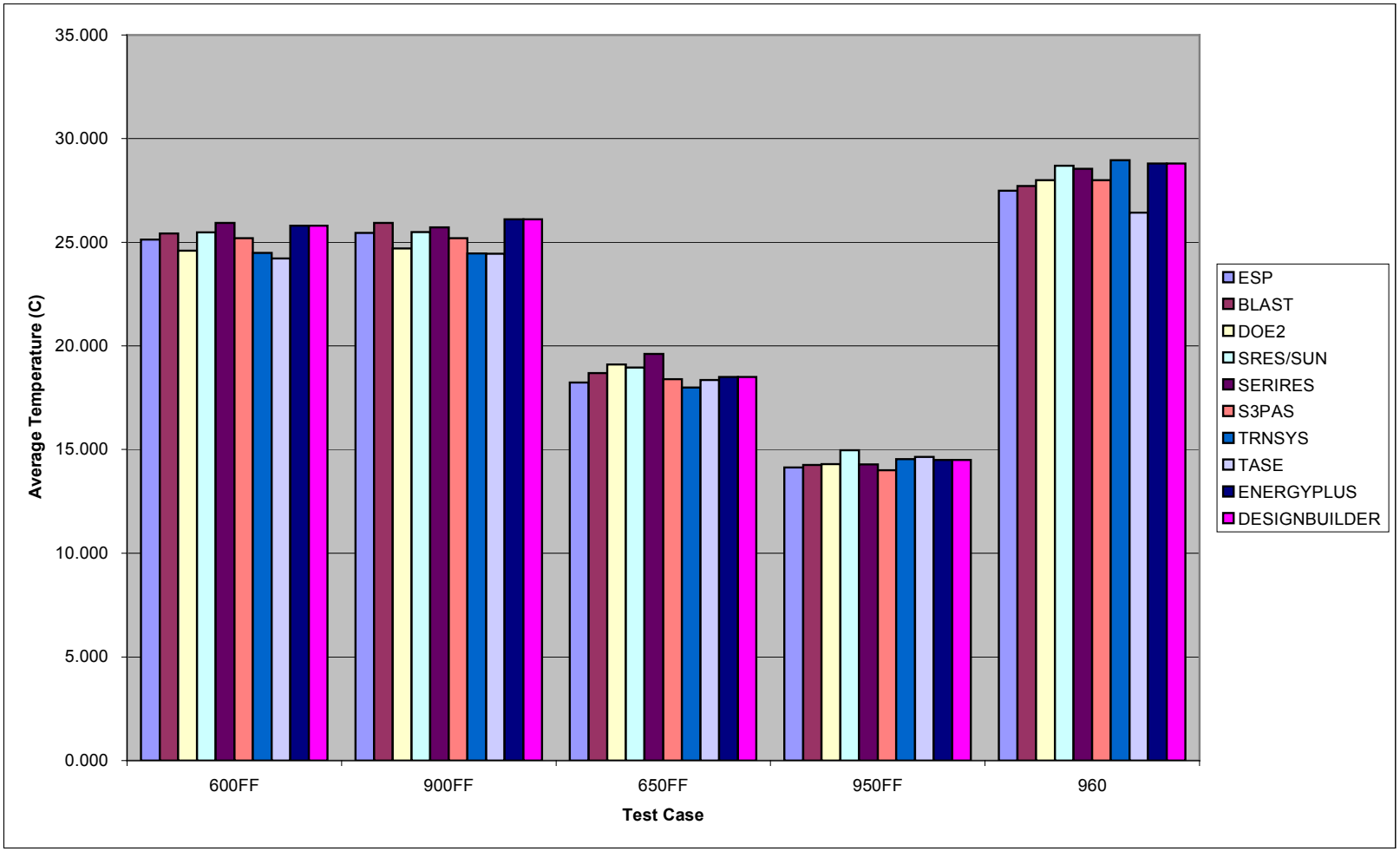
Maximum Free Floating Temperature



Minimum Free Floating Temperature



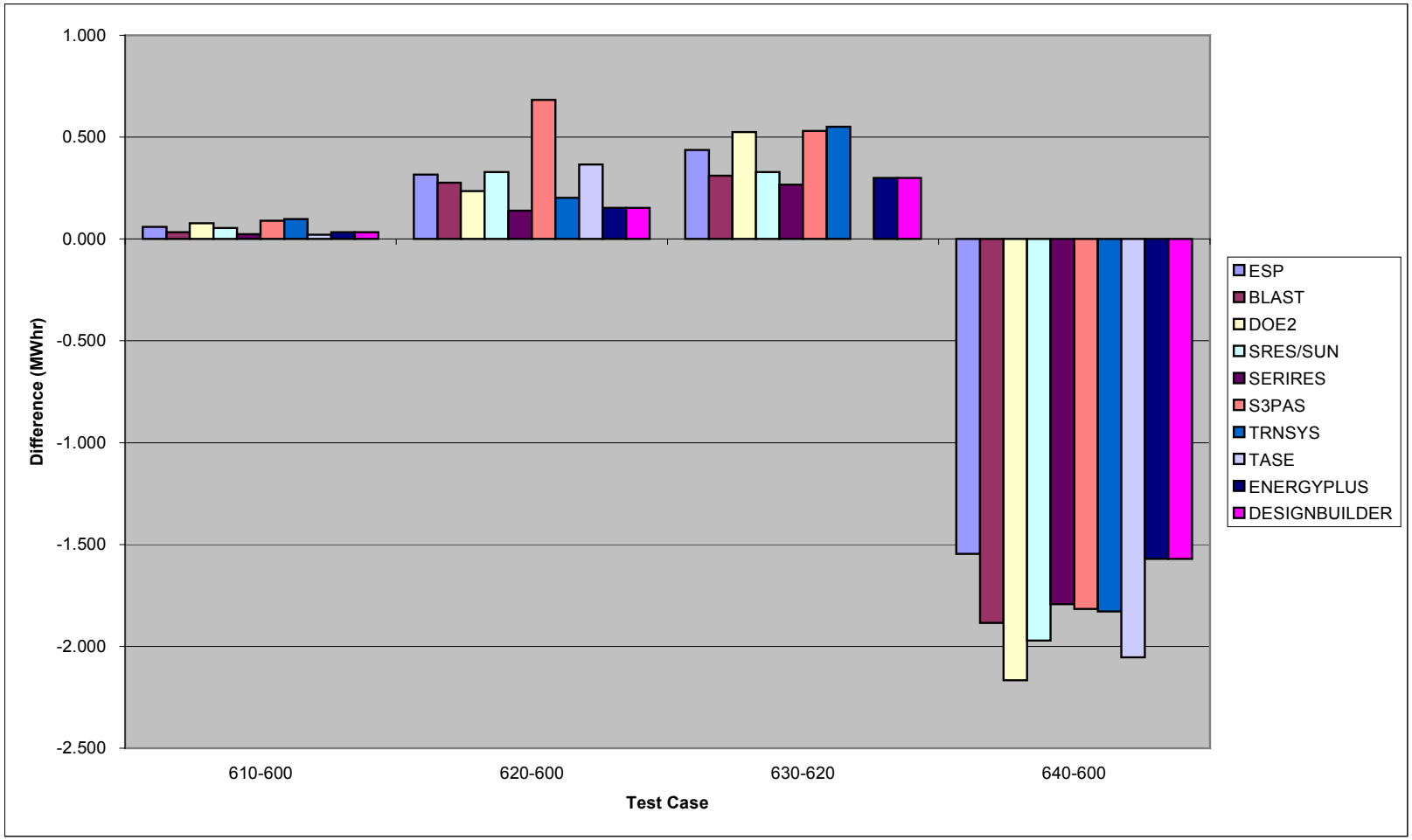
Average Free Floating Temperature



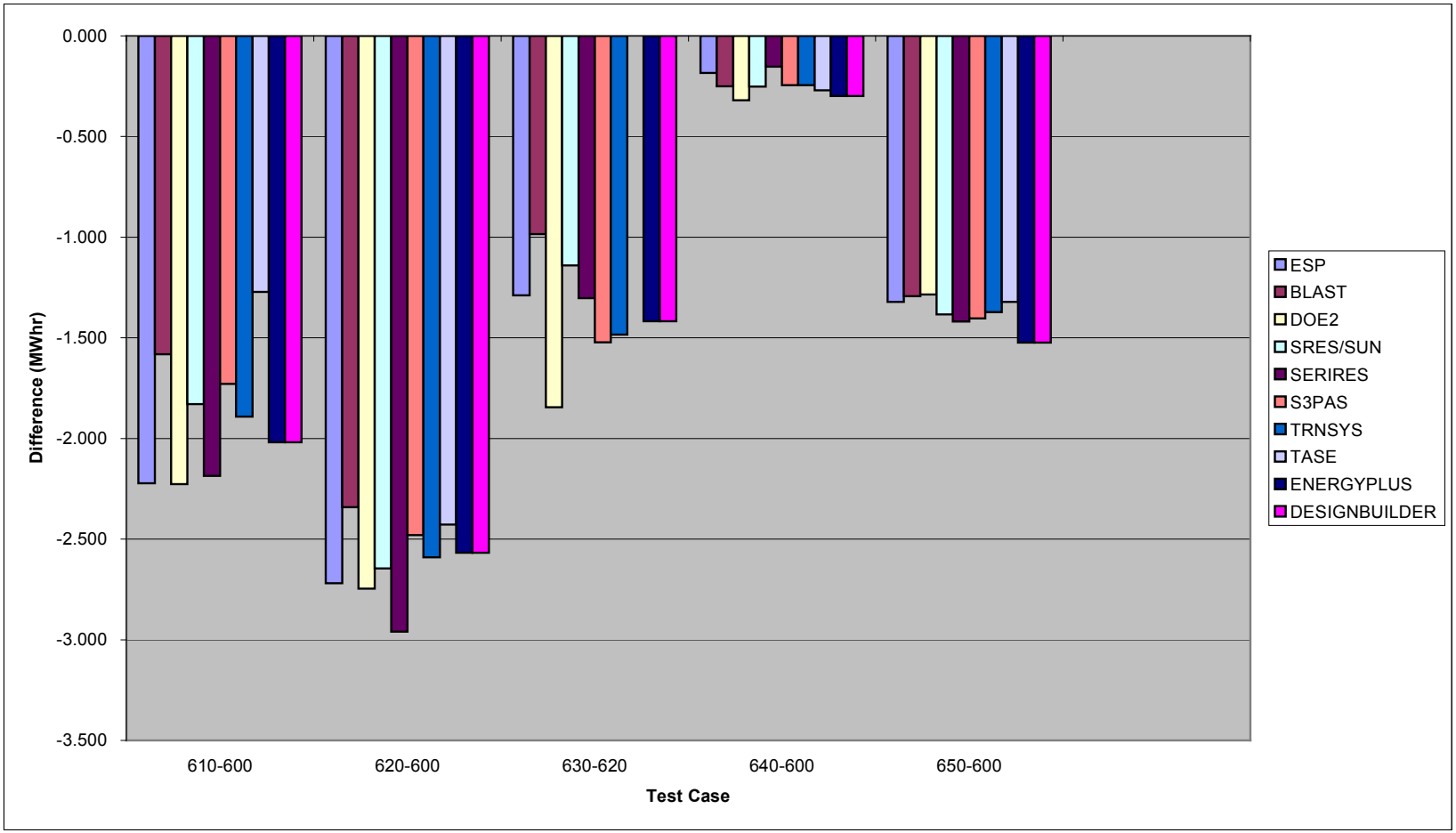
Appendix IV

Sensitivity Comparison Charts

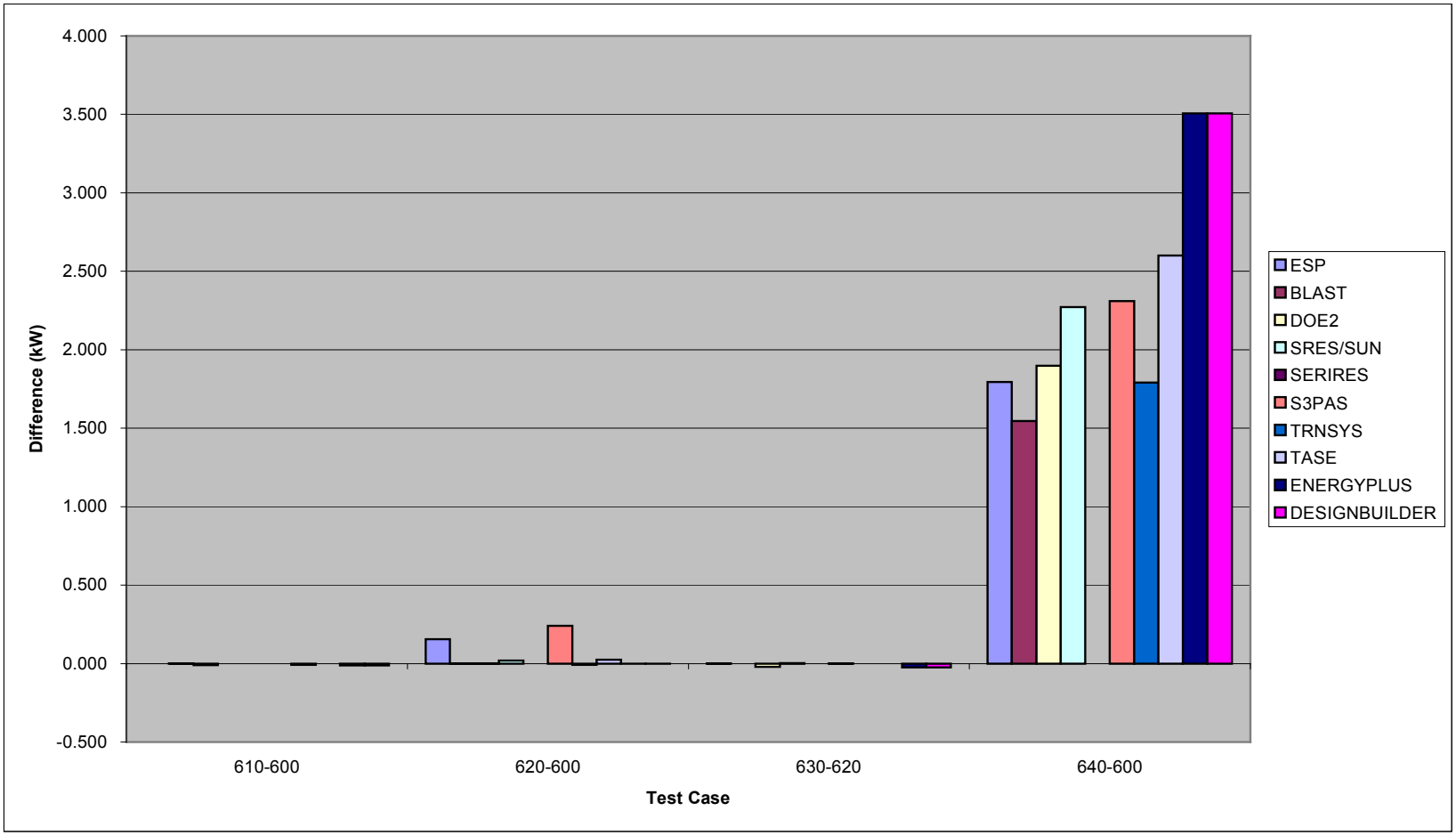
Low Mass Annual Heating (Sensitivity)



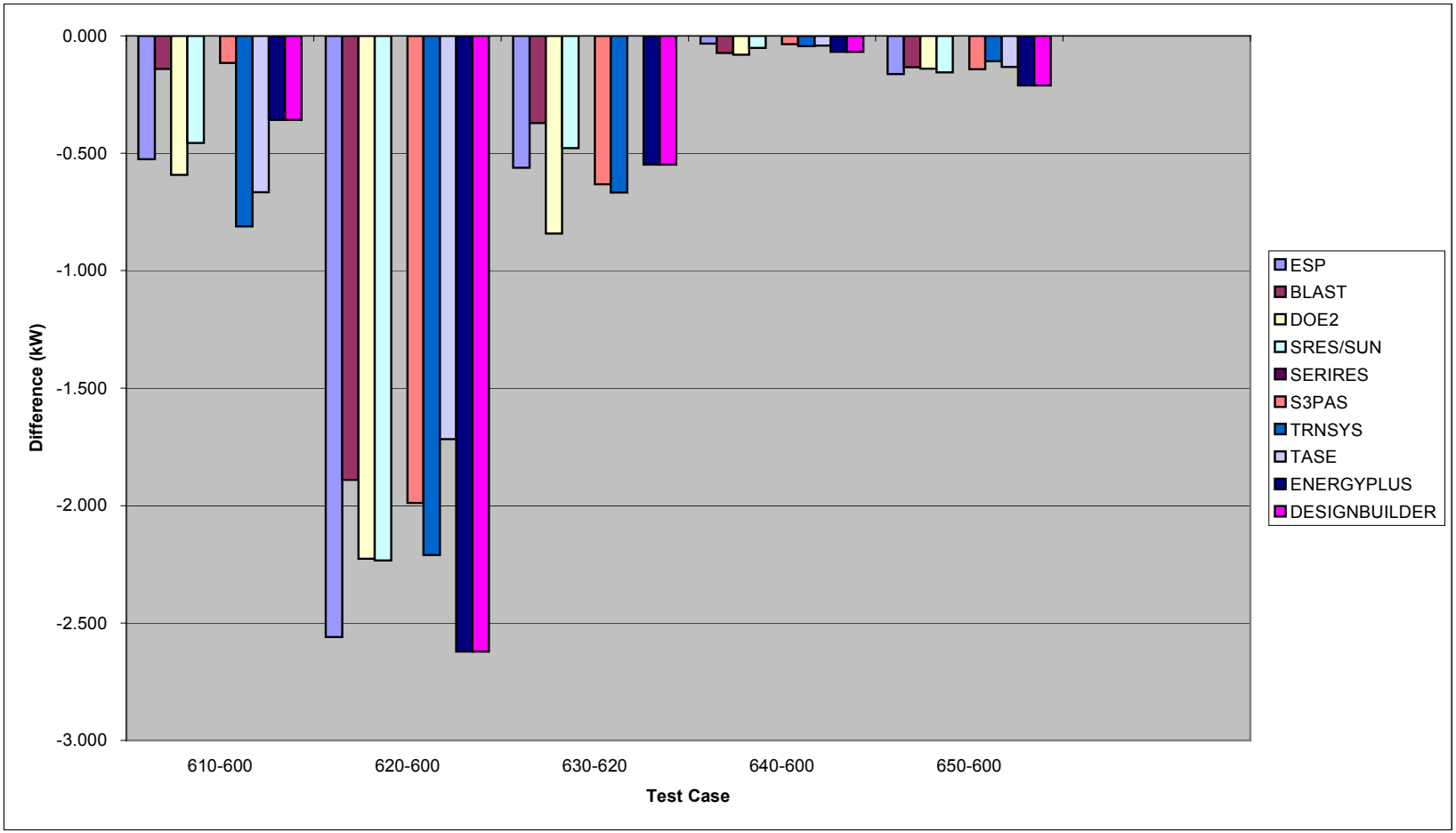
Low Mass Annual Cooling (Sensitivity)



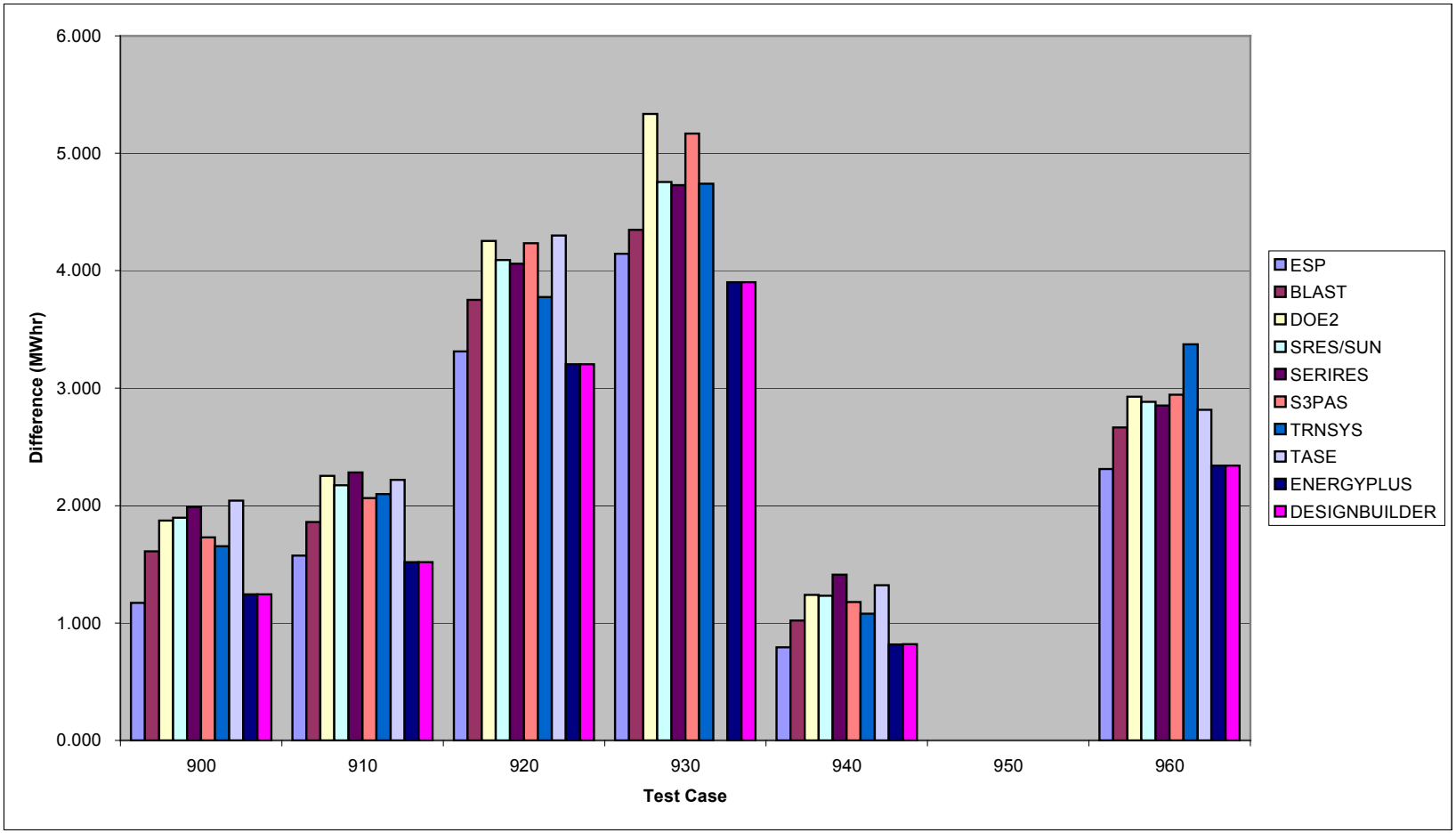
Low Mass Peak Heating (Sensitivity)



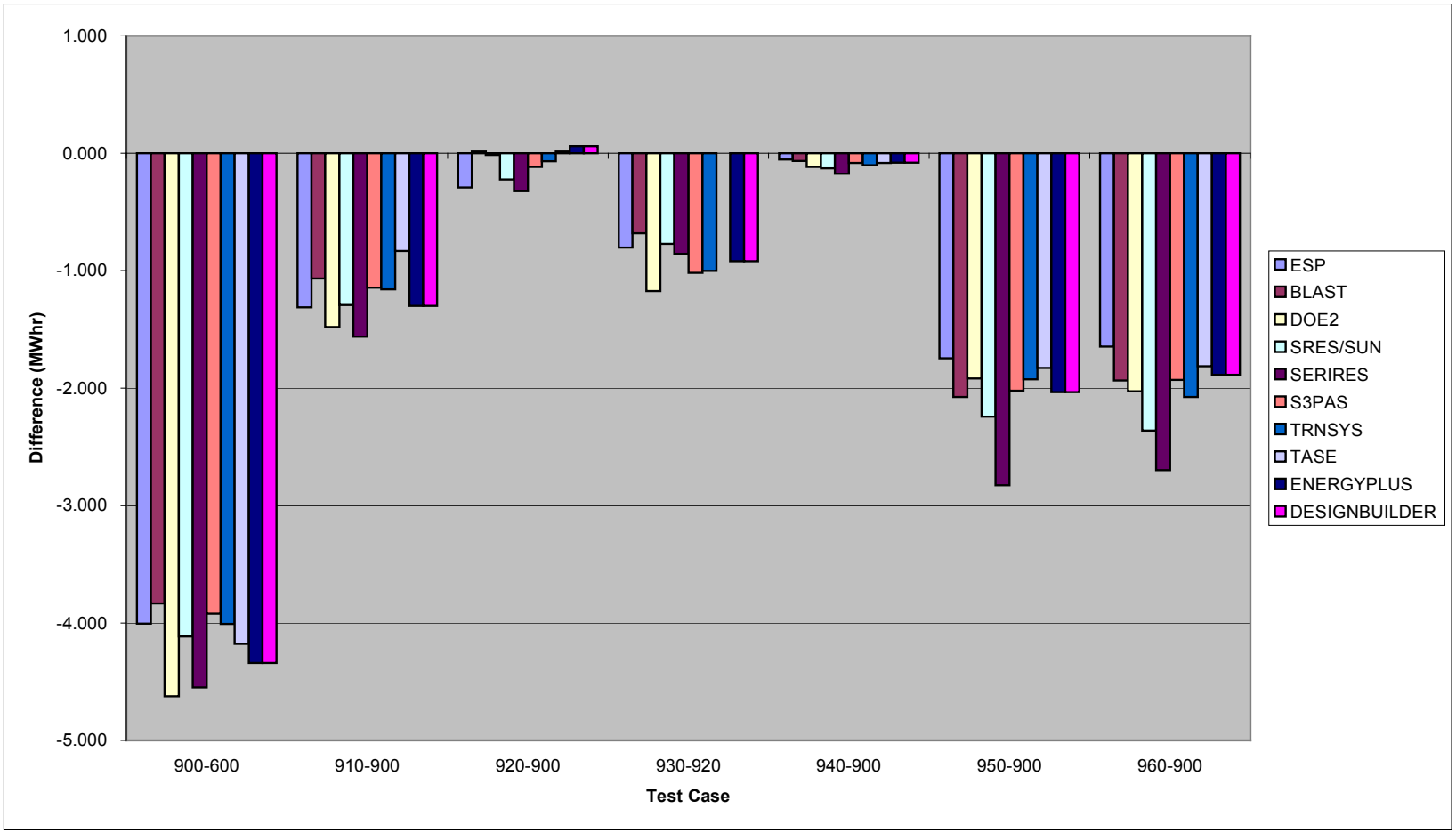
Low Mass Peak Cooling (Sensitivity)



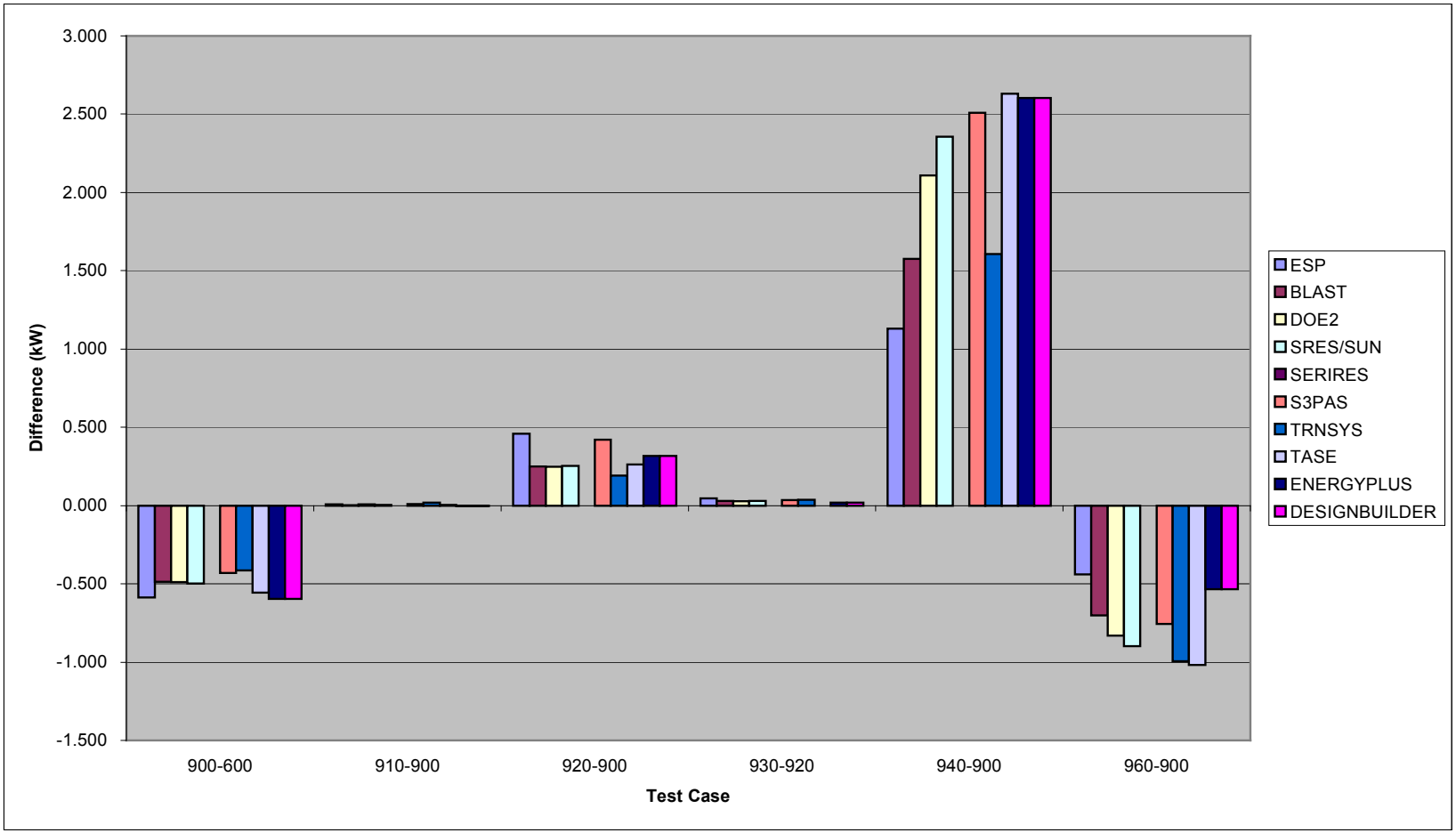
High Mass Annual Heating (Sensitivity)



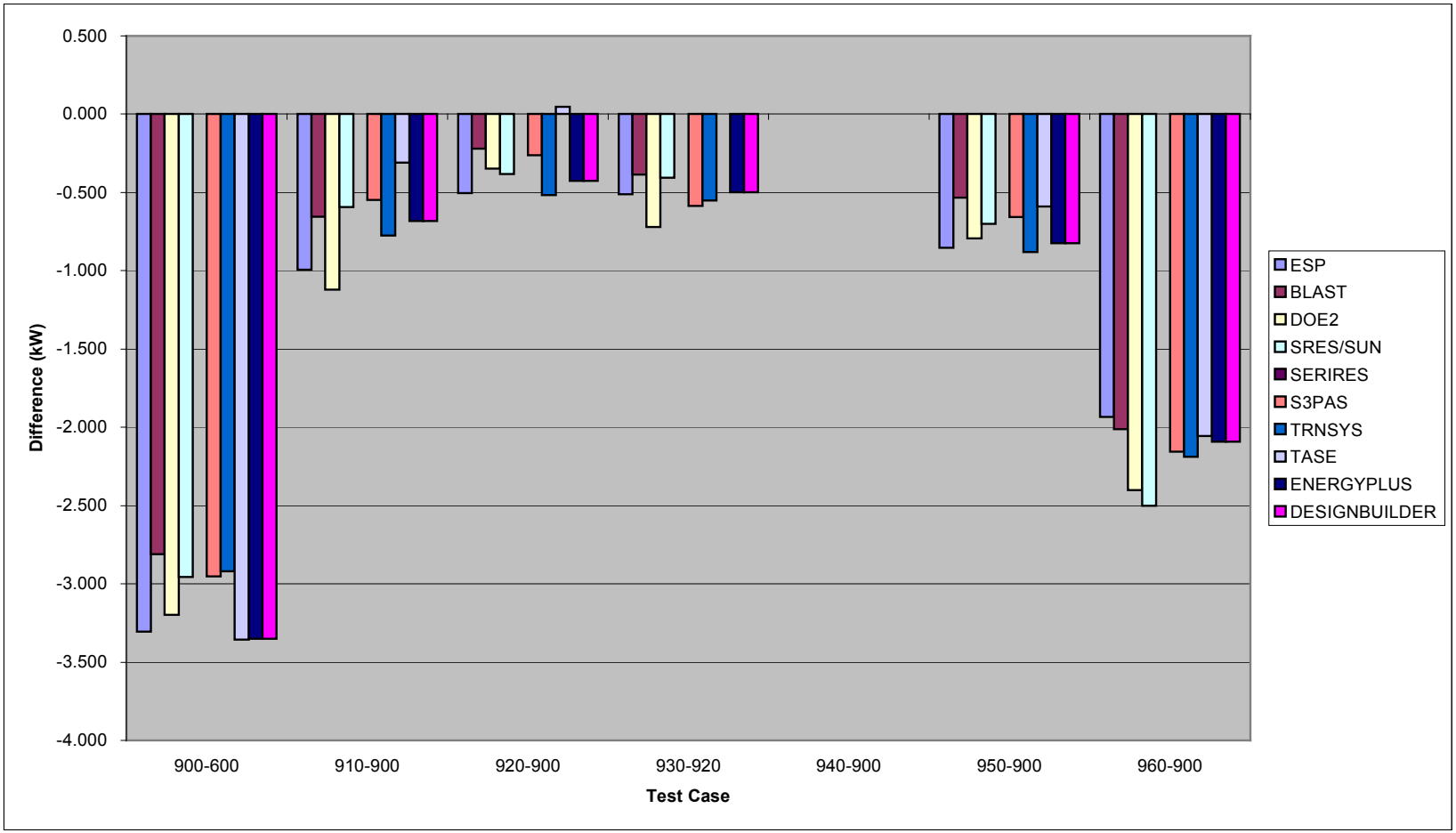
High Mass Annual Cooling (Sensitivity)



High Mass Peak Heating (Sensitivity)



High Mass Peak Cooling (Sensitivity)



Appendix V

ANSI/ASHRAE Standard 140-2004 Output Form – Modelling Notes

STANDARD 140 OUTPUT FORM – MODELING NOTES

Software: DesignBuilder
Version: 1.2.0

Simulated Effect:

Inside and Outside convection algorithm

Optional Settings or Modelling Capabilities:

Inside convection algorithm:
1.Detailed
2. Simple
3. CIBSE
4. Ceiling diffuser
5. Glazed cavity

Outside convection algorithm:
1. Detailed
2. Simple
3. CIBSE
4. BLAST
5. TARP
6. DOE-2
7. MoWiTT

Setting or Capability Used:

Inside convection algorithm: *1.Detailed*
Outside convection algorithm: *1.Detailed*

Physical Meaning of Option Used:

The same detailed calculation method that was used for the GARD Analytics tests for EnergyPlus are used to test DesignBuilder.

Simulated Effect:

Solar distribution effect

Optional Settings or Modelling Capabilities:

Solar distribution:
1. Minimal shadowing
2. Full exterior
3. Full interior and exterior

Setting or Capability Used:

Solar distribution: *3. Full interior and exterior*

Physical Meaning of Option Used:

Full interior and exterior shadow calculations are performed each hour

---

Simulated Effect:

Various variables used to describe properties of surfaces

Optional Settings or Modelling Capabilities:

Thermal Absorptance:	*0.0 to 1.0*
Solar Absorptance:	*0.0 to 1.0*
Roughness:	*Very rough* *Medium rough* *Rough* *Smooth* *Medium smooth* *Very smooth*

Setting or Capability Used:

Thermal Absorptance:	*0.9*
Solar Absorptance:	*0.6*
Roughness:	*Rough*

Physical Meaning of Option Used:

Thermal Absorptance:	*surface property describing ability to absorb incident longwave radiation*
Solar Absorptance:	*surface property describing ability to absorb incident solar radiation*
Roughness:	*surface roughness*

Simulated Effect:

Simulation time increment

Optional Settings or Modelling Capabilities:

Number of time steps per hour=whole number between 1 and 60

Setting or Capability Used:

Number of time steps per hour=4

Physical Meaning of Option Used:

The simulation time increment is 15 minutes.

Simulated Effect:

Window properties for double pane glazing made of standard 3mm clear glass with 13mm air gap.

Optional Settings or Modelling Capabilities:

EnergyPlus requires window properties for front and back of window surface.

Setting or Capability Used:

Window properties were described as follows:

Thermal Properties

Property	**Value**
Thickness	3.175 mm
Conductivity	1.060 W/mK

Solar Properties

Property	**Value**
Solar transmittance	0.86156
Outside solar reflectance	0.07846
Inside solar reflectance	0.07846

Visible Properties

Property	**Value**
Visible transmittance	0.91325
Outside visible reflectance	0.08200
Inside visible reflectance	0.08200

Infra-Red Properties

Property	**Value**
Infra-red transmittance	0.00000
Outside infra-red reflectance	0.84000
Inside infra-red reflectance	0.84000

Physical Meaning of Option Used:

Description of window properties for double pane clear glass windows for determining solar and conduction heat gain.

Simulated Effect:

Ground reflectance

Optional Settings or Modeling Capabilities:

Ground surface solar reflectance=0.0 to 1.0

Setting or Capability Used:

Ground surface solar reflectance=0.2

Physical Meaning of Option Used:

Property of the ground surface that describes the amount of incident solar radiation that is reflected.
