

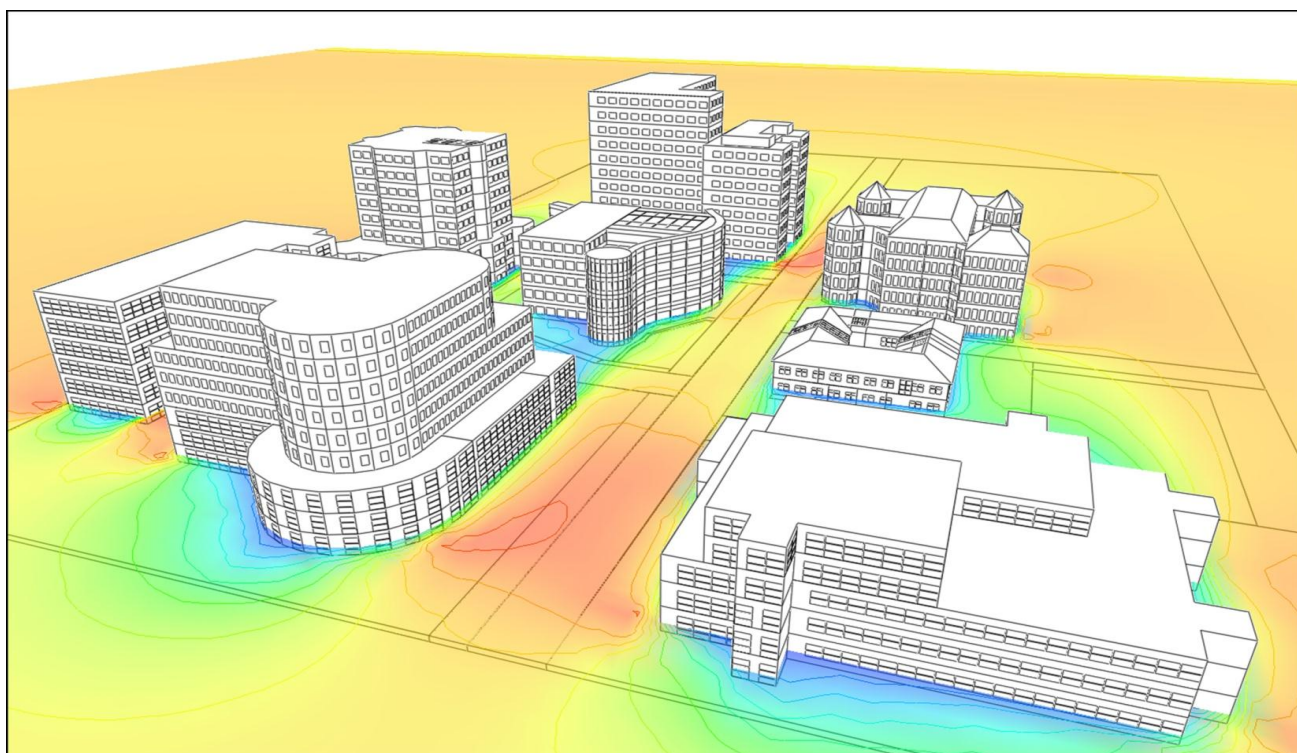


**INTEGRATED  
ENVIRONMENTAL  
SOLUTIONS**

# Building Envelope and Fabric Load Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2007

**ApacheSim Version <VE>2013  
June 2013**

Integrated Environmental Solutions  
[www.iesve.com](http://www.iesve.com)



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## References

1. 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.ashrae.org](http://www.ashrae.org)
2. Judkoff, R., and J. Neymark. (1995). International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method. NREL/TP-472-6231. Golden, CO: National Renewable Energy Laboratory.
3. ApacheSim Building Thermal Simulation Program. IES Ltd. Helix Building, Kelvin Campus, West of Scotland Science Park, Glasgow G20 0SP
4. ASHRAE Standard 90.1-2001, Addendum p. ASHRAE Inc., 1791 Tullie Circle NE Atlanta, GA 30329. [www.ashrae.org](http://www.ashrae.org)
5. CIBSE Guide A Environmental Design. The Chartered Institution of Building Services Engineers, London, 2006.
6. EnergyPlus Testing with ANSI/ASHRAE Standard 140-2001 (BESTEST). EnergyPlus Version 1.1.0.020. May 2003. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California. Prepared by Robert H. Henniger and Michael J. Witte, GARD Analytics, 1028 Busse Highway, Park Ridge, Illinois 60068, USA. [www.gard.com](http://www.gard.com)

# 1 Introduction

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

The building envelope and fabric load tests, which have their origin in the IEA 12B/21C 'BESTEST' diagnostic tests[2], require the simulation of a number of variants of a test building. The test cases increase in complexity from a simple building shell without glazing, infiltration or internal gains to comparatively realistic building types.

The aim of the tests is to identify and diagnose differences in predictions that may be caused by software errors.

- 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 emphasises 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.

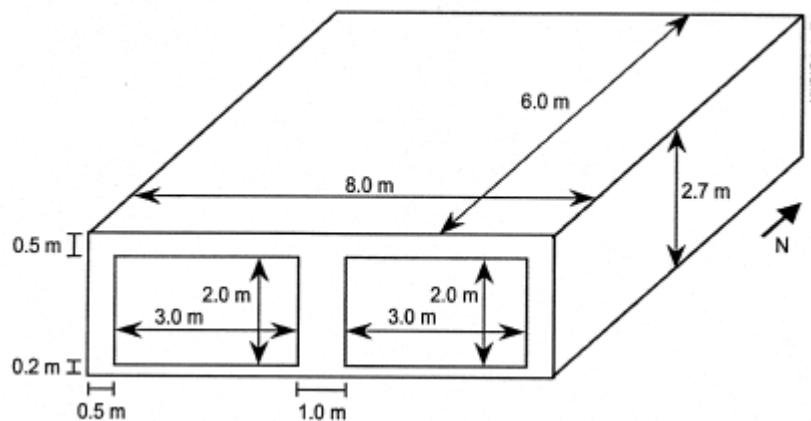
A brief outline of the tests is provided. This is followed by a description of the modelling assumptions and settings used to run the tests in the ApacheSim program.

## 2 Overview of Tests

A full description of the tests, including input data, output reporting conventions and terminology, is provided in the ASHRAE Standard. Here it will suffice to enumerate and briefly describe the cases.

Figure 2.1 shows a sketch of the building which forms the subject of Case 600. This is referred to in the Standard as the 'Base Case', of which all other cases are variants.

The building is a cuboid with one of its longer sides facing south. In Case 600 it has two south-facing windows each of area  $6\text{ m}^2$ .



**Figure 2.1 – Case 600 geometry**

Two groups of cases are identified: 'basic tests' (cases 600-650 and 900-960) and 'in-depth' tests (the remainder).

Each case consists of simulating a variant of the test building over a year using a Denver, Colorado weather dataset. The cases explore different combinations of the following parameters and settings:

Glazing: none, high conductance opaque panel or double glazed window

Glazing orientation: south or east/west

Glazing shading devices: none, overhang (south), overhang + side-fins (E/W)

Fabric: low-mass or high-mass construction

Infra-red emissivity of internal ( $\epsilon_i$ ) and external ( $\epsilon_e$ ) surfaces: 0.1 or 0.9

Solar-spectrum absorptance of internal ( $\alpha_i$ ) and external ( $\alpha_e$ ) surfaces: 0.1, 0.6, 0.9

Internal gains: 0 or 200W

Infiltration: 0.0, 0.5 or 1.0 ach

Heating and cooling: different setpoint combinations or no heating/cooling

Venting: an option using night ventilation and free cooling

Sunspace: Case 960 examines the effect of an attached sunspace

The following simulation variables are specified for output:

- Heating load
- Cooling load
- Air temperature
- Incident solar gain on the various surfaces
- Direct transmitted solar gain

In all the tests the issue of heat transfer with the ground is largely eliminated by the inclusion of a thick layer of insulation in the floor construction.

Table 2.1 provides a summary of the test cases. The 'basic' cases are indicated by underlining. Bold text indicates salient differences from previously listed cases. The table is divided into sections covering different heating and cooling control regimes. For example, 'Setpoints 20, 27' means heating to 20°C and cooling to 27°C. 'Setback' means heating to 10°C overnight (2300-0700) and to 20°C at other times, with cooling to 27°C. 'Venting' means continuous night ventilation between 1800 and 0700, cooling to 27°C during the rest of the day, and no heating.

Cases including the letters 'FF' test free-floating conditions with no heating or cooling. Case 960 is a version of Case 600 with an attached sunspace. The outputs tested are heating and cooling loads in the room and the temperature in the sunspace.

Case		Glazing	Internal Infiltration					
Low-mass	High-mass	Type	Emissivity		Absorptance		Gains	(ach)
			$\epsilon_i$	$\epsilon_e$	$\alpha_i$	$\alpha_e$	(W)	
Setpoints 20, 20								
195		None	0.1	0.1	N/A	0.1	0	0
200		Opaque	0.1	0.1	N/A	0.1	0	0
210		Opaque	0.1	0.9	N/A	0.1	0	0
215		Opaque	0.9	0.1	N/A	0.1	0	0
220		Opaque	0.9	0.9	N/A	0.1	0	0
230		Opaque	0.9	0.9	N/A	0.1	0	1.0
240		Opaque	0.9	0.9	N/A	0.1	200	0
250		Opaque	0.9	0.9	N/A	0.9	0	0
270		South	0.9	0.9	0.9	0.1	0	0
280		South	0.9	0.9	0.1	0.1	0	0
290		S + shade	0.9	0.9	0.9	0.1	0	0
300		East/West	0.9	0.9	0.9	0.1	0	0
310		E/W + shade	0.9	0.9	0.9	0.1	0	0
Setpoints 20, 27								
320		South	0.9	0.9	0.9	0.1	0	0
395		None	0.9	0.9	N/A	0.1	0	0
400		Opaque	0.9	0.9	N/A	0.1	0	0
410		Opaque	0.9	0.9	N/A	0.1	0	0.5
420		Opaque	0.9	0.9	N/A	0.1	200	0.5
430	800	Opaque	0.9	0.9	N/A	0.6	200	0.5
440	810	South	0.9	0.9	0.1	0.6	200	0.5
600, 600FF	900, 900FF	South	0.9	0.9	0.6	0.6	200	0.5
610	910	S + shade	0.9	0.9	0.6	0.6	200	0.5
620	920	East/West	0.9	0.9	0.6	0.6	200	0.5
630	930	E/W + shade	0.9	0.9	0.6	0.6	200	0.5
Setback								
640	940	South	0.9	0.9	0.6	0.6	200	0.5
Venting								
650, 650FF	950, 950FF	South	0.9	0.9	0.6	0.6	200	0.5
Sunspace								
960		South	0.9	0.9	0.6	0.6	200	0.5

## **3 Overview of ApacheSim**

### **ApacheSim Models**

Modelling options used in ApacheSim are set out in Appendix A, using the format specified in the Standard.

### **ApacheSim Results**

The ApacheSim results are presented graphically in Figures 1-326, alongside the results for 8 other programs reported in ANSI/ASHRAE Standard 140-2007[1]. Results from the program EnergyPlus version 1.1.0.020[6] are also included.

The results are presented in tabular form in the file 'ASHRAE 140 ApacheSim.xls', as required by the Standard. This file contains certain additional data not included in this report, including time series comparisons and binned temperature data for Case 900FF.



## **4 Notes on ApacheSim Results**

The building envelope and fabric load tests set out in ANSI/ASHRAE Standard 140-2007 have been applied to the program ApacheSim, version <VE>2013. The ApacheSim results are in good overall agreement with those from the reference programs. Out of 326 tests, Apache predicted a value outside the range set by the other programs in only 17.

## Appendix A. ApacheSim Settings

### STANDARD 140 OUTPUT FORM - MODELING NOTES

INSTRUCTIONS: See Annex A2.

SOFTWARE: *ApacheSim*

VERSION: <VE>2013

DOCUMENT BELOW THE MODELING METHODS USED IF ALTERNATIVE MODELING METHODS OR ALGORITHMS ARE AVAILABLE IN THE SOFTWARE BEING TESTED. (See Annex A2 for examples.)

**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:

*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:

*60 minutes*

Physical Meaning of Option Used:

*Time interval over which simulation results are averaged for output. 60 minutes was chosen in accordance with the reporting instructions.*

**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 direct solar shading and internal solar tracking was used for all cases with glazing.*

Physical Meaning of Option Used:

*SunCast direct shading and internal solar tracking calculates the effect of shading of the external surfaces of the building from the solar beam, and traces the solar beam through glazing elements onto internal building surfaces. This is the method used to simulate the direct shading effect of overhangs and side-fins. Solar tracking is an important feature of Case 960 (sunspace).*

**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 diffuse solar shading was used for all cases with glazing.*

Physical Meaning of Option Used:

*SunCast diffuse shading calculates the effect of shading of the external surfaces of the building from short-wave radiation emanating from the sky vault. This is the method used to simulate the diffuse shading effect of overhangs and side-fins.*

**Simulated Effect:**

*Infiltration*

Optional Settings or Modeling Capabilities:

*Room air exchanges, MacroFlo natural ventilation simulation program*

Setting or Capability Used:

*Room air exchanges*

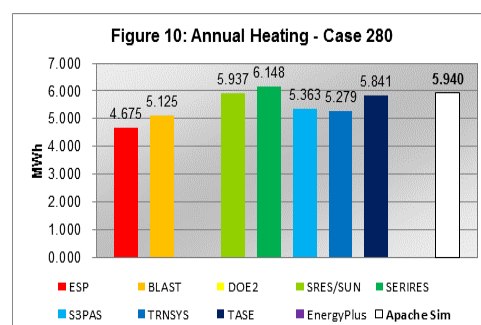
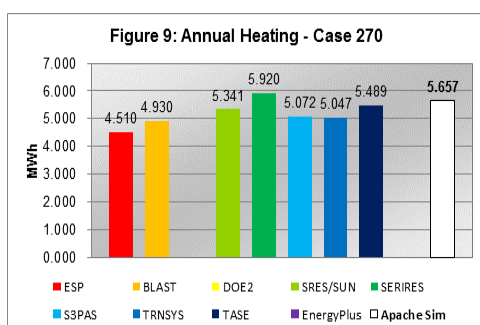
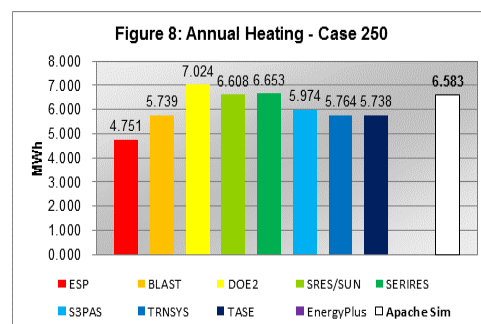
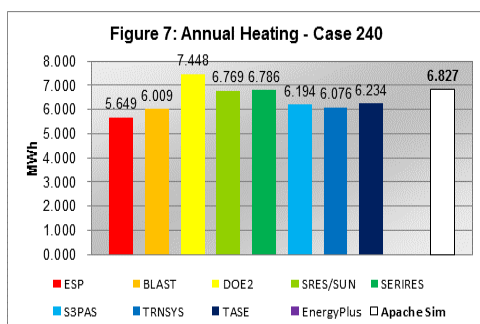
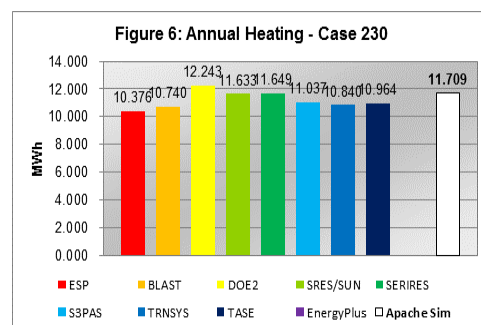
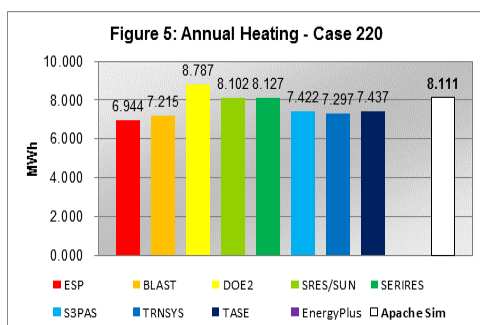
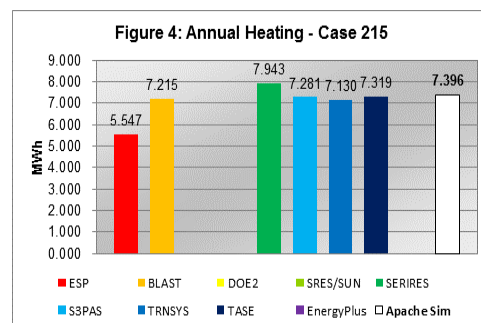
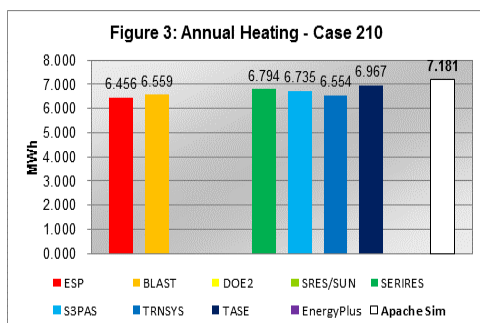
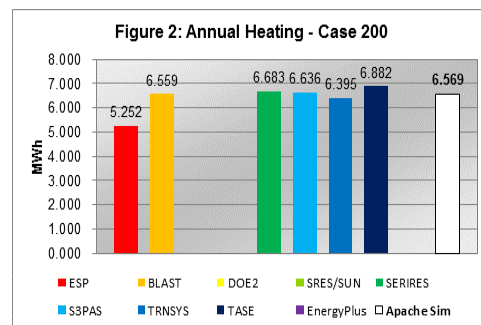
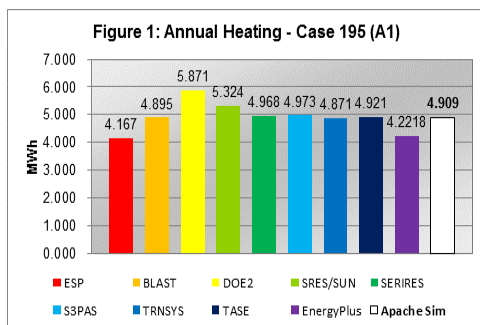
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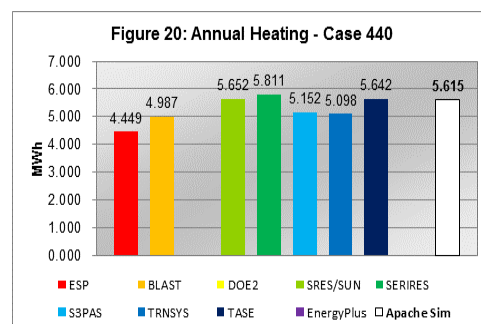
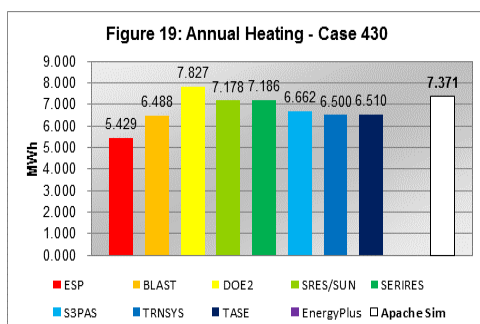
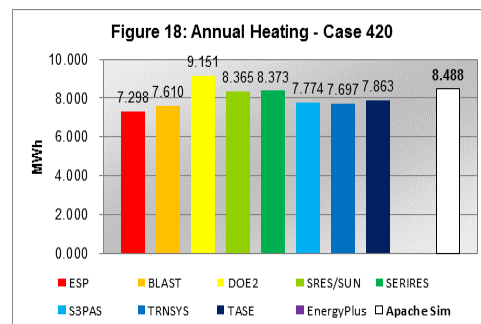
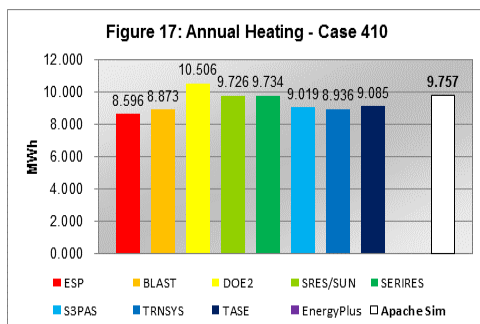
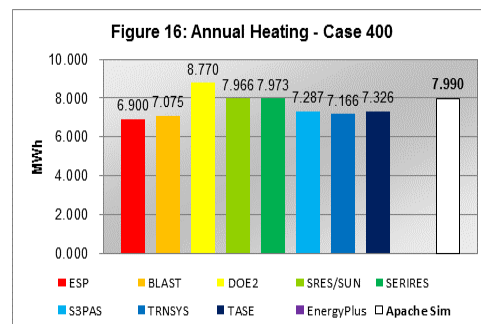
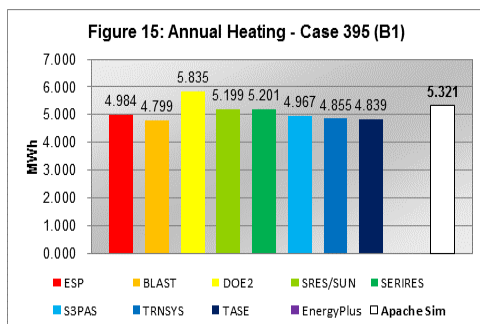
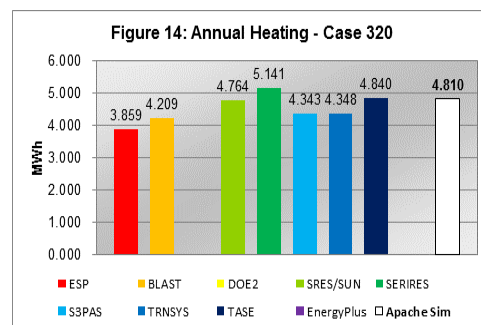
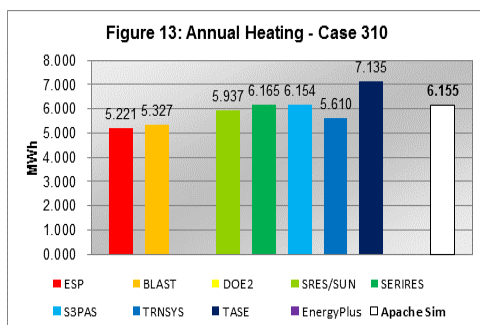
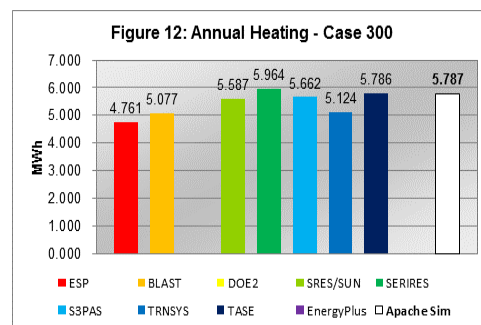
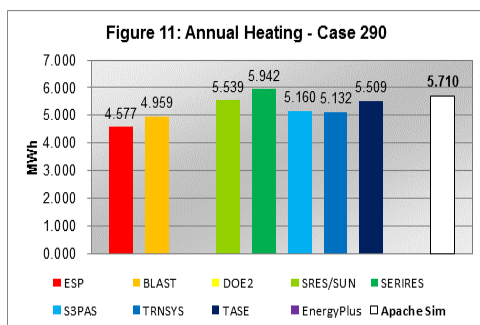
*The infiltration rates were adjusted for the altitude of the site using the method described in the Standard.*

## **Appendix B. Graphical Representation of Results**

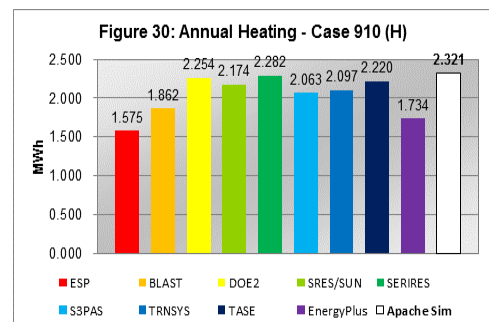
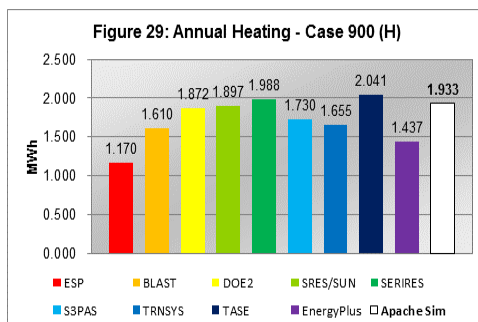
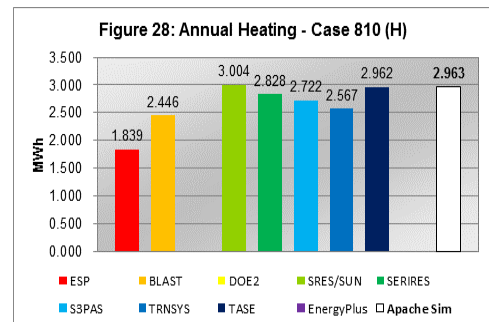
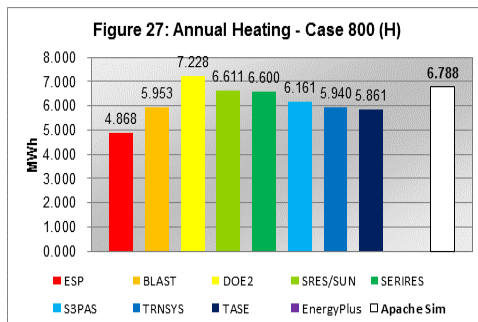
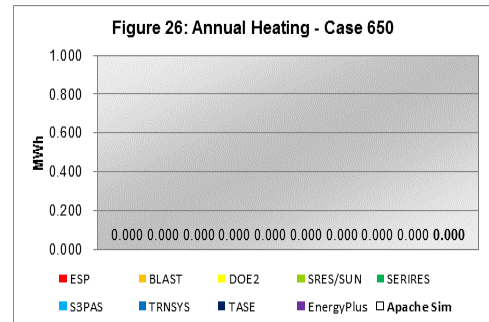
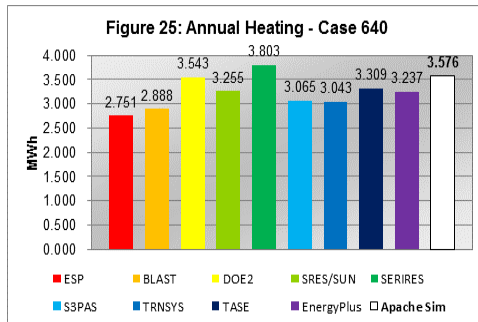
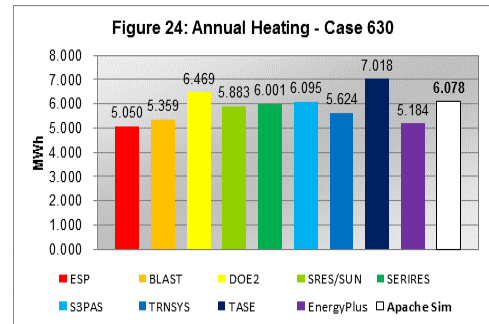
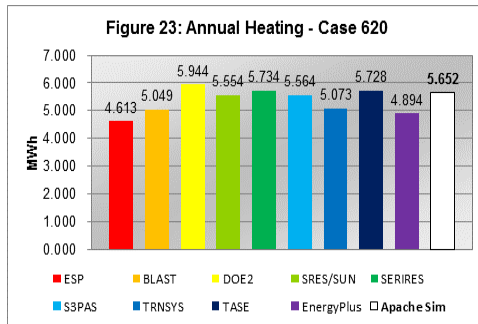
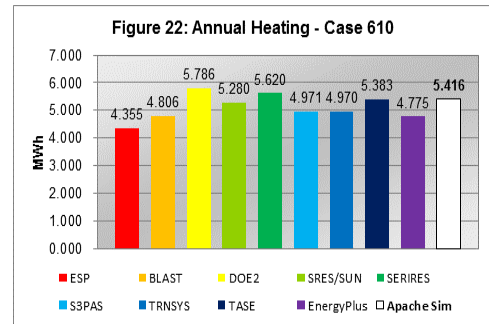
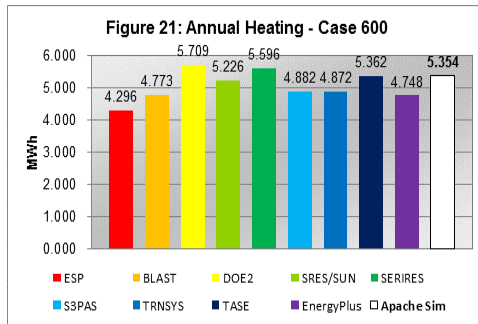
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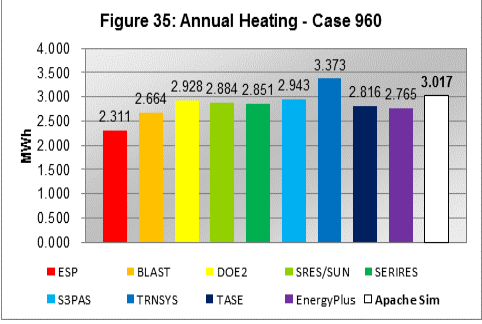
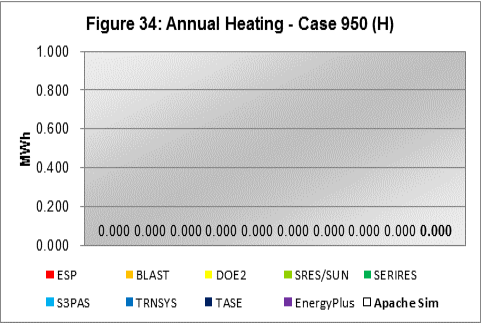
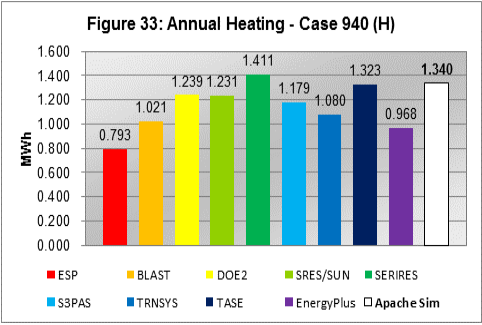
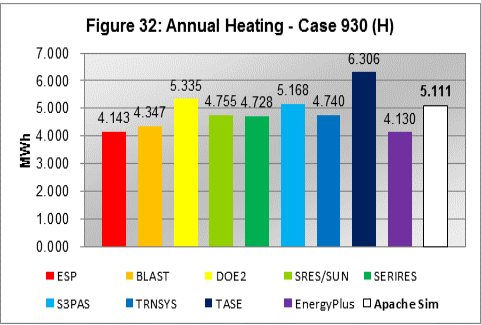
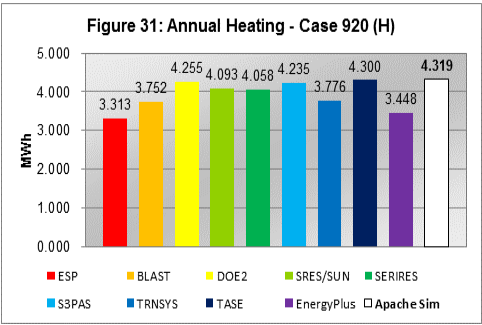
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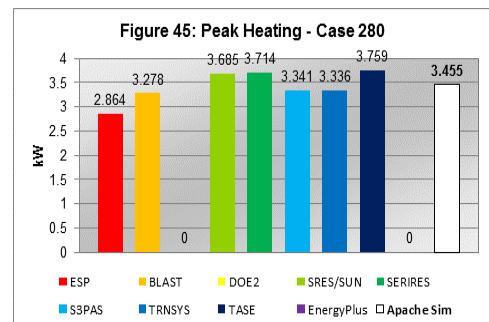
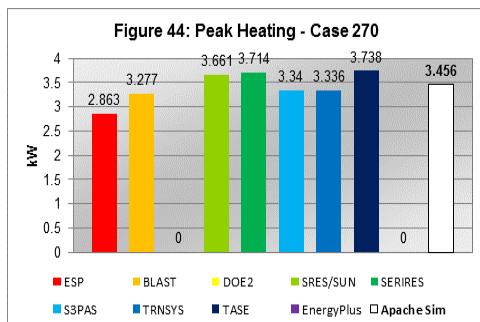
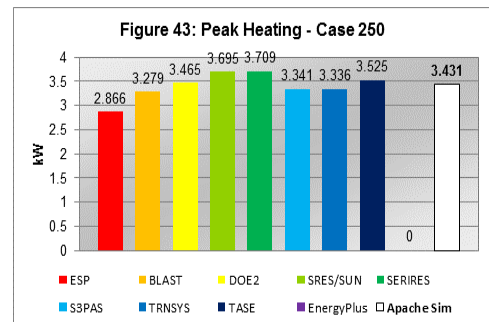
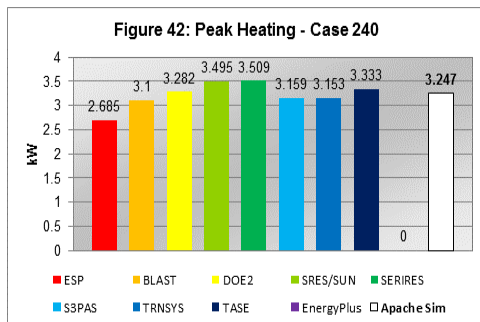
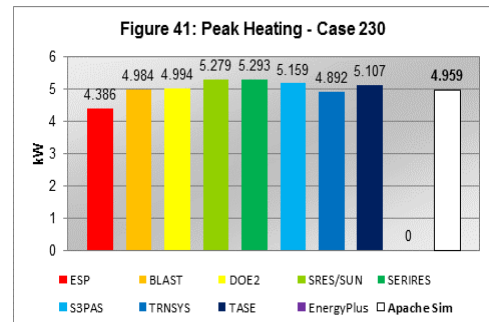
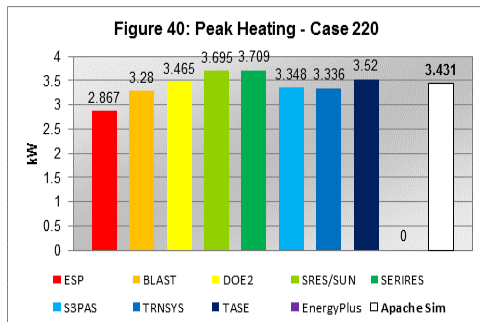
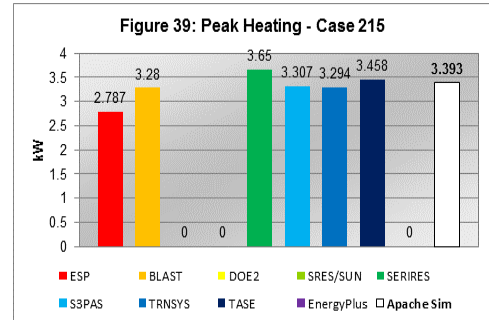
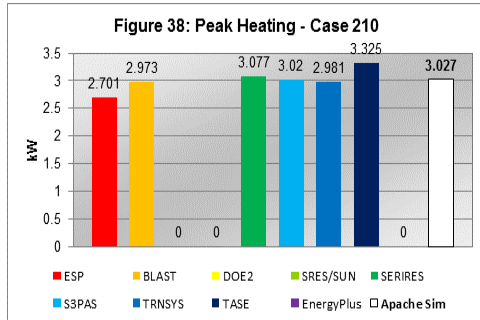
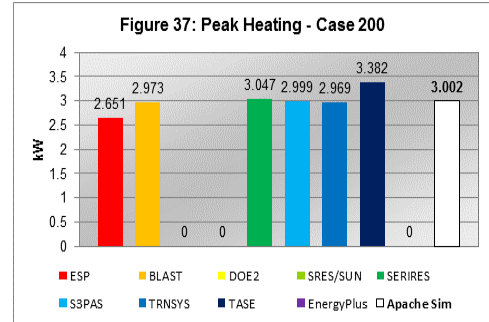
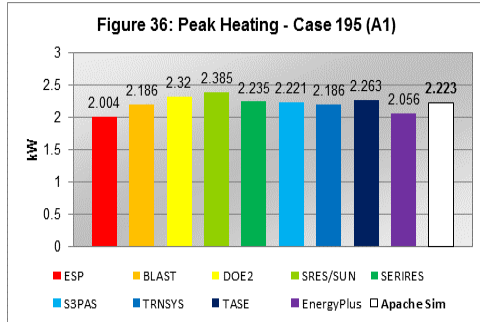


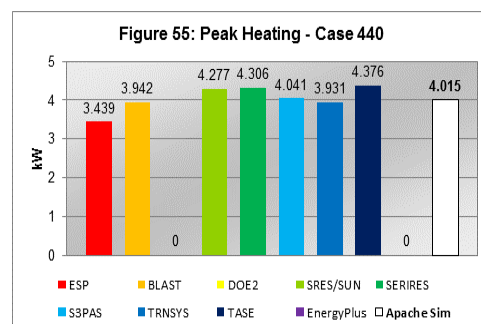
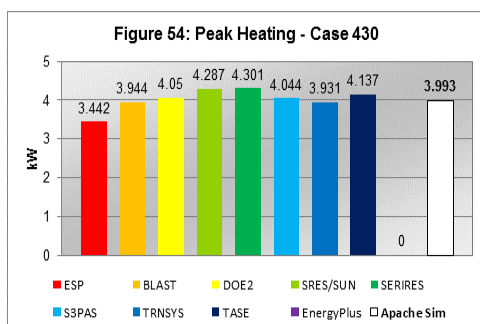
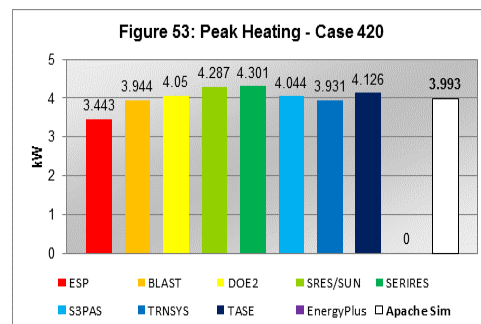
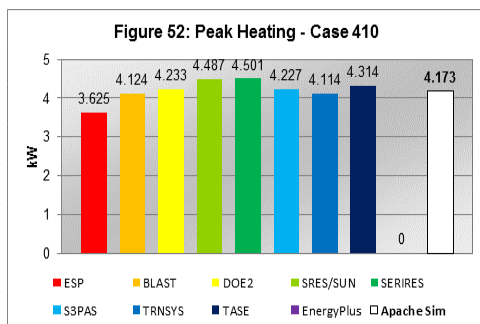
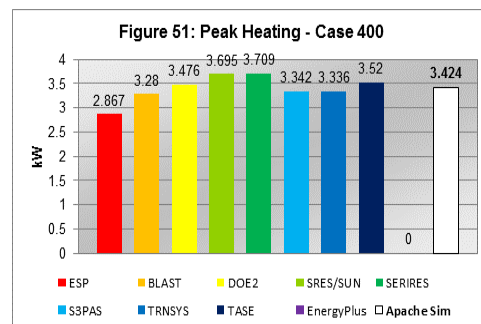
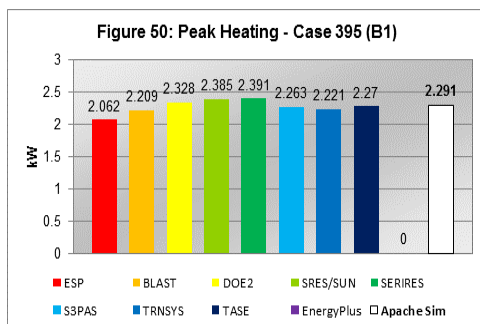
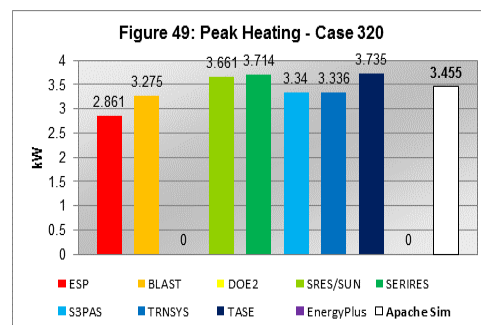
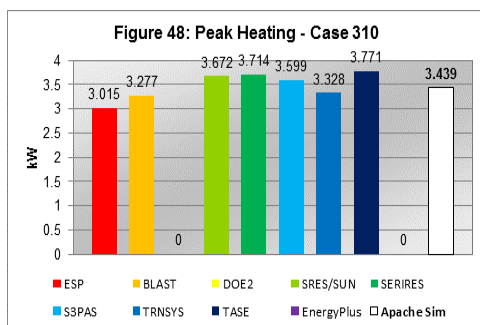
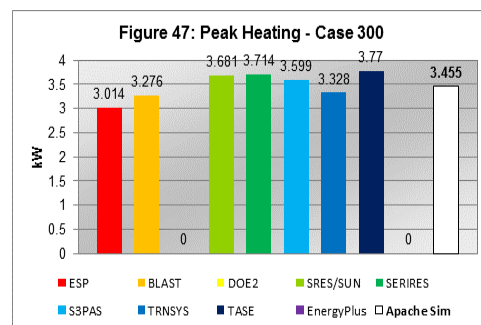
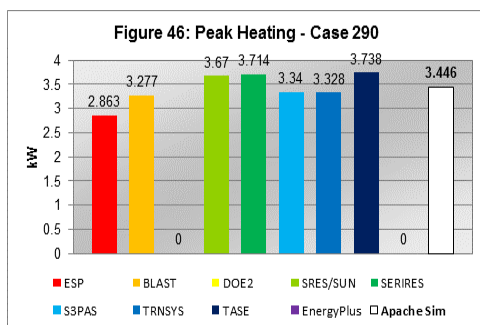


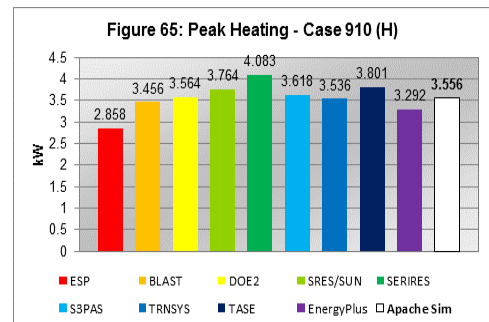
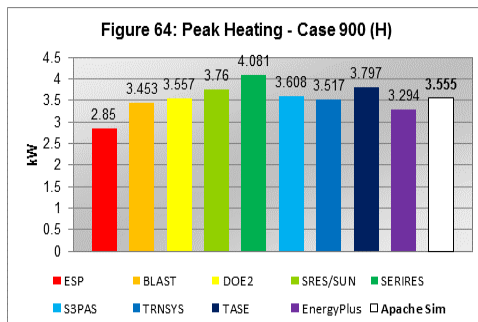
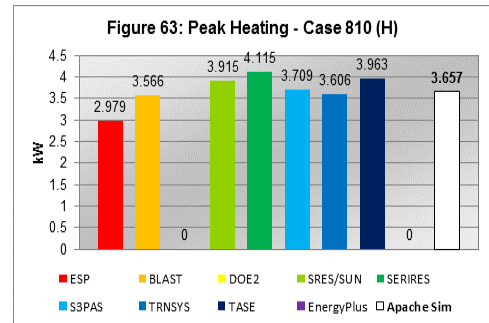
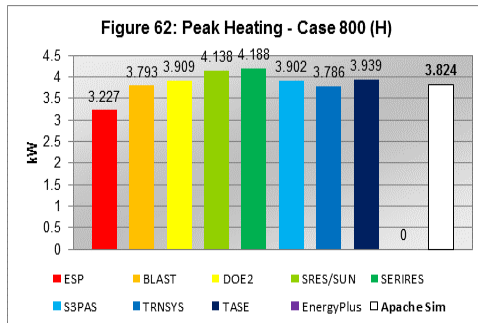
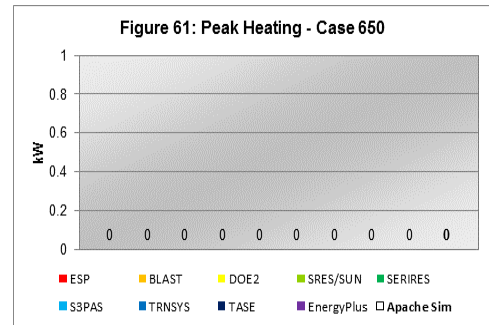
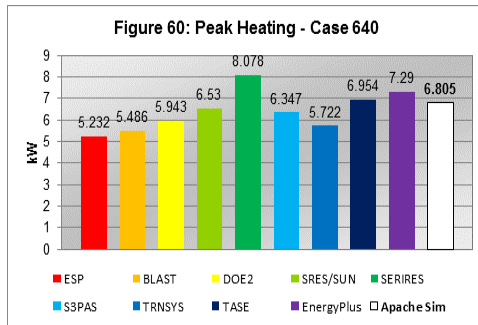
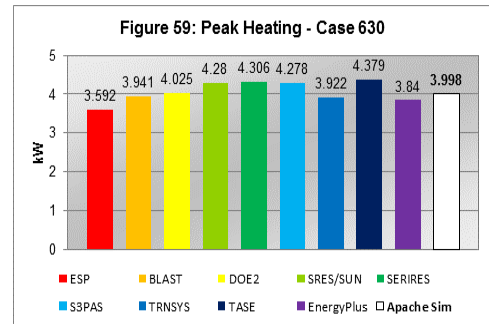
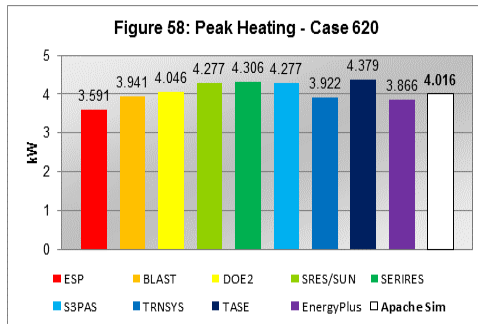
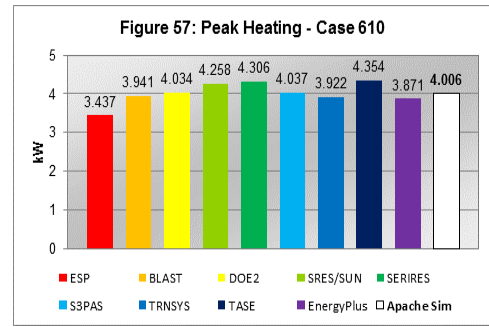
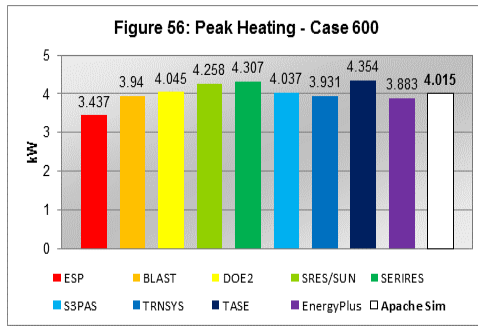


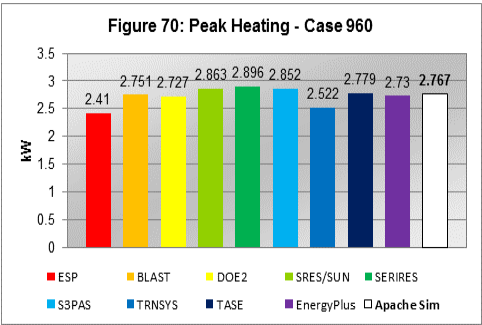
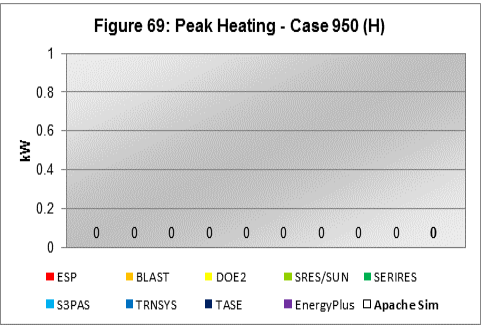
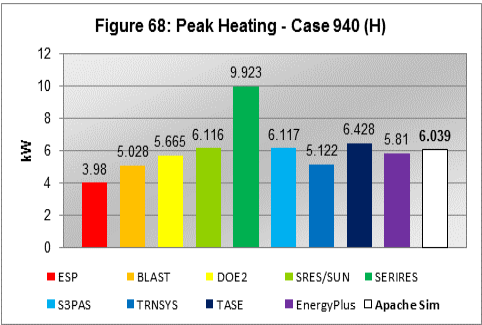
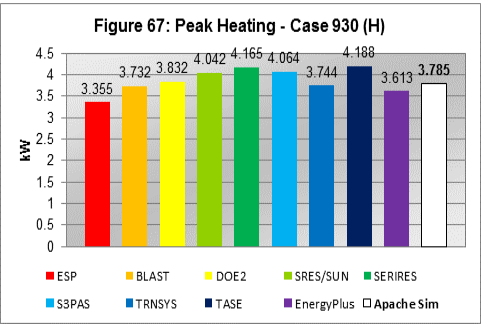
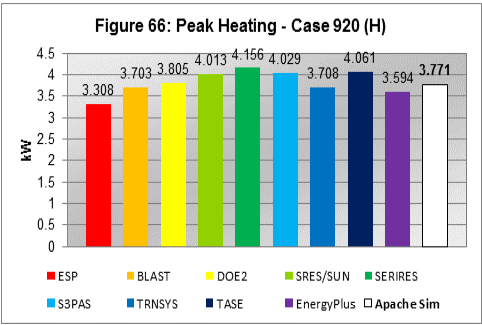
## **Figures 36 - 70**

### **Peak Heating Load**





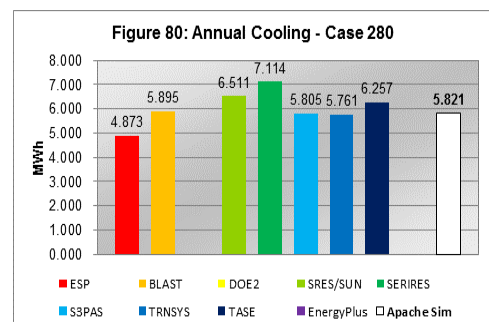
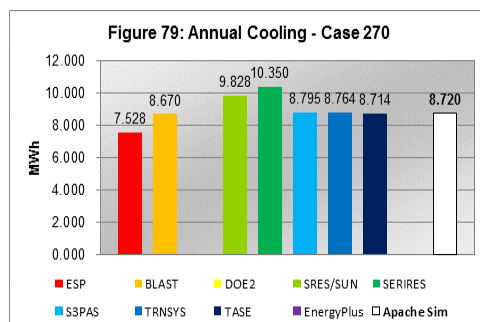
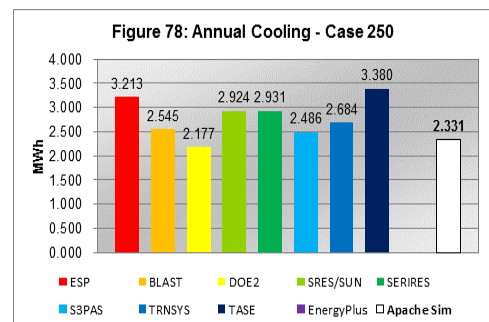
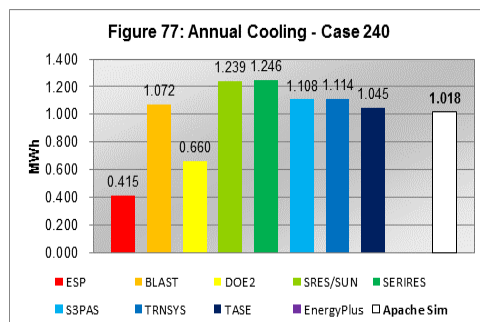
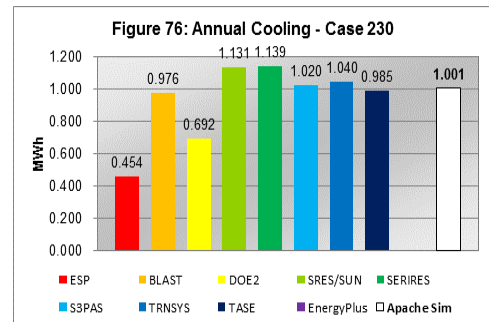
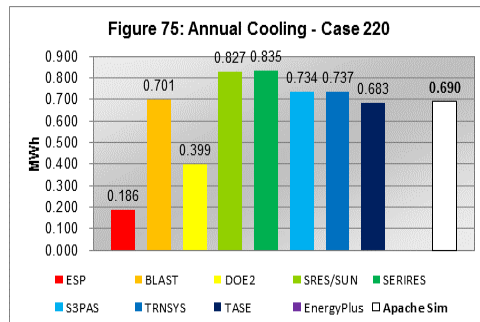
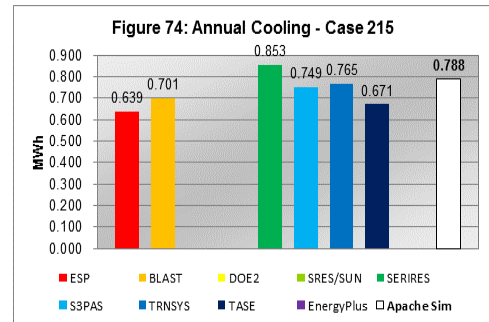
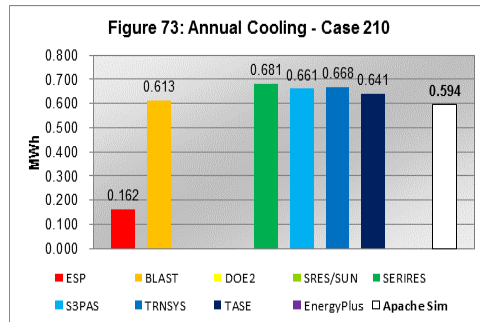
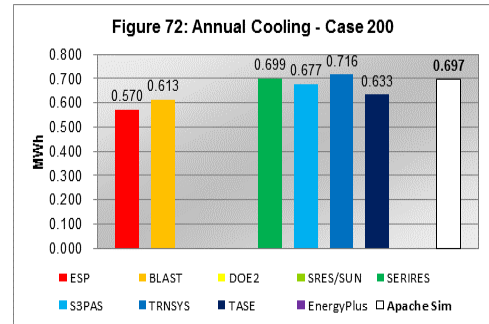
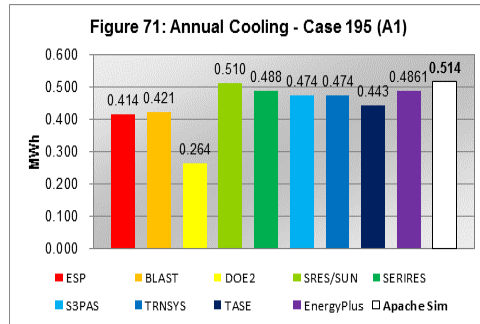


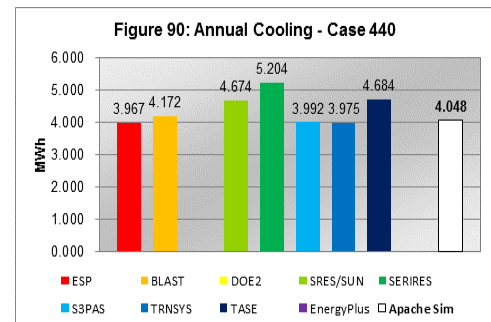
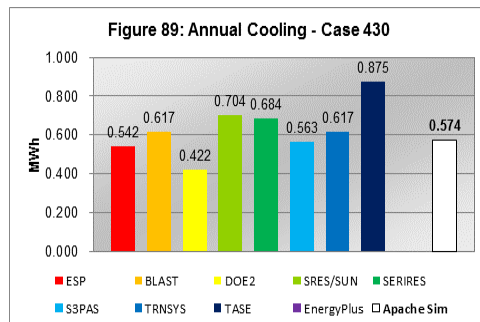
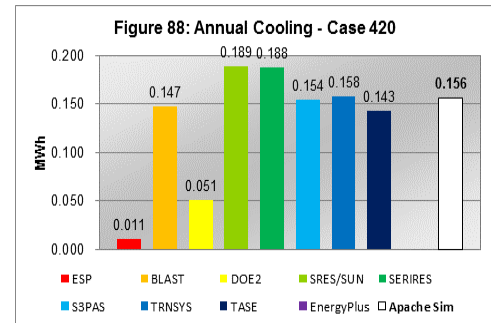
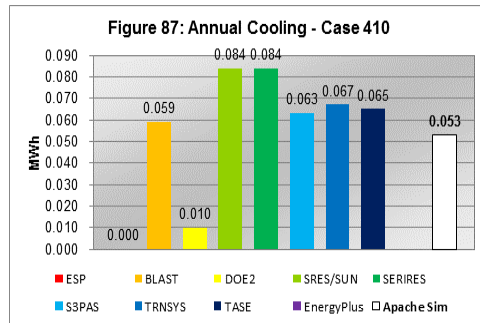
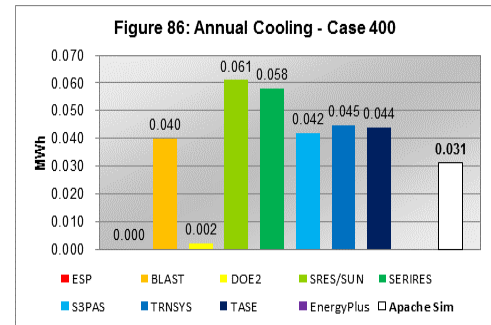
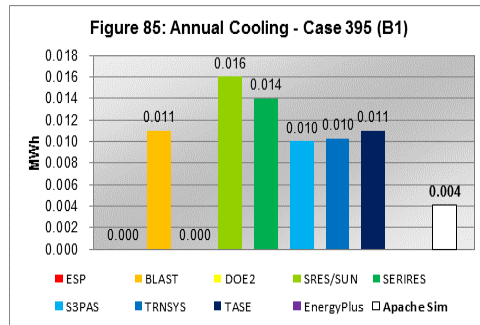
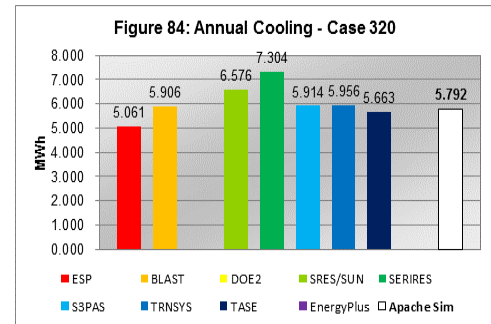
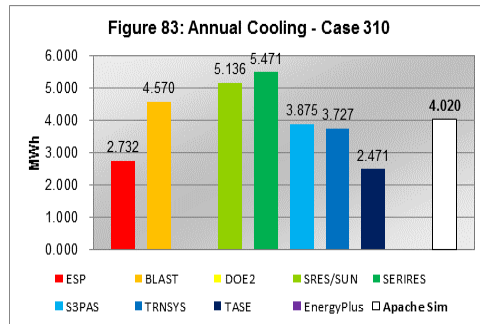
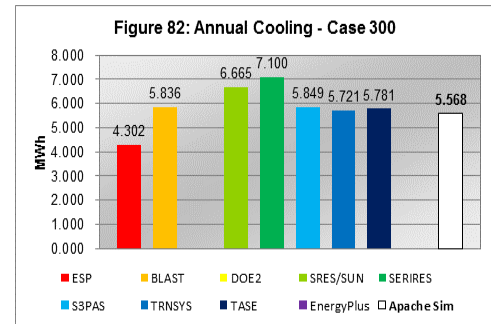
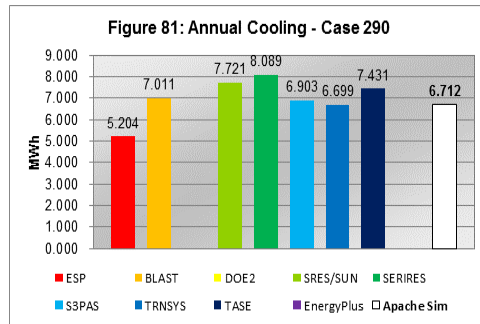


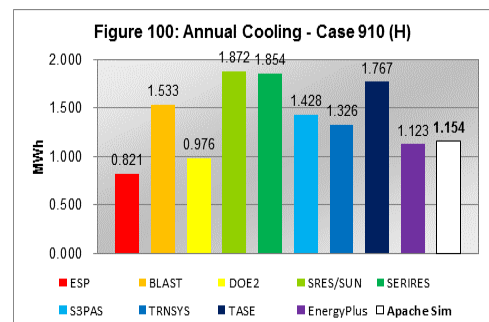
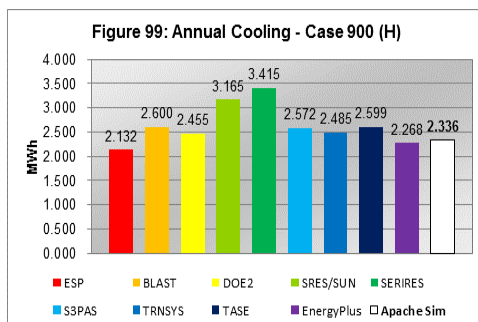
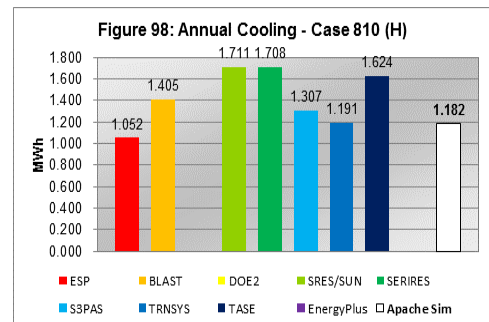
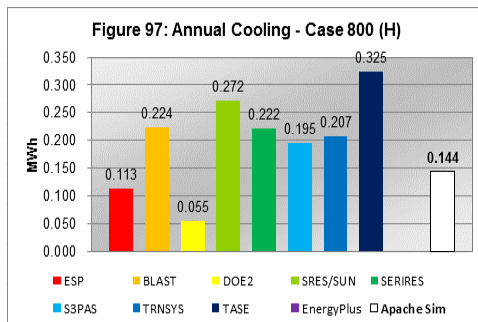
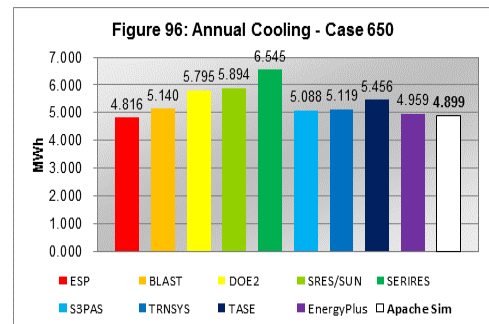
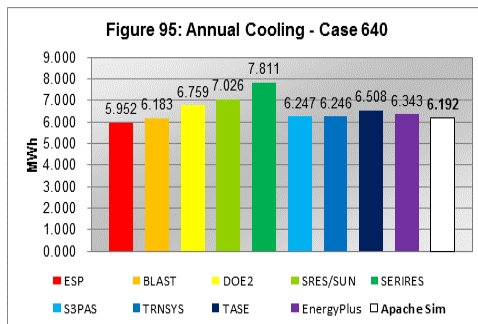
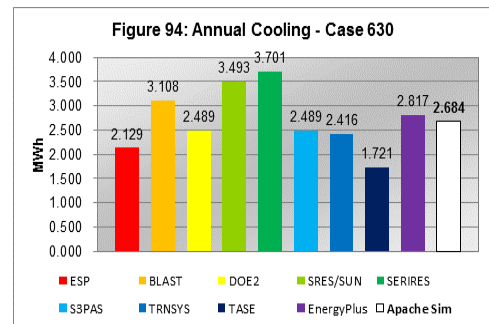
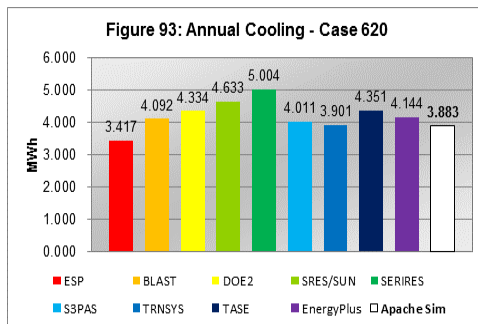
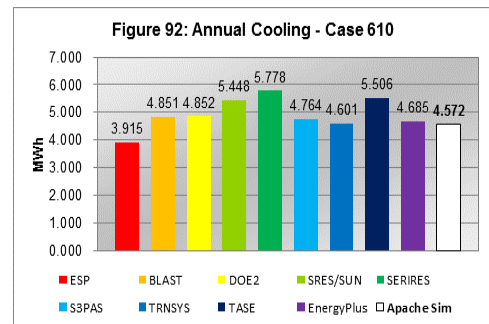
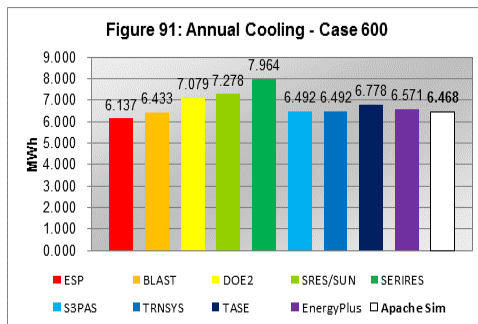
# **Figures 71 - 105**

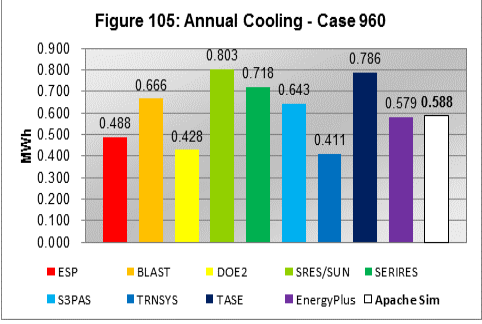
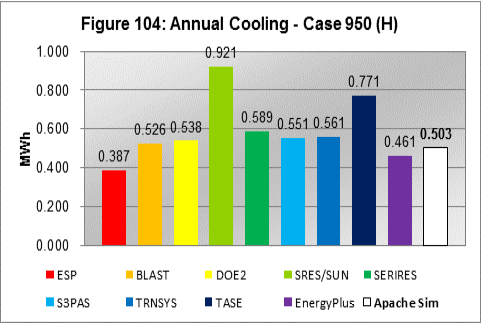
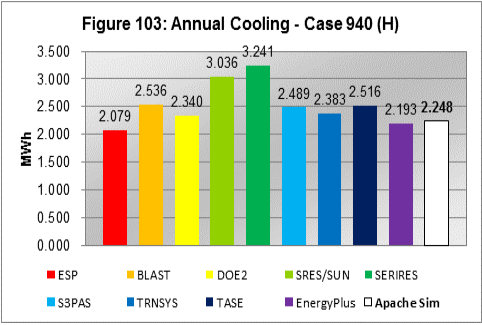
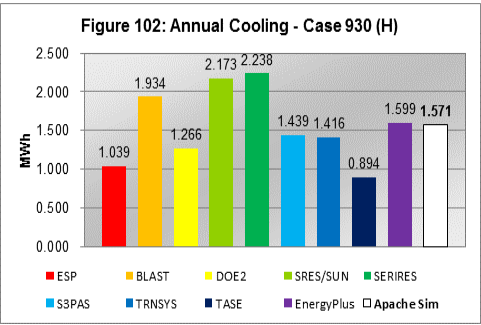
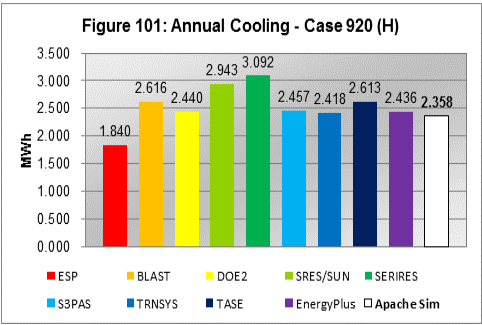
## **Annual Cooling Load**





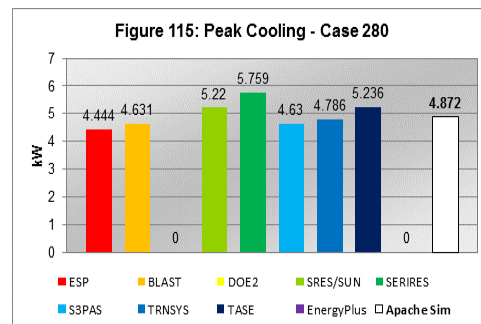
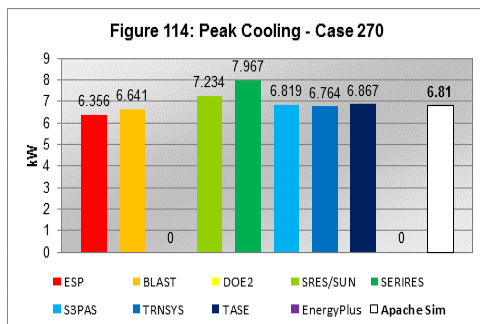
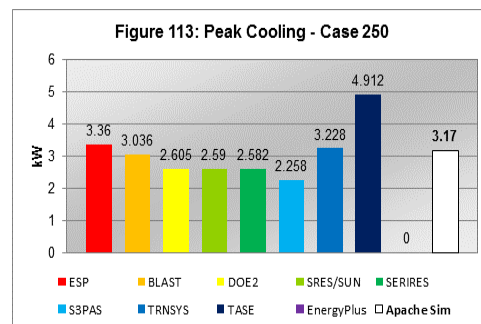
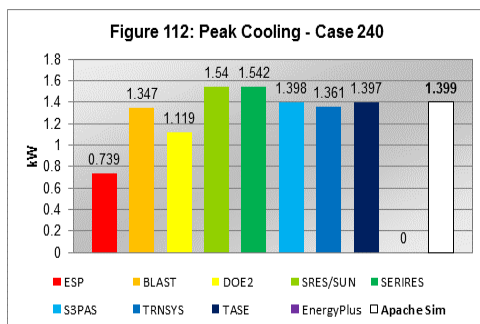
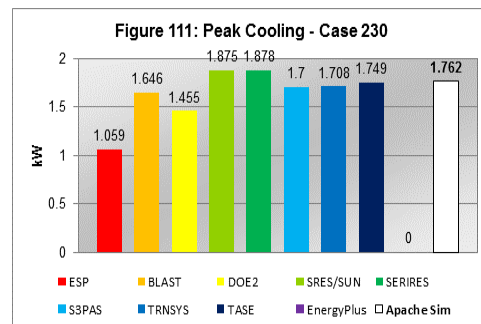
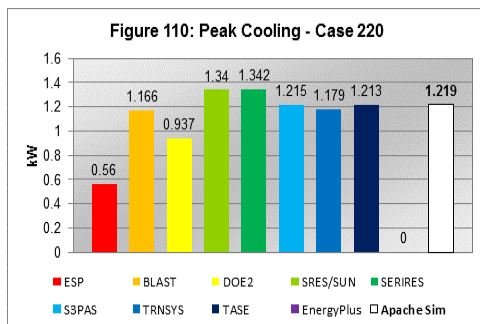
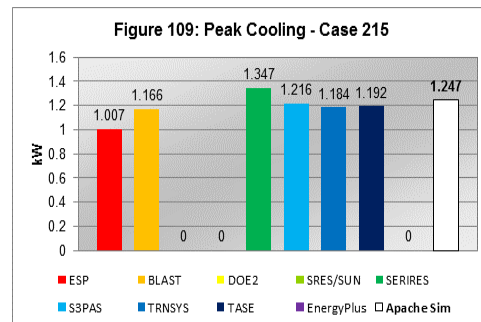
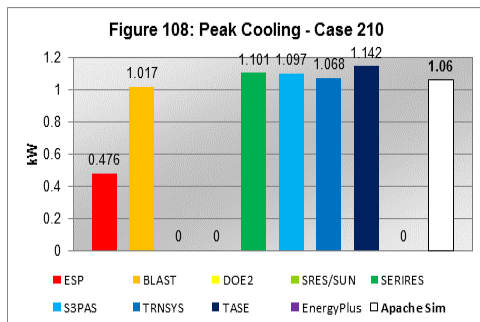
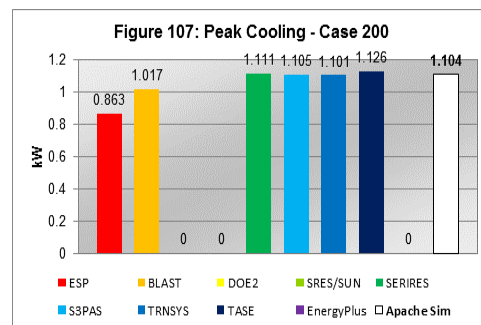
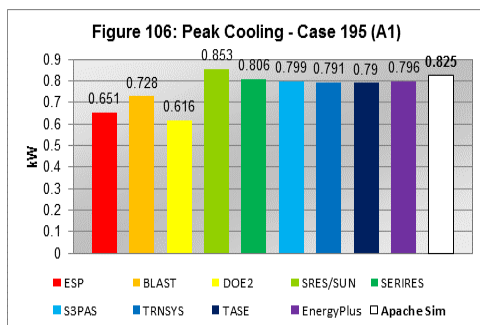


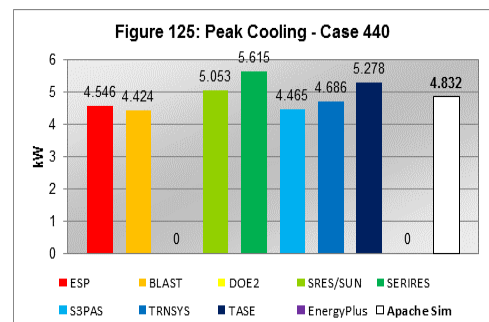
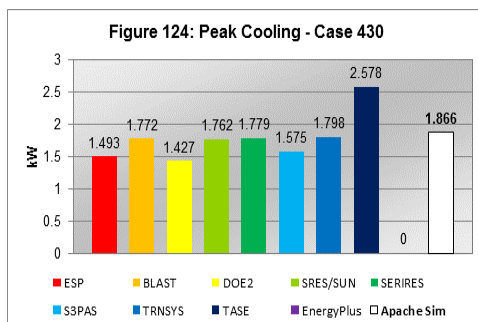
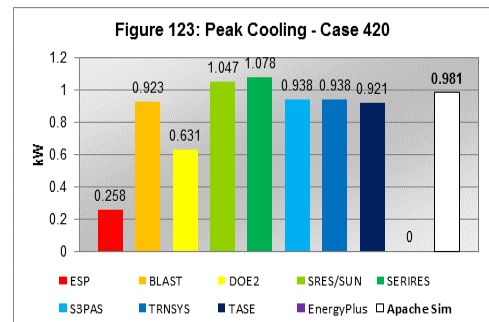
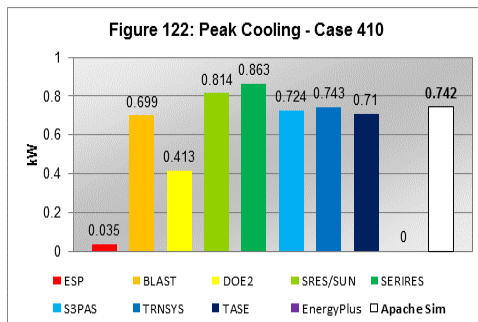
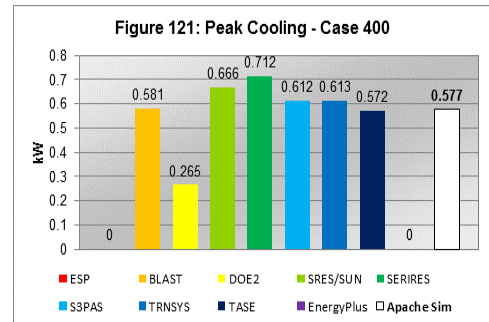
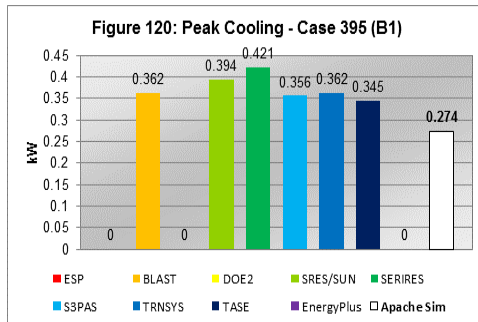
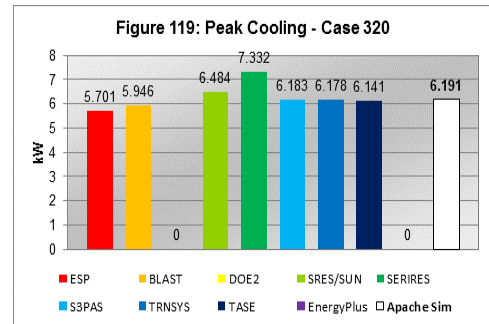
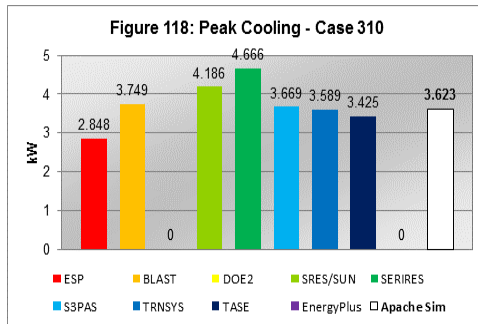
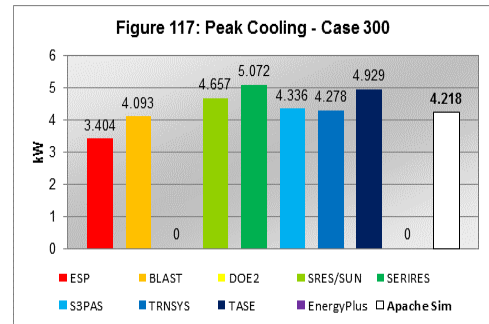
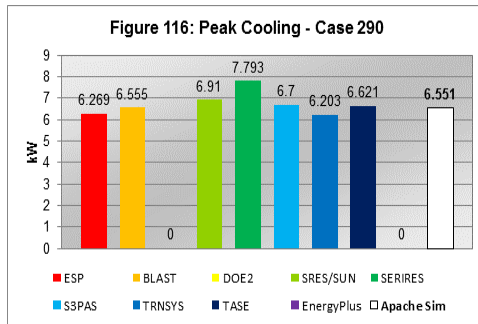


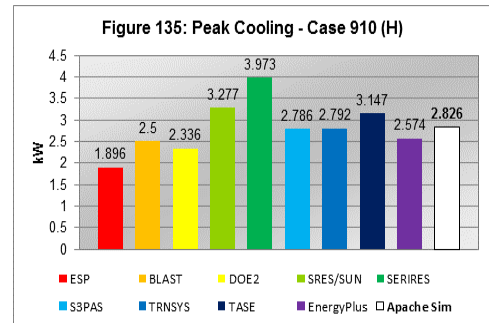
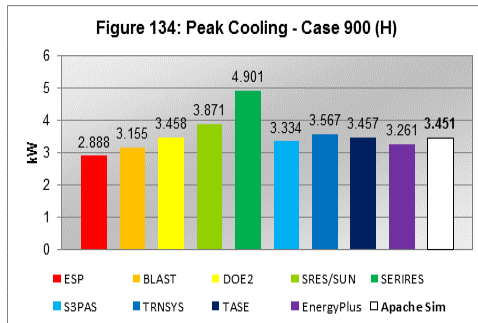
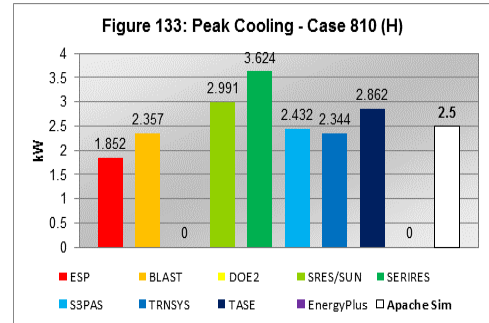
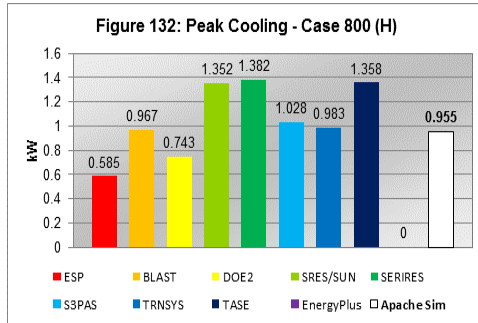
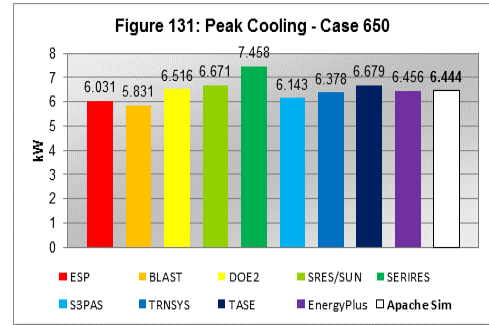
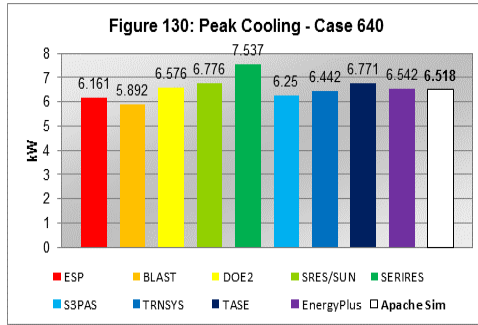
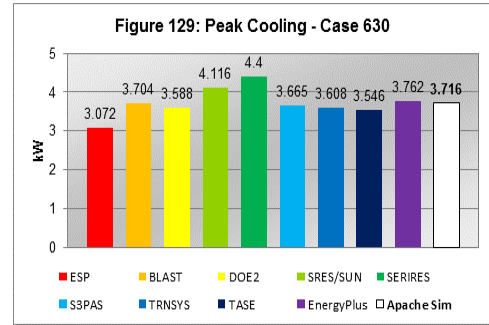
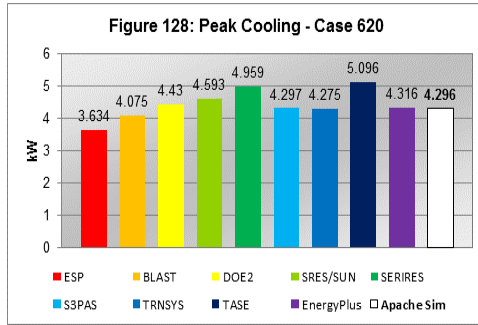
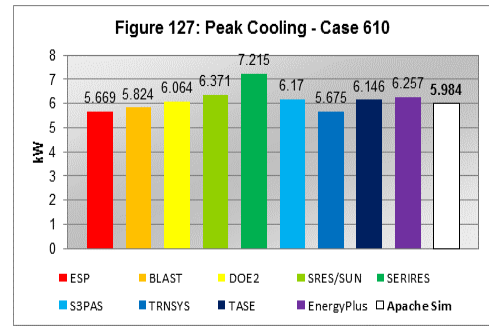
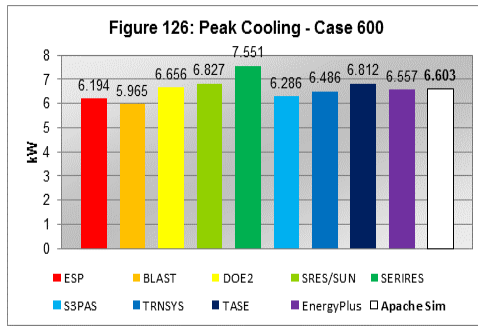


## **Figures 106 - 140**

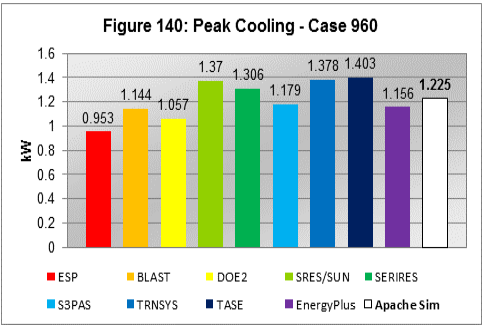
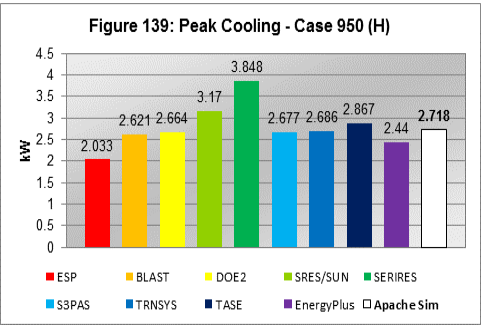
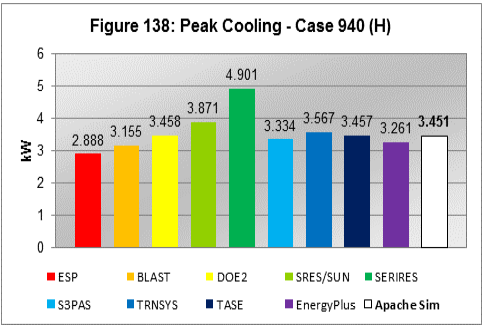
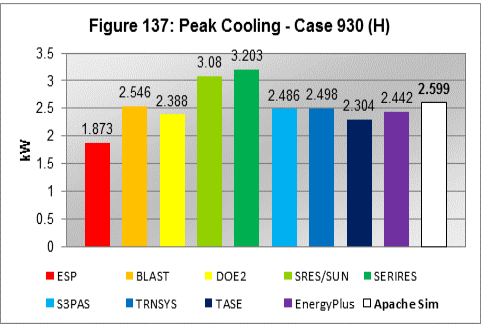
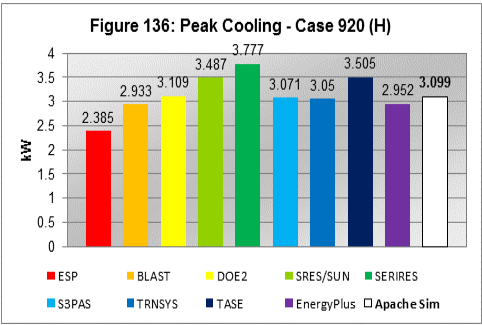
### **Peak Cooling Load**





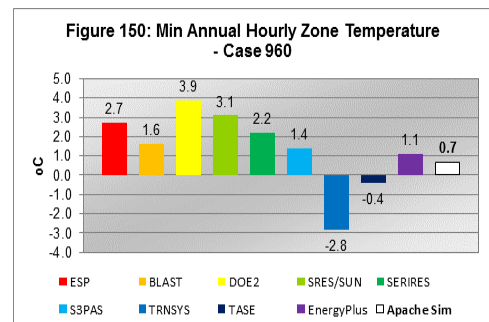
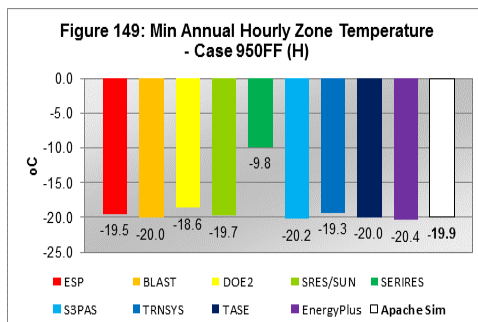
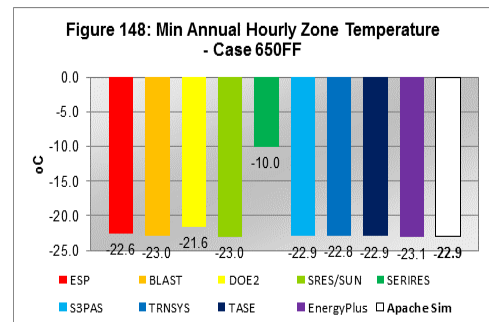
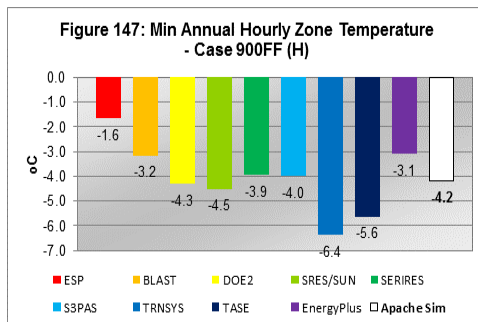
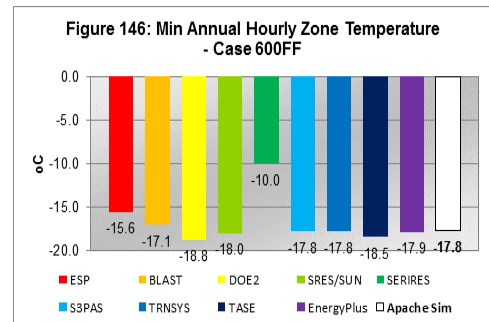
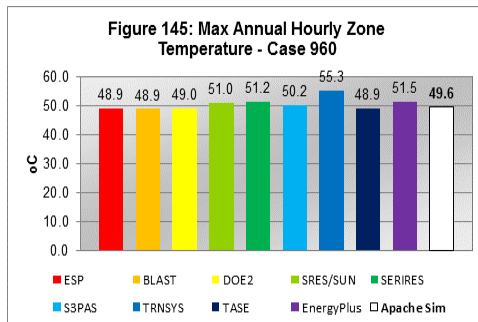
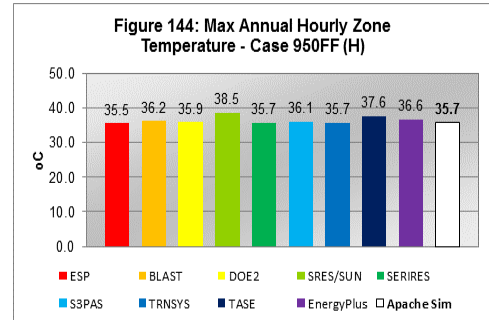
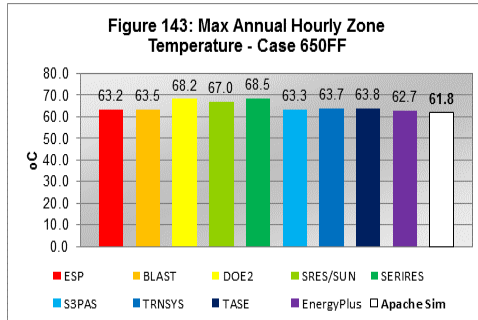
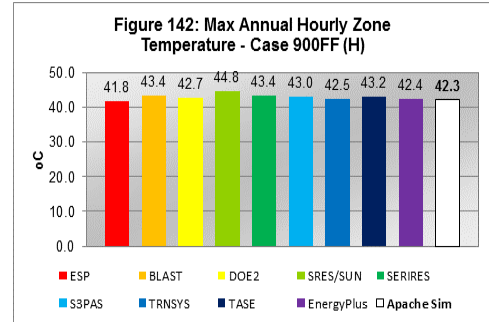
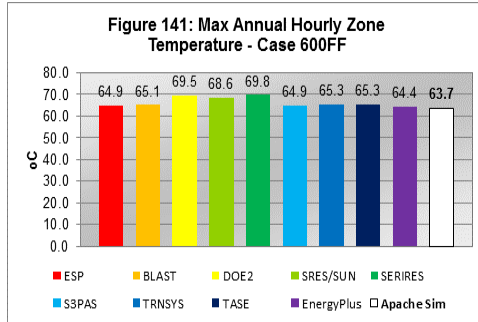


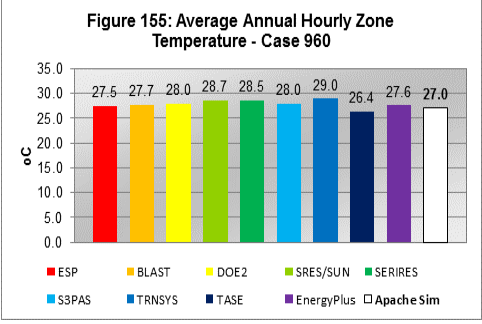
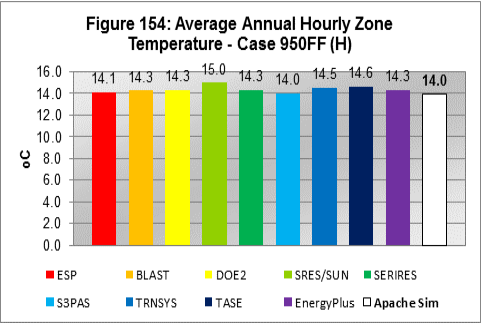
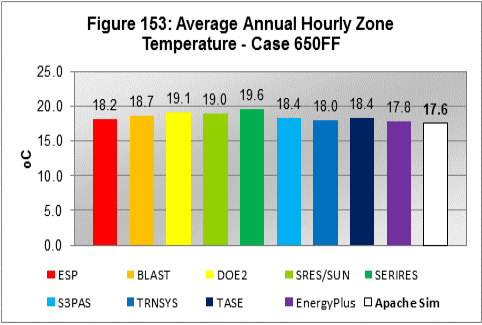
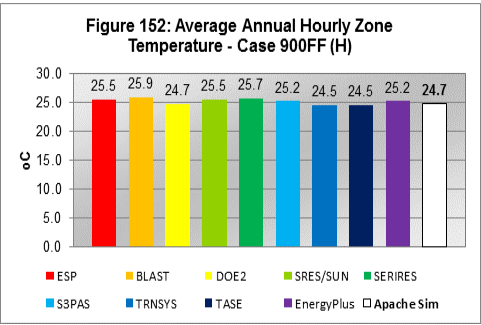
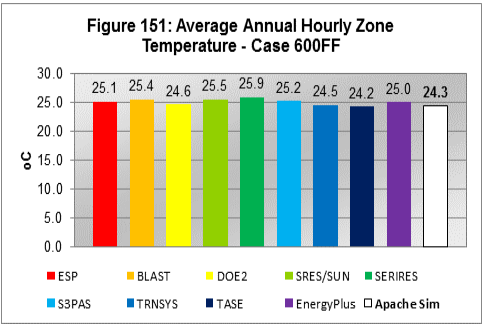




## **Figures 141 - 155**

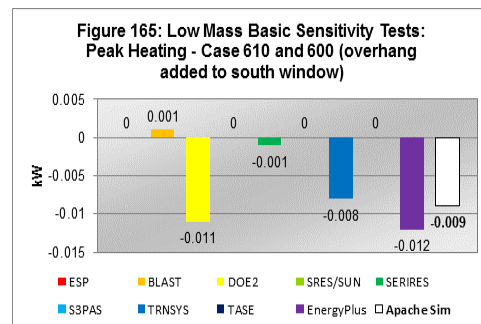
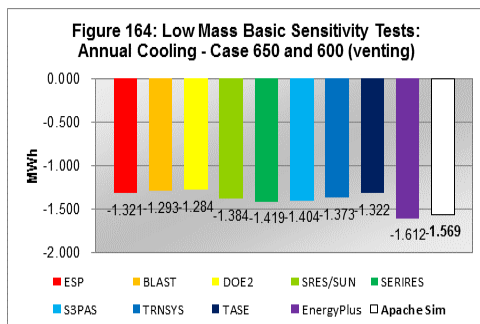
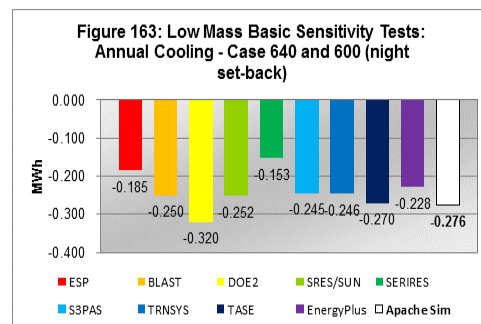
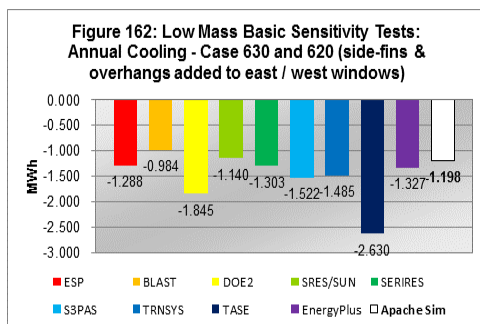
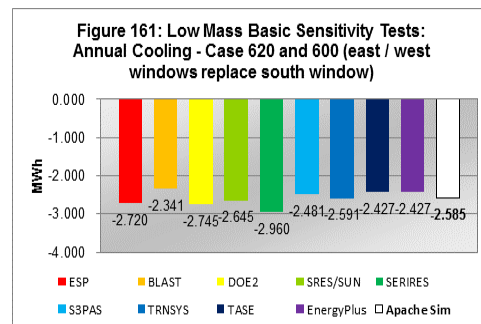
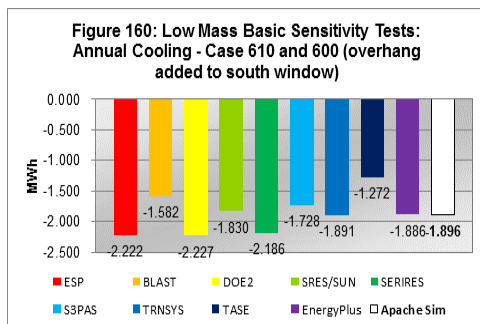
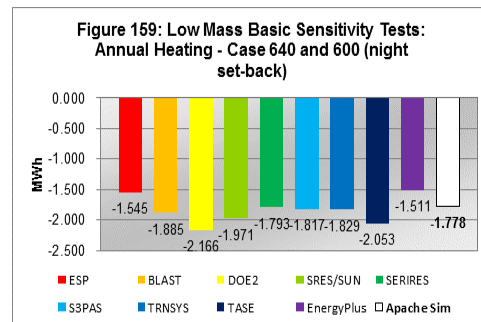
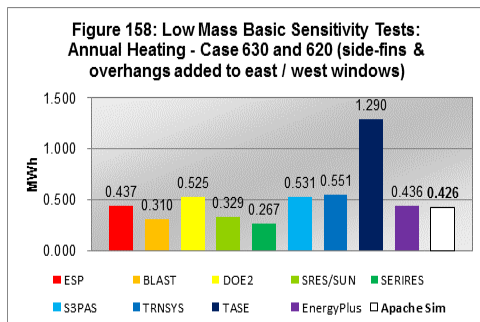
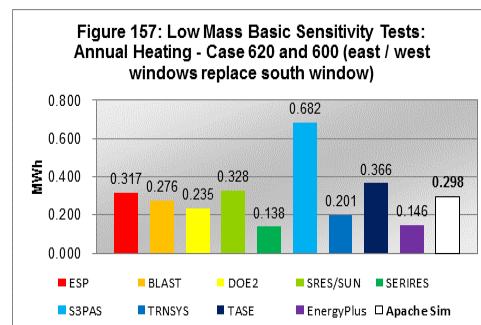
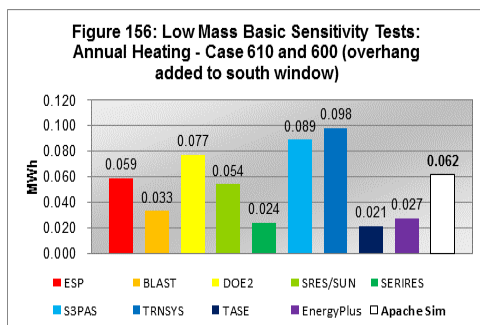
### **Free-Floating Temperatures**

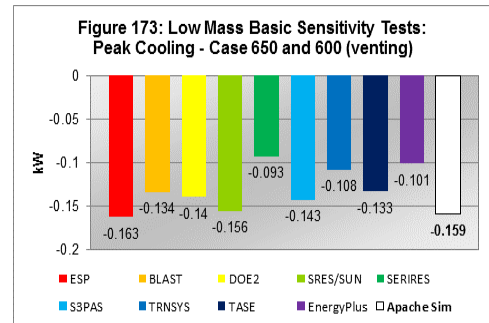
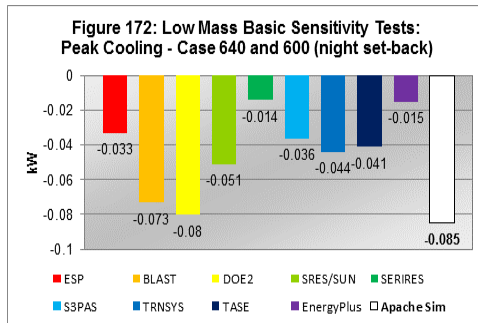
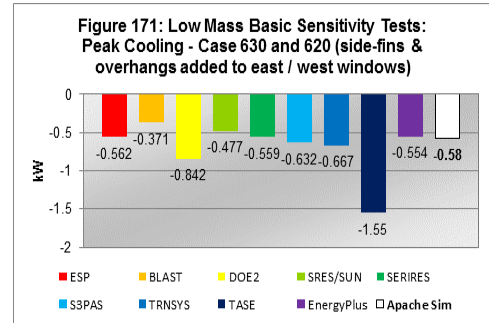
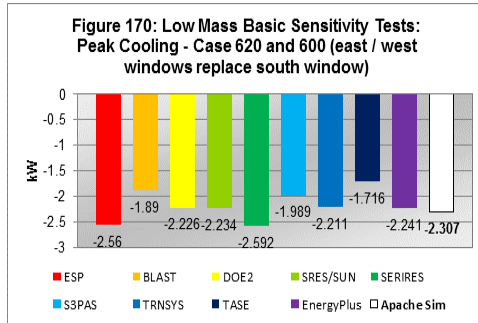
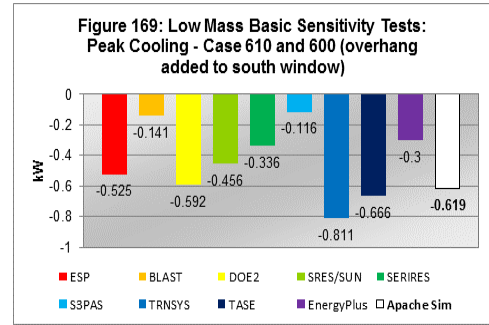
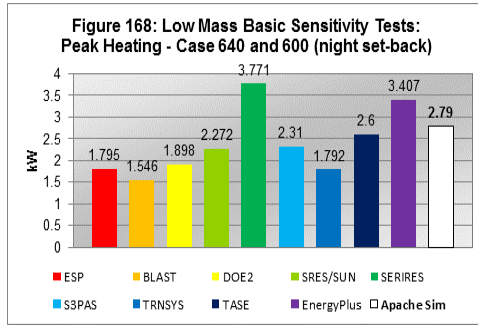
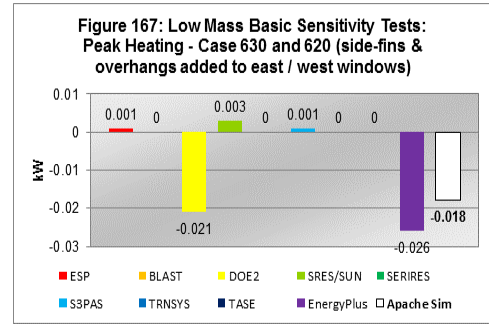
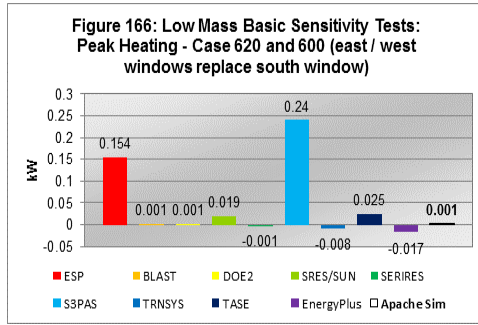




## **Figures 156 - 173**

### **Low-mass Basic Sensitivity Tests**

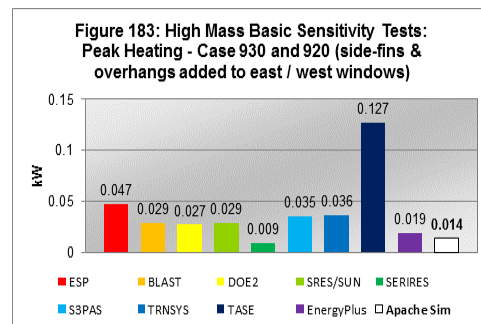
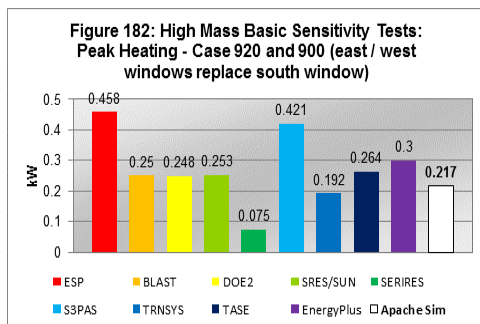
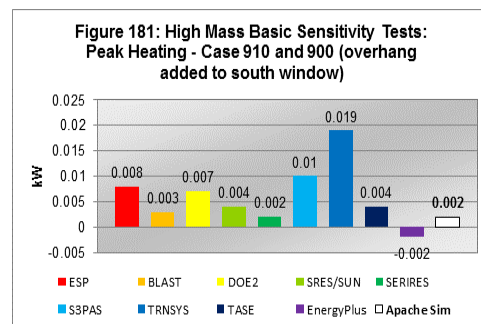
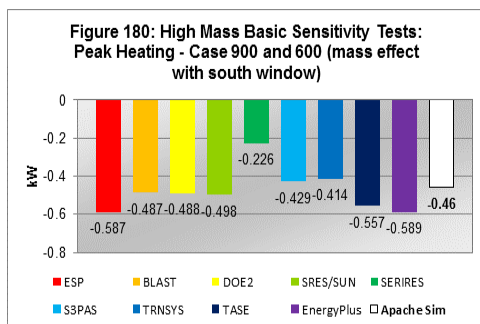
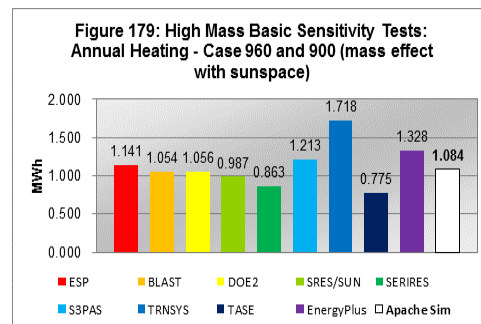
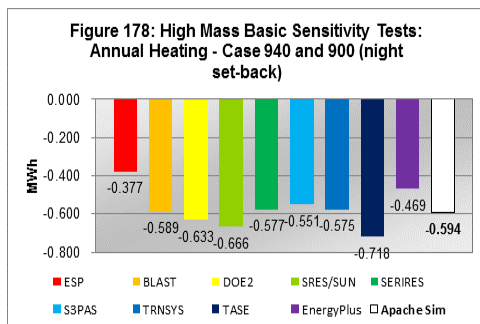
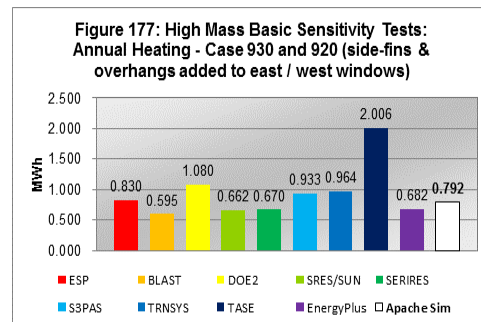
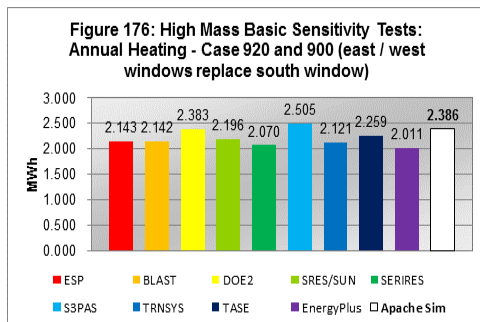
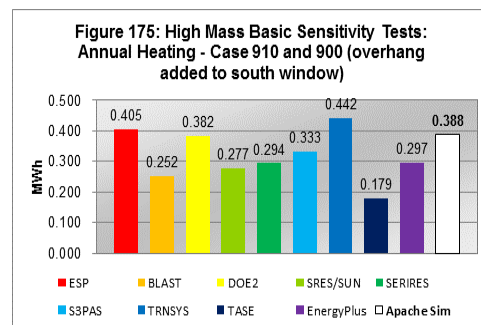
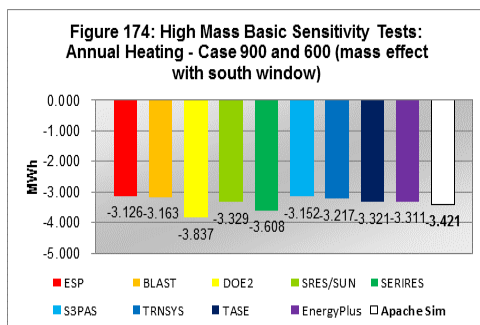


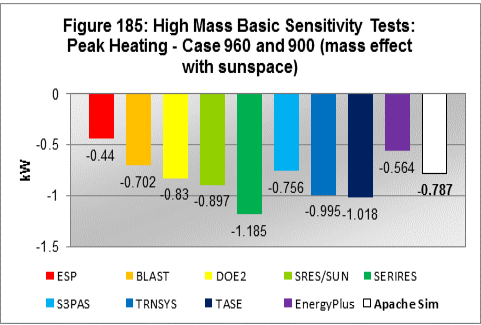
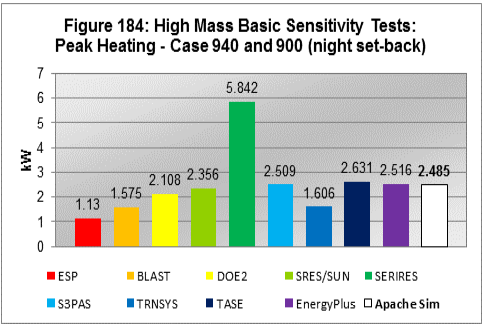


## **Figures 174 - 185**

### **High-mass Basic Sensitivity Tests - Heating**

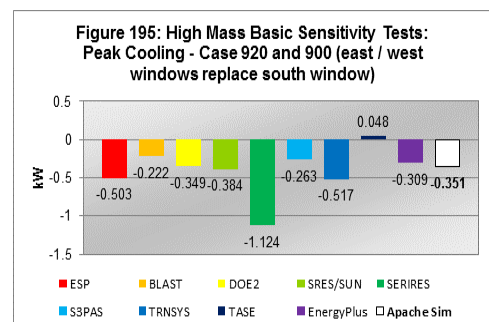
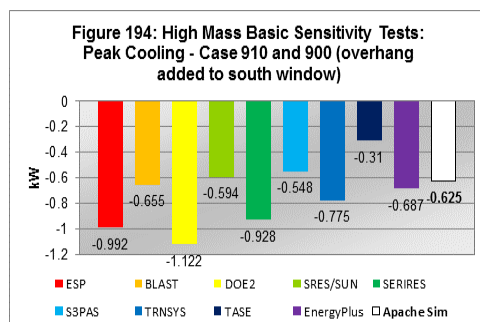
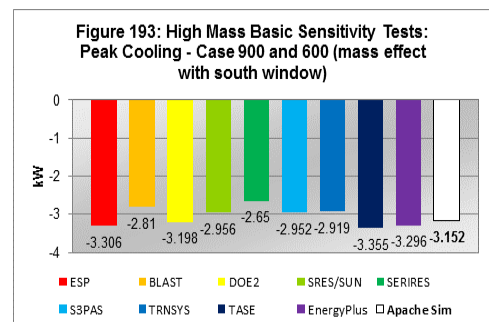
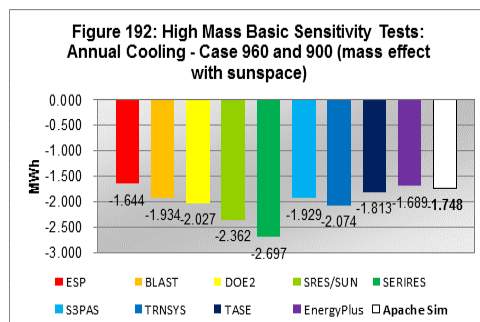
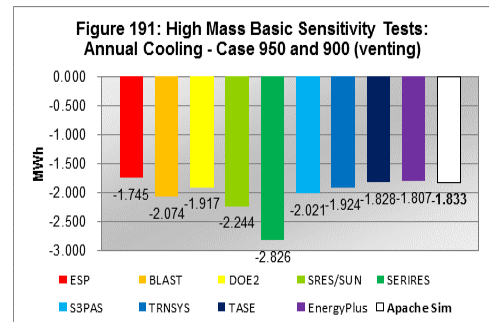
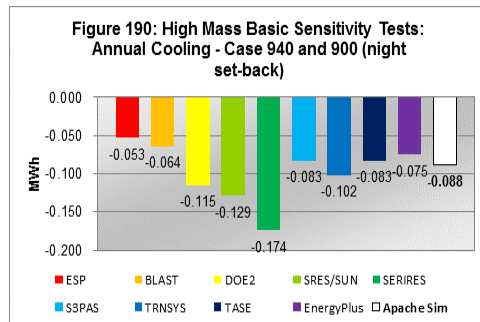
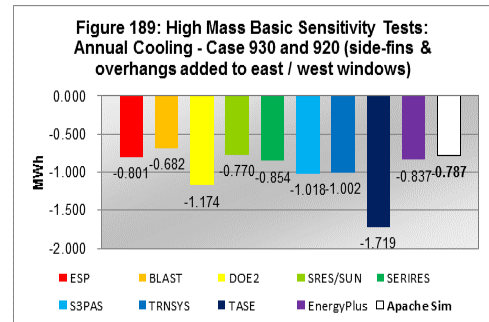
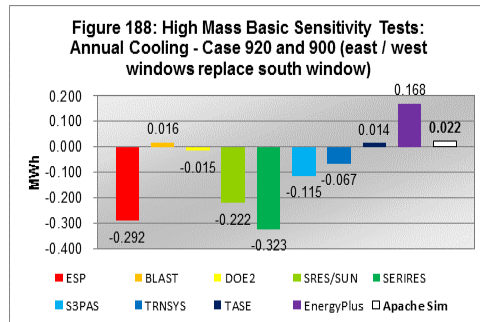
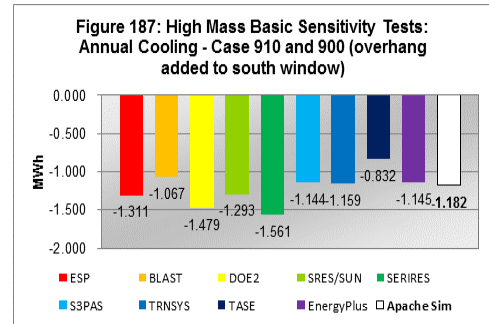
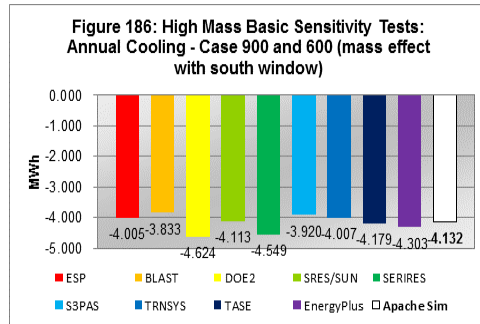


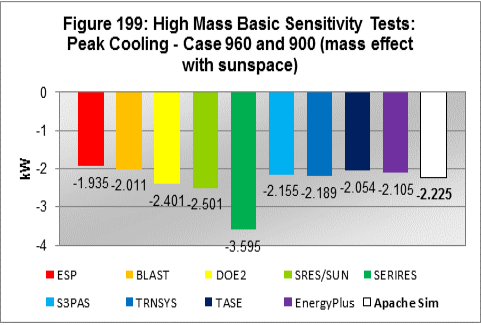
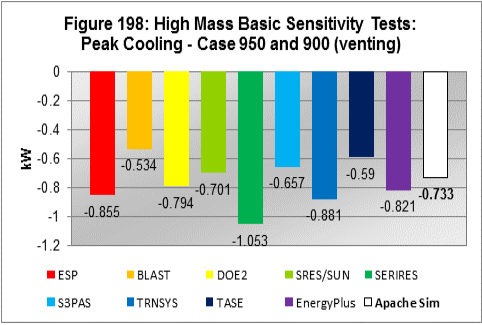
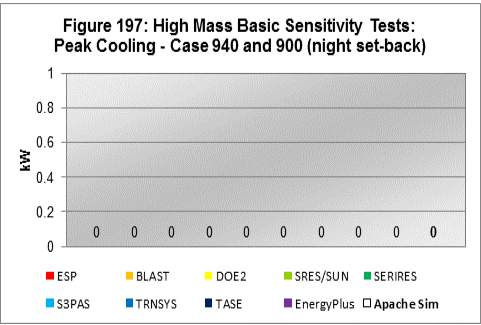
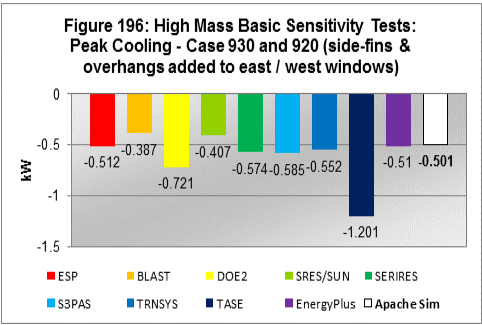




## **Figures 186 - 199**

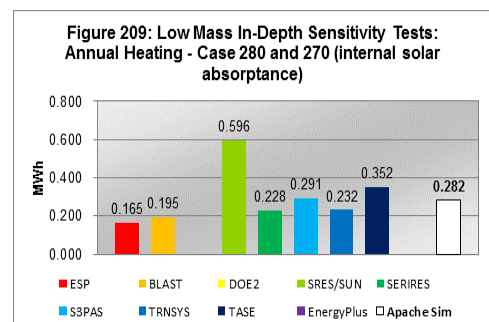
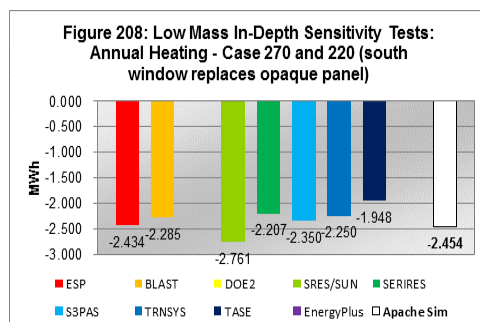
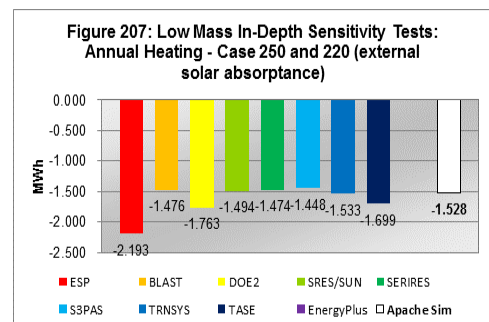
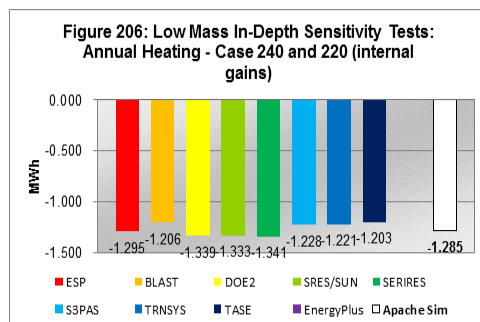
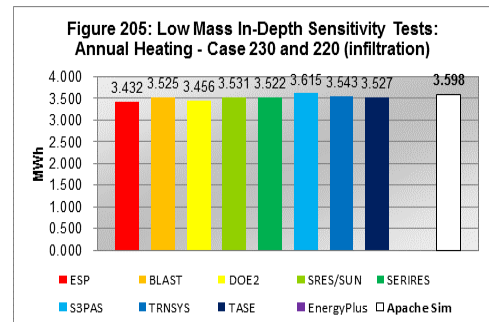
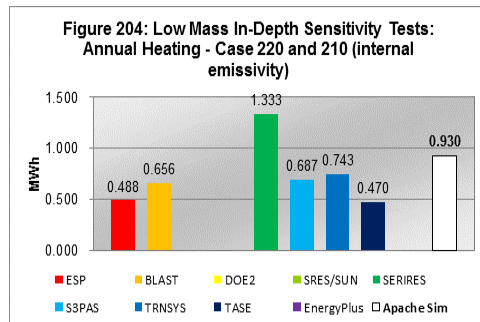
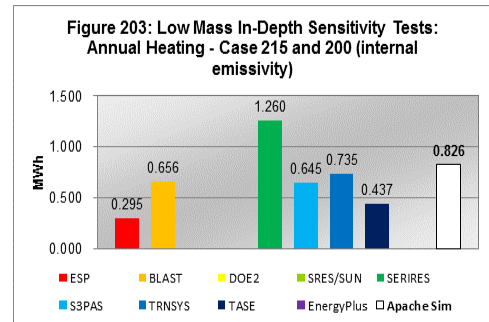
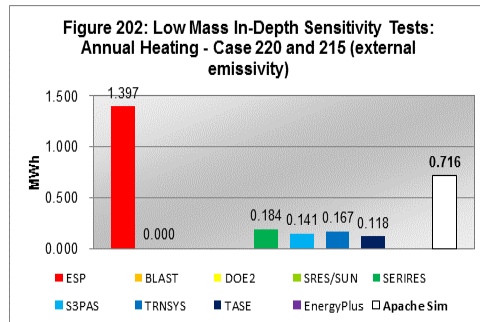
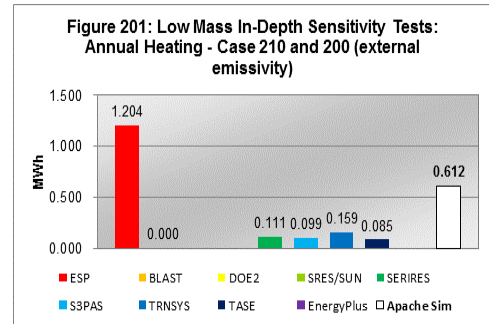
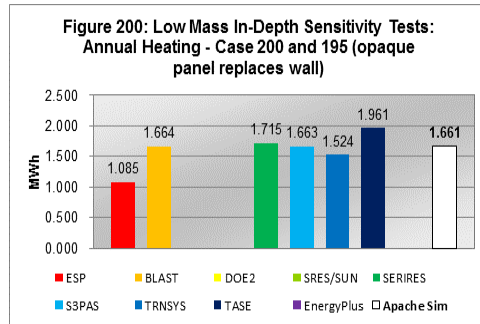
### **High-mass Basic Sensitivity Tests - Cooling**

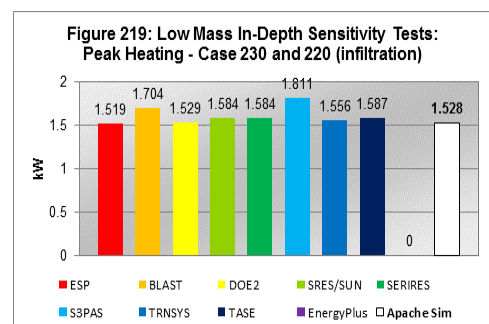
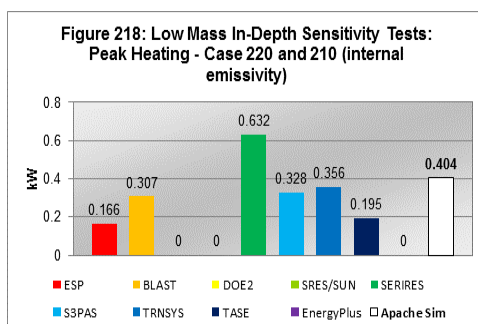
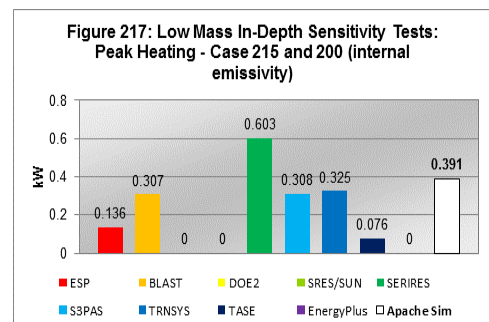
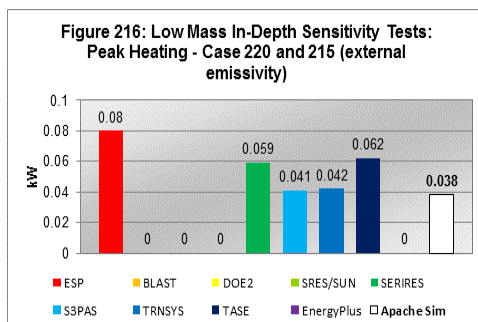
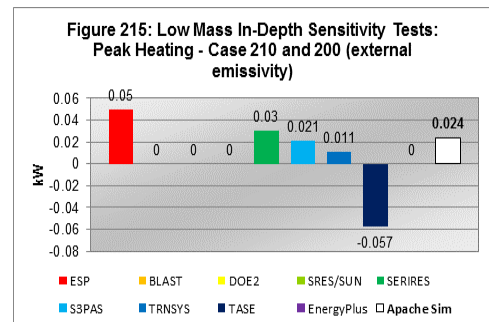
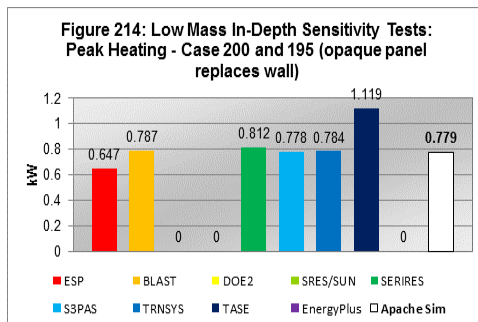
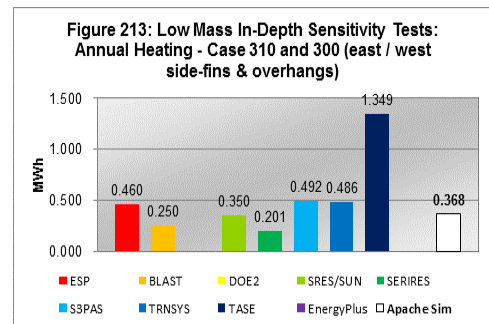
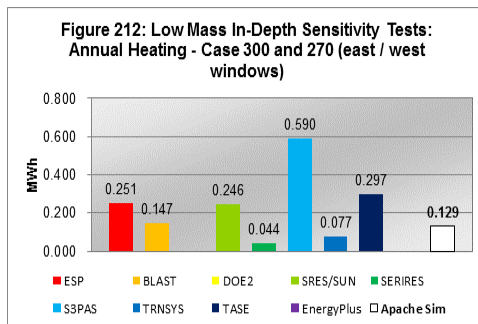
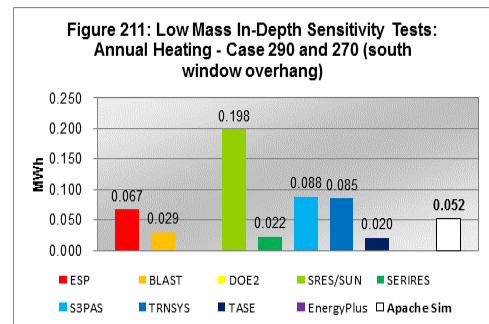
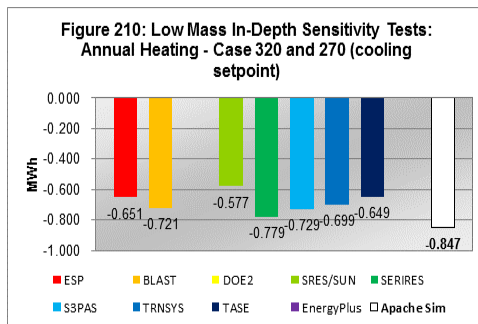




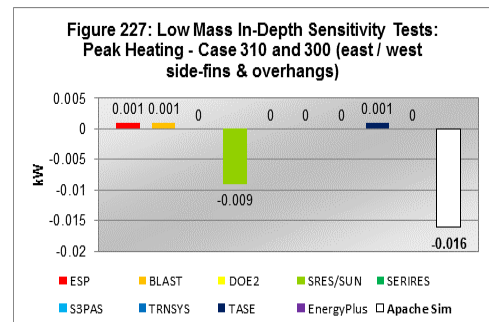
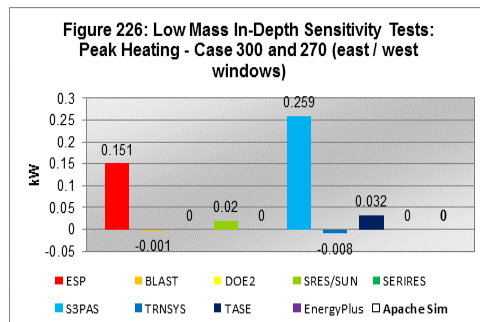
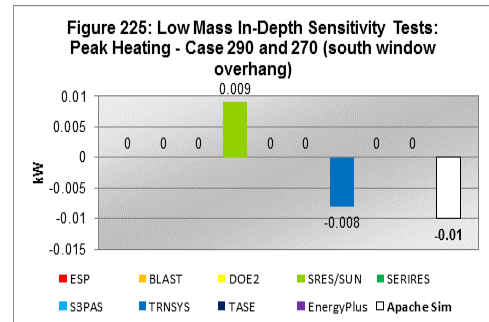
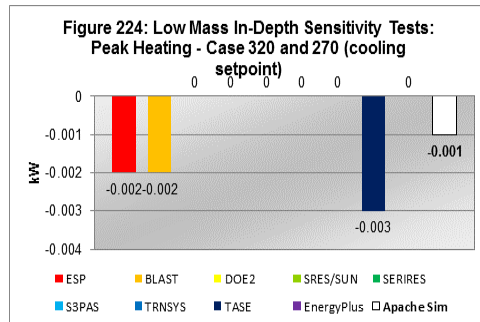
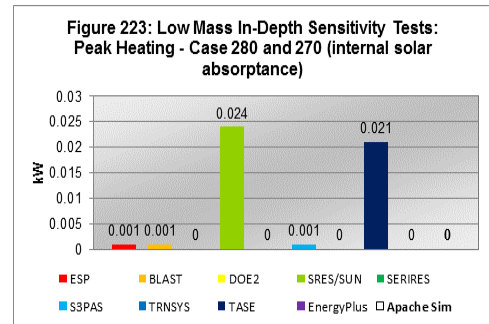
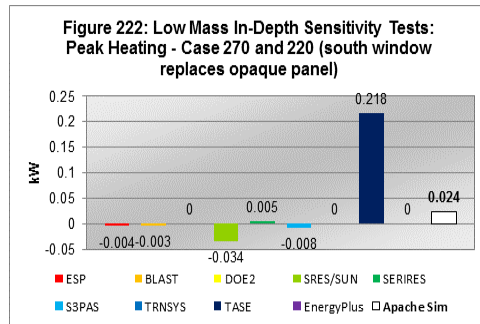
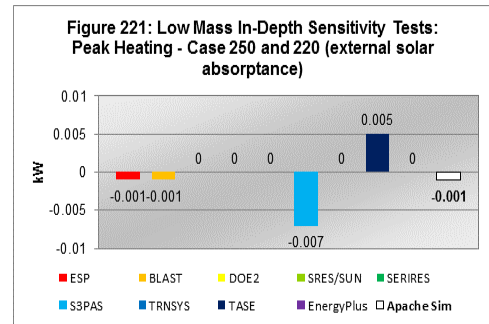
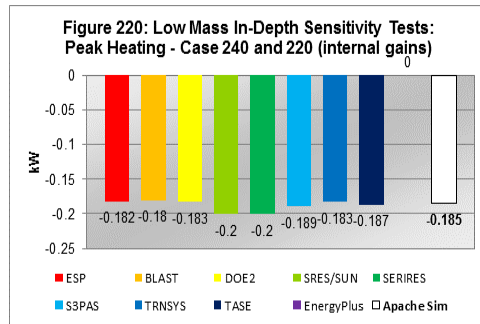
## **Figures 200 - 227**

### **Low-mass In-Depth Sensitivity Tests Cases 195-320: Heating**



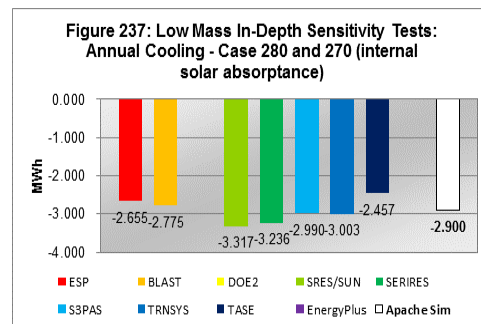
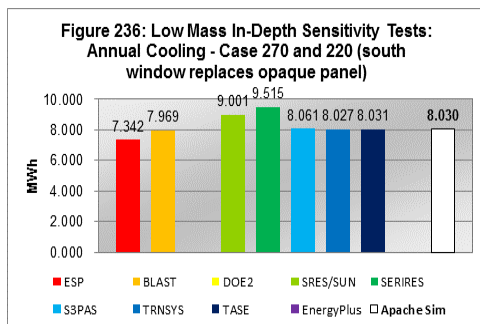
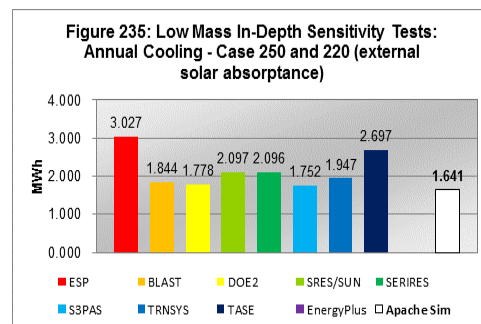
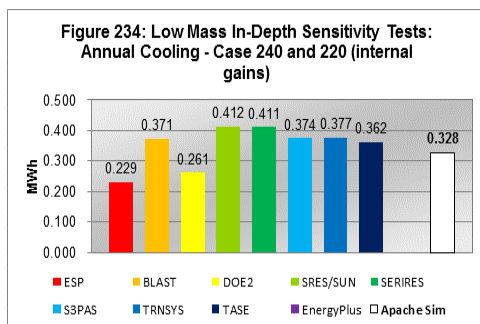
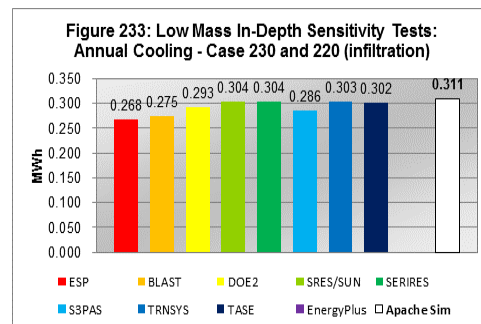
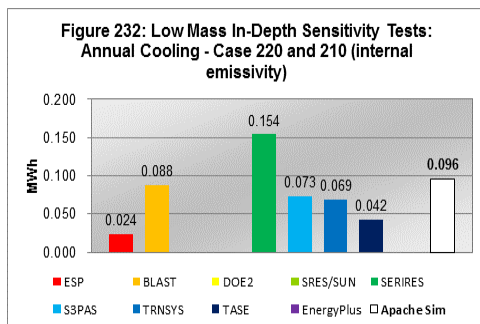
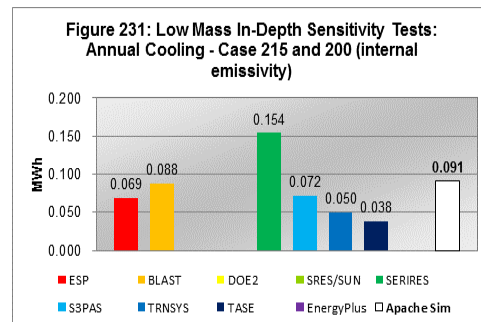
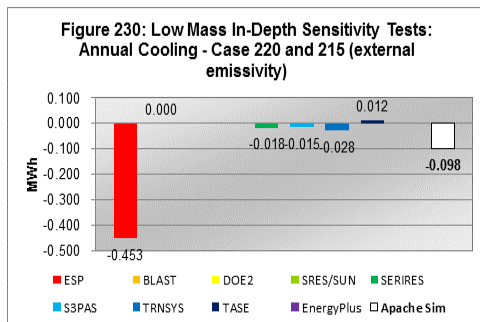
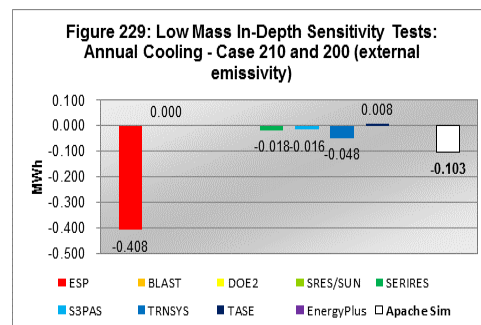
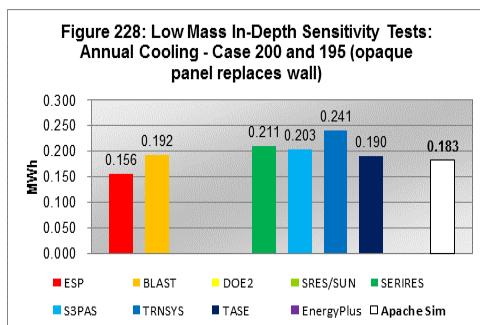


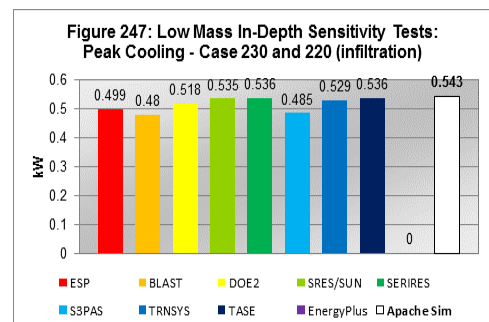
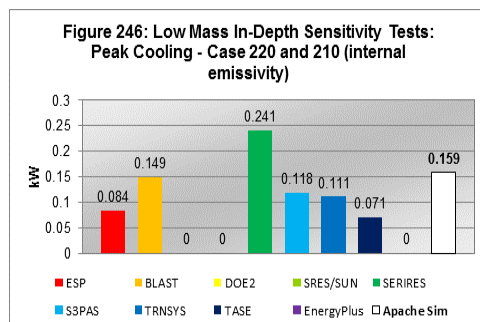
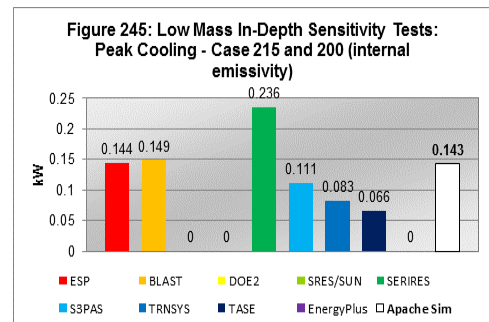
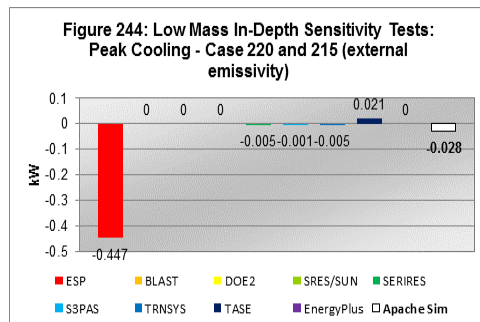
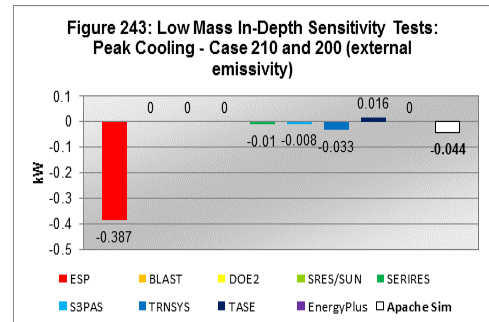
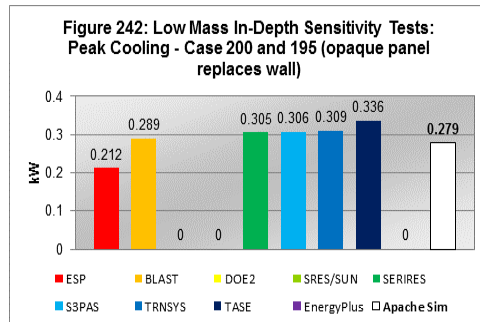
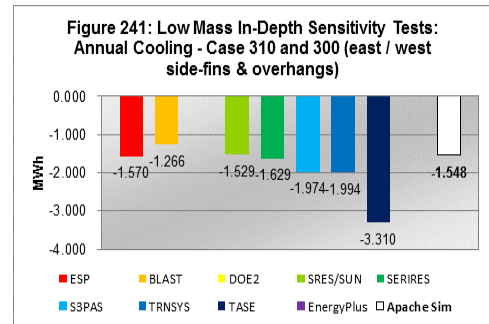
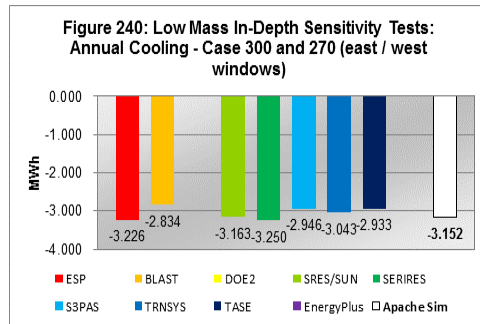
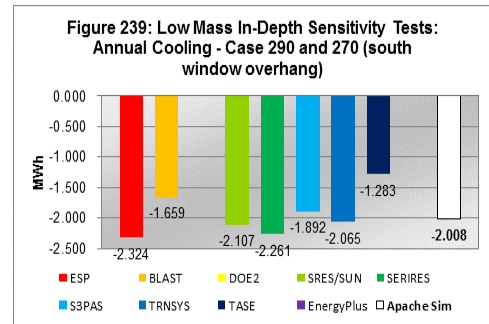
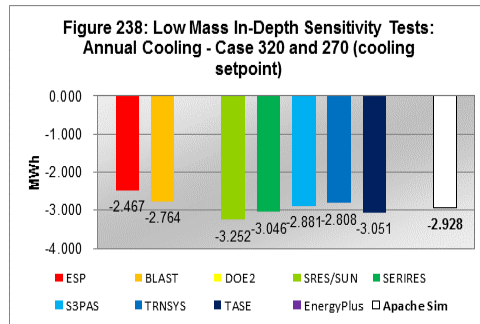


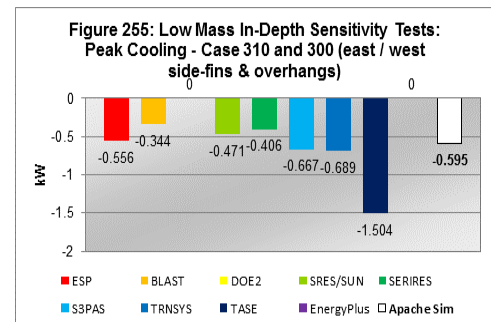
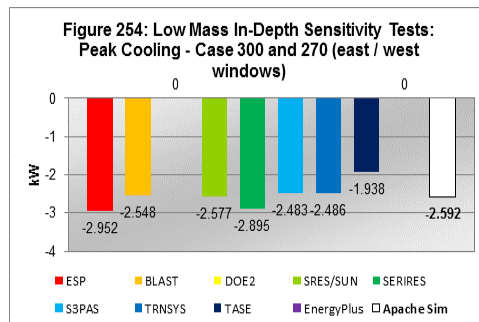
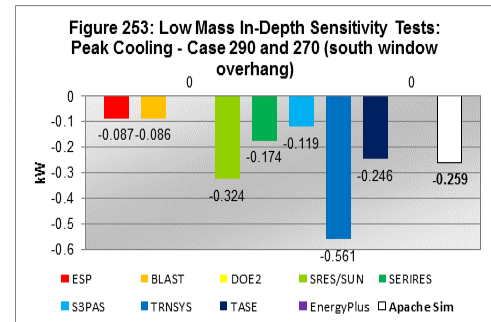
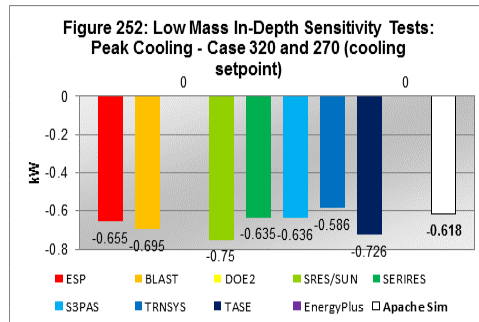
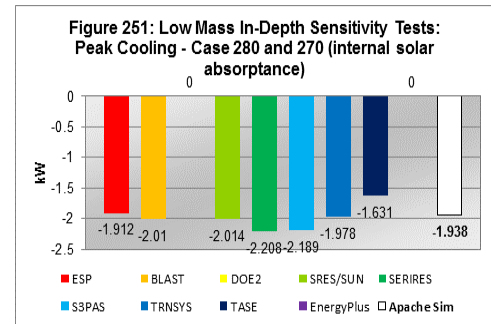
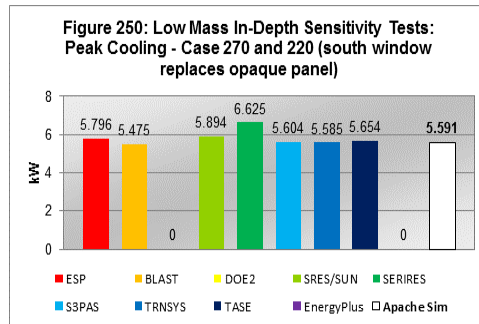
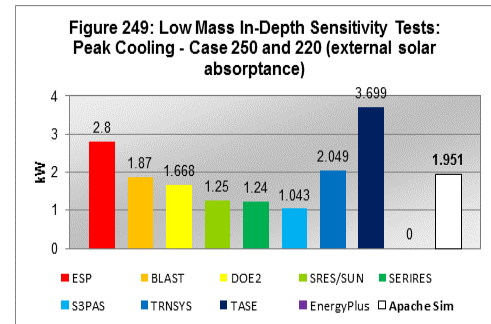
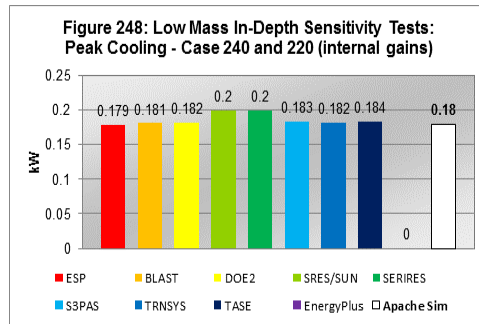


## **Figures 228 - 255**

### **Low-mass In-Depth Sensitivity Tests Cases 195-320: Cooling**

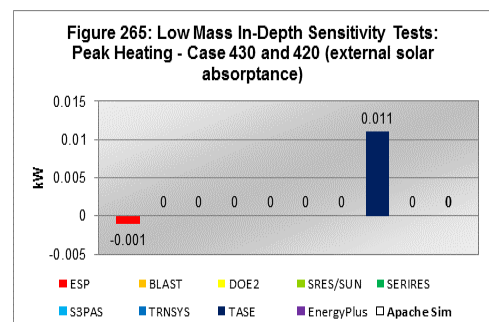
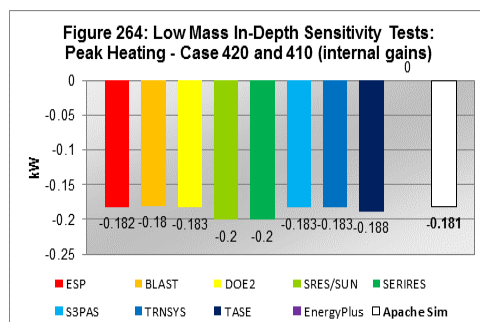
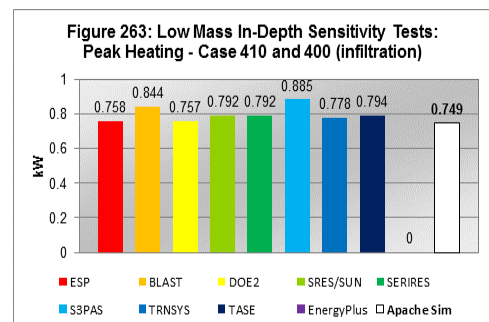
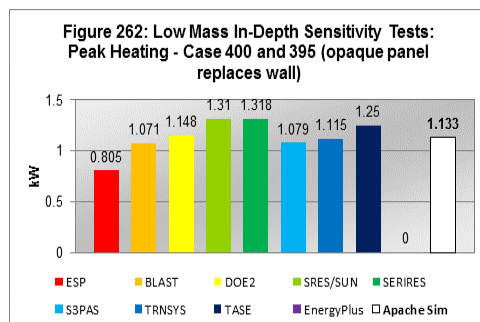
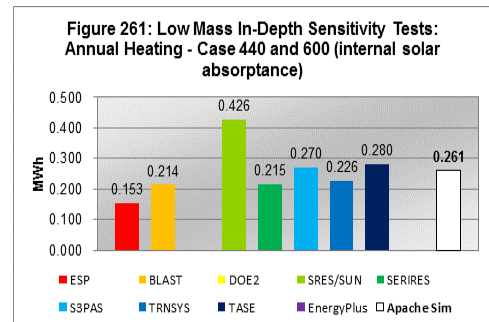
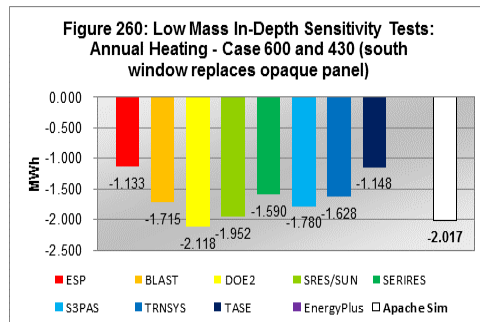
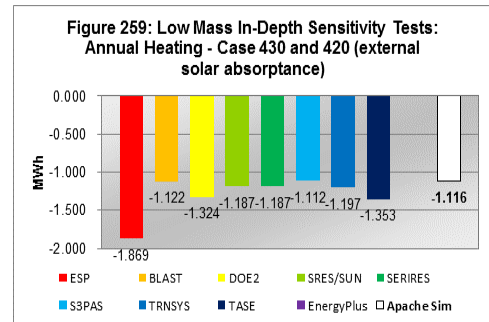
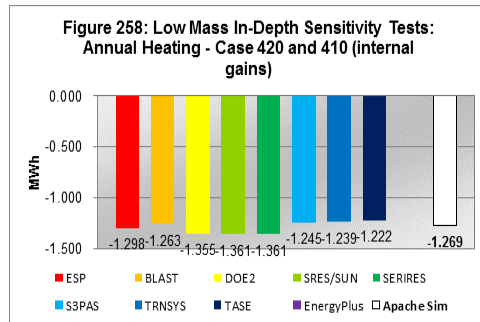
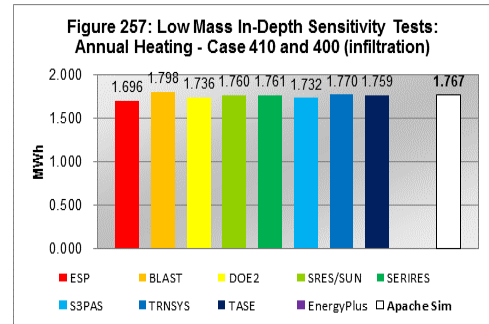
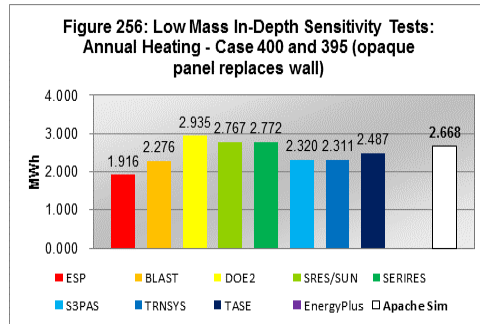


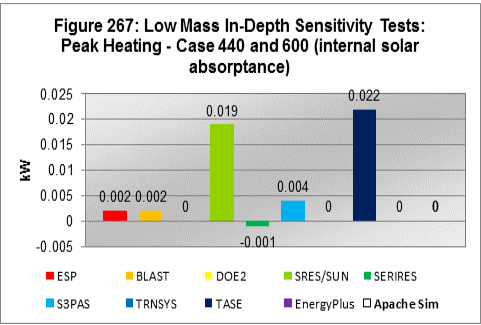
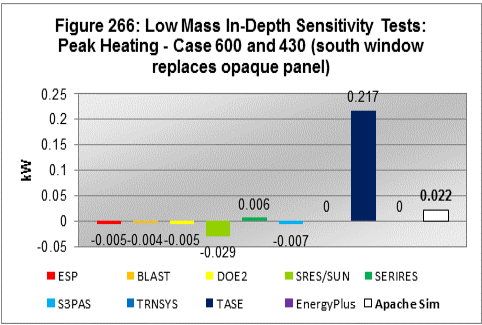




## **Figures 256 - 267**

### **Low-mass In-Depth Sensitivity Tests Cases 395-440: Heating**

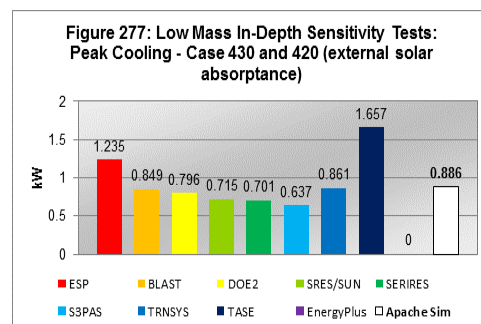
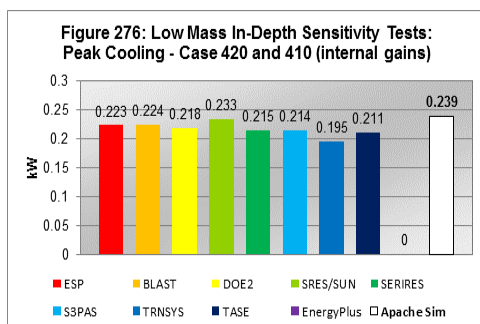
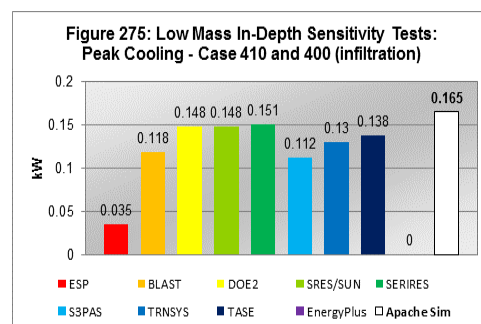
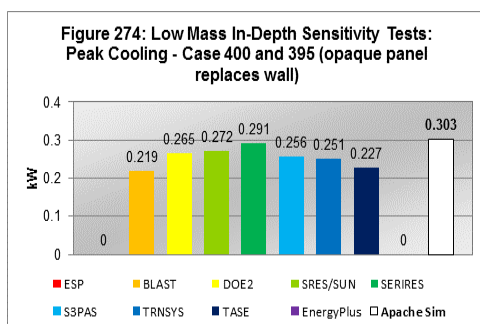
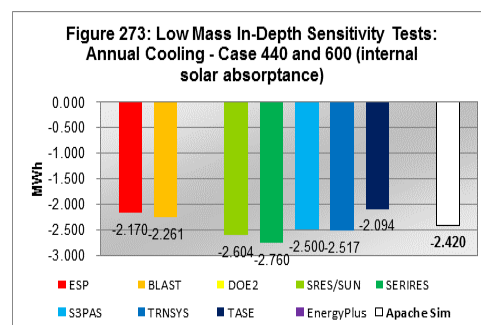
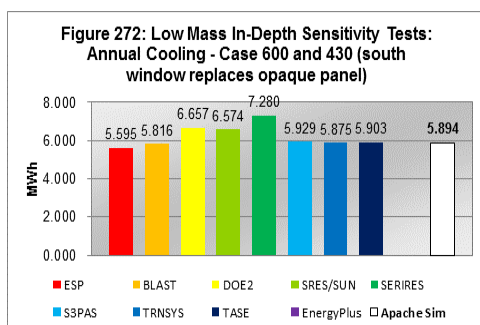
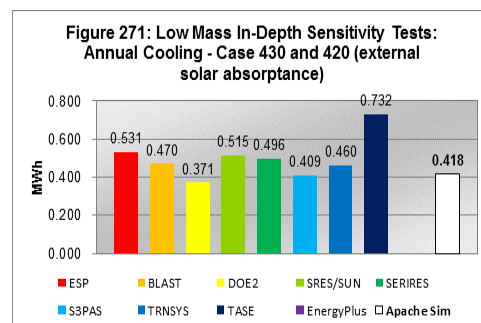
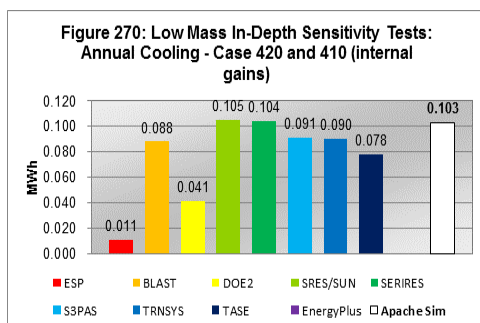
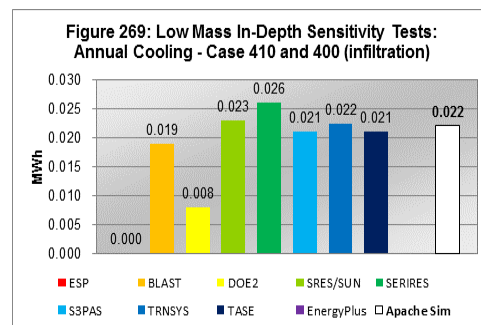
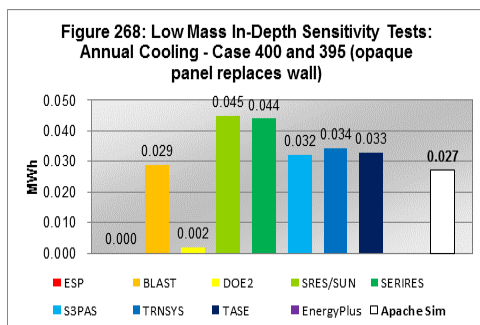


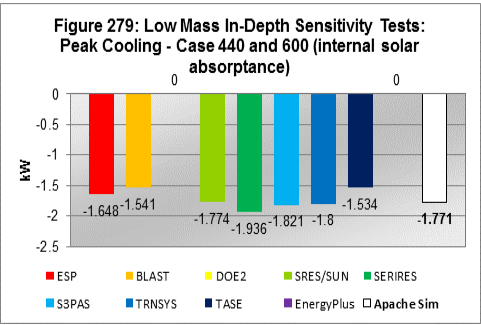
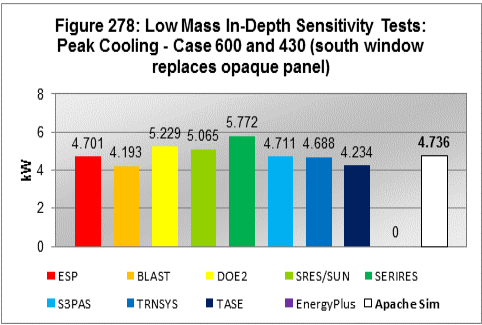




## **Figures 268 - 279**

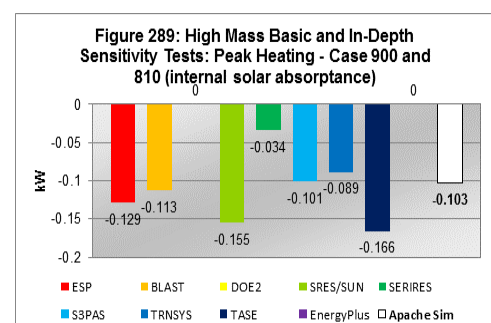
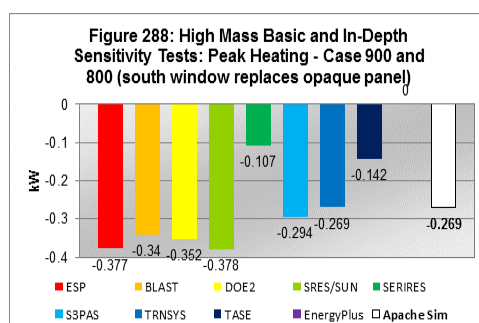
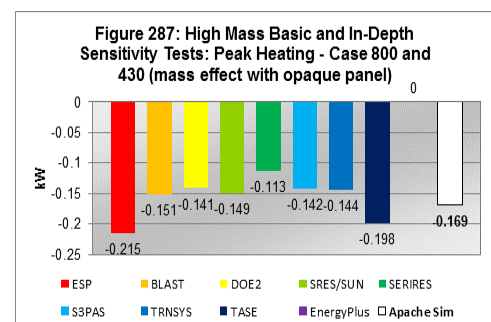
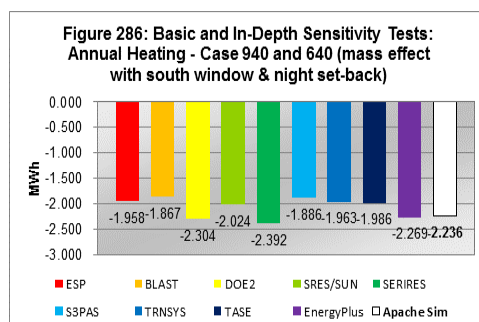
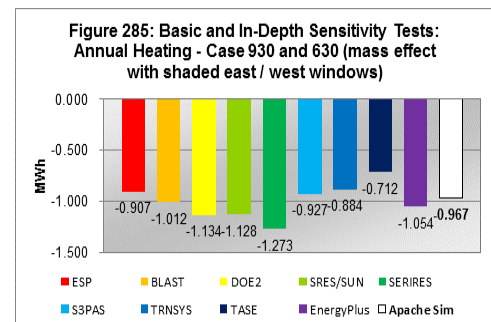
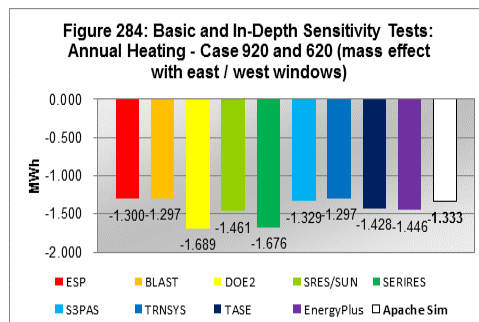
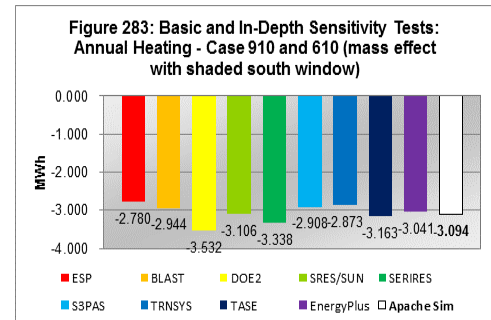
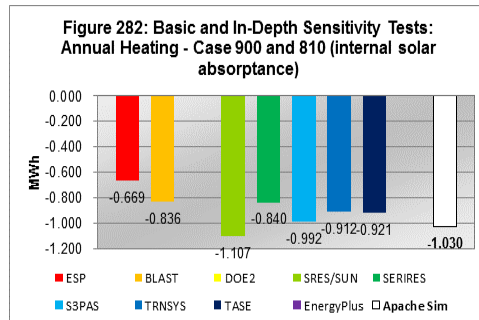
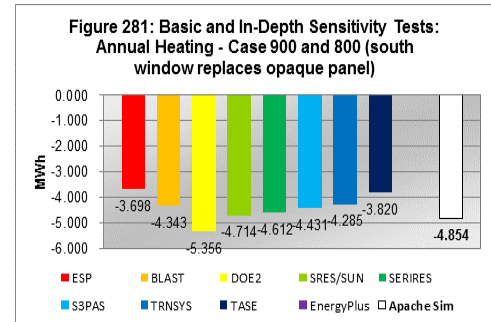
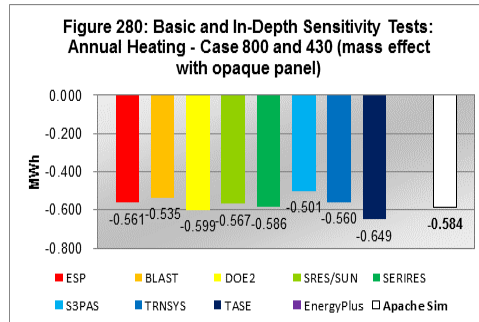
### **Low-mass In-Depth Sensitivity Tests Cases 395-440: Cooling**

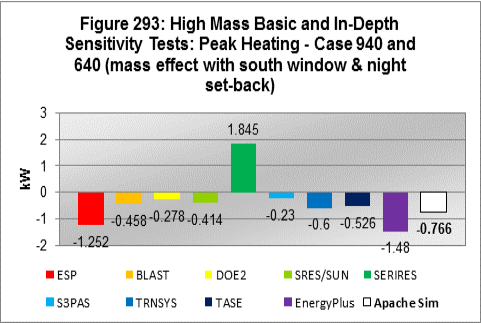
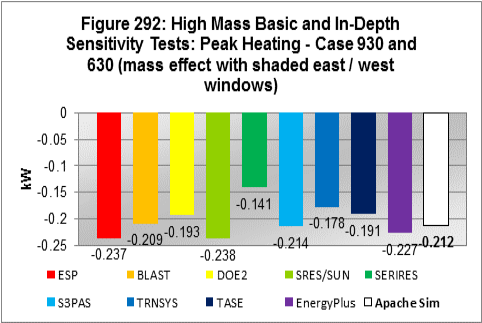
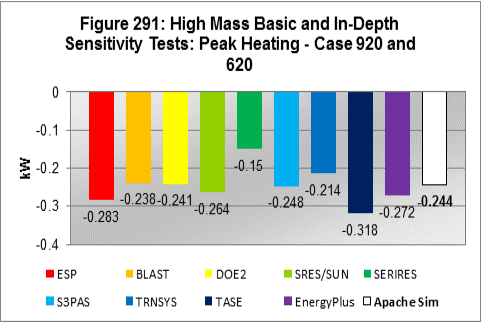
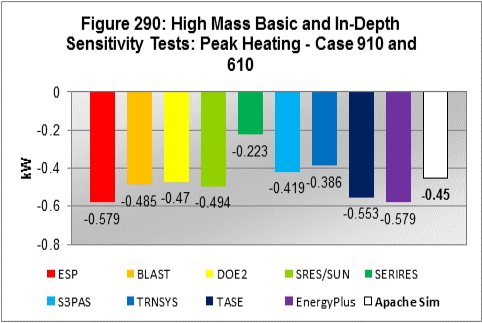




## **Figures 280 - 293**

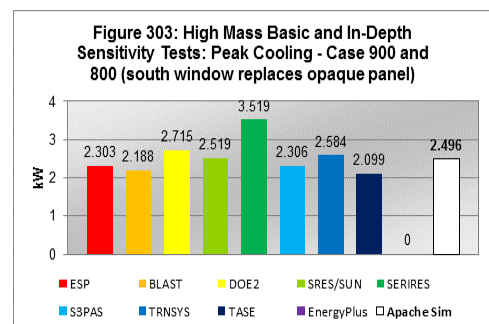
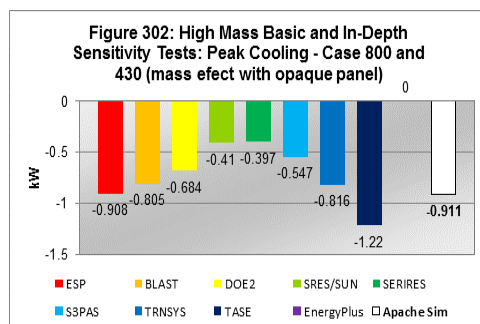
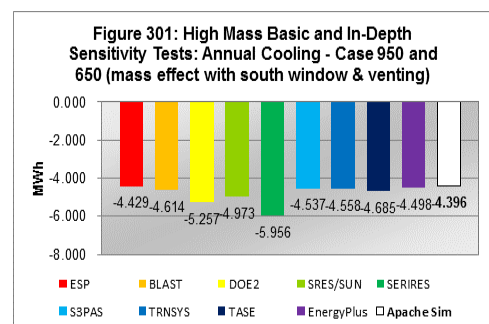
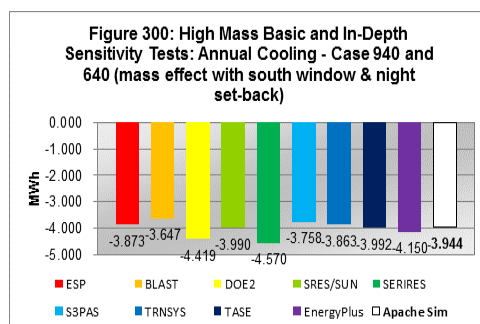
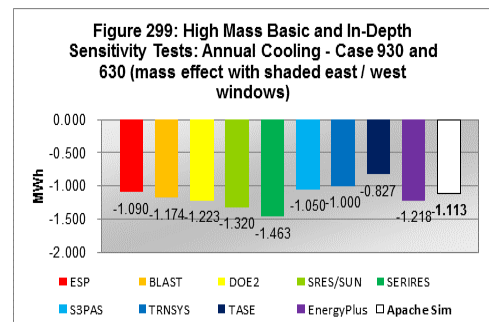
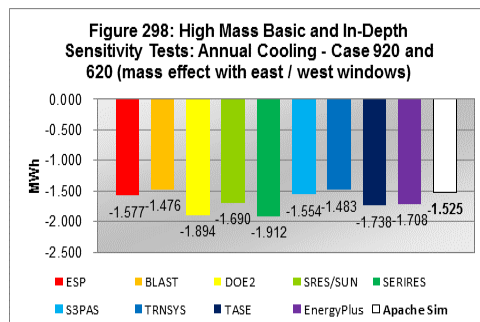
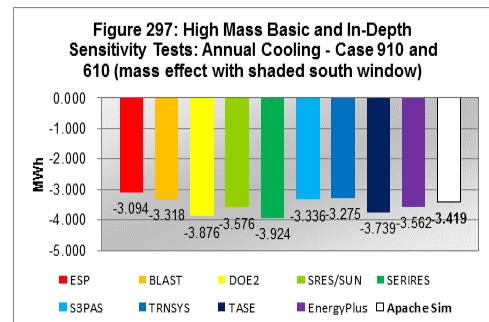
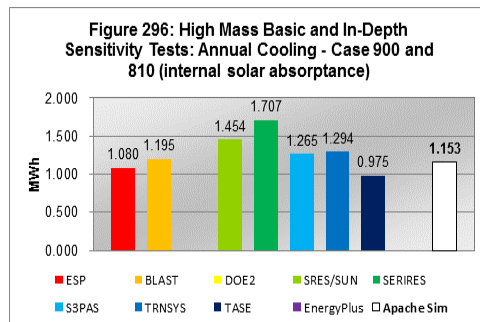
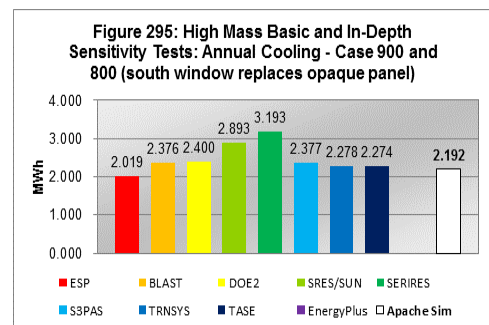
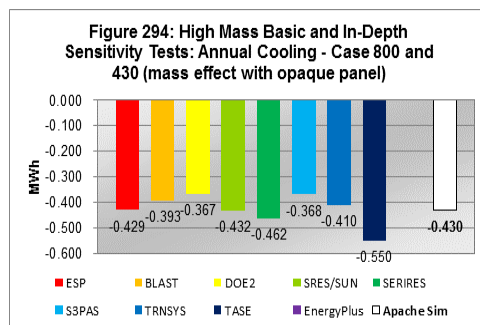
### **High-mass In-Depth Sensitivity Tests Cases 800-950: Heating**



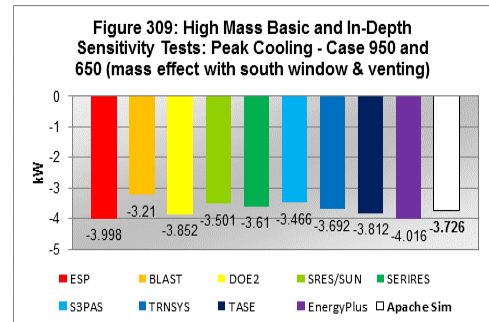
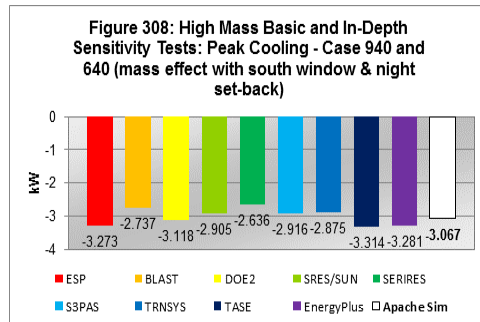
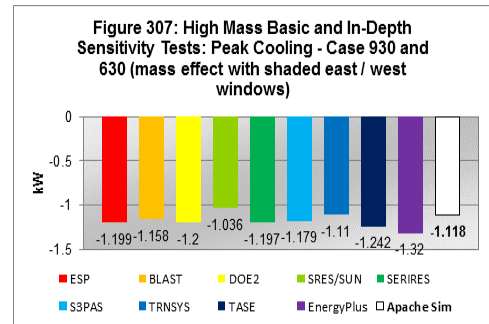
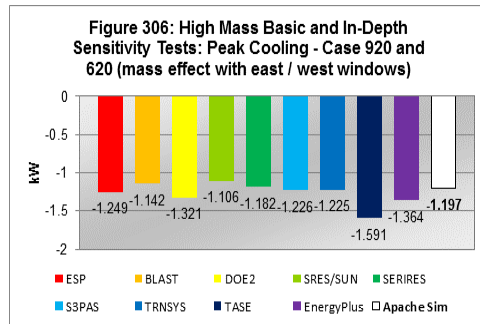
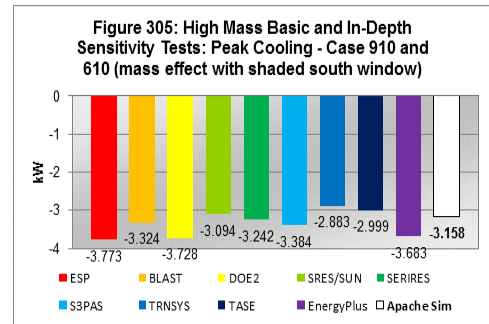
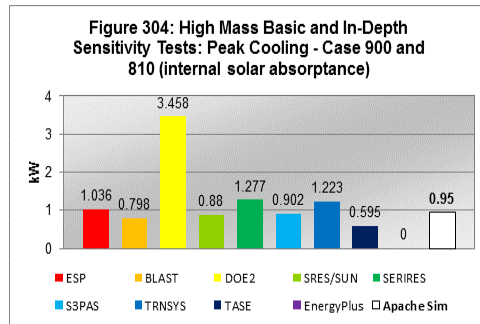


## **Figures 294 - 309**

### **High-mass In-Depth Sensitivity Tests Cases 800-950: Cooling**



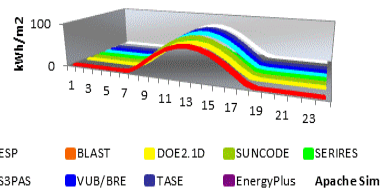




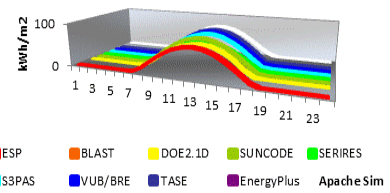
## **Figures 310 - 326**

### **Solar radiation tests**

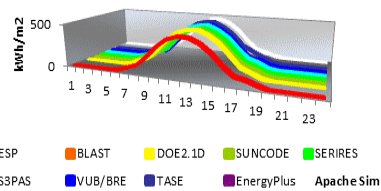
**Figure 310: Hourly Incident Solar Radiation South Surface, March 5th - Case 600 OR 900**



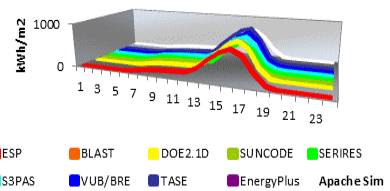
**Figure 311: Hourly Incident Solar Radiation West Surface, March 5th - Case 600 OR 900**



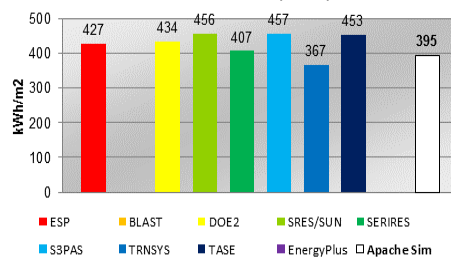
**Figure 312: Hourly Incident Solar Radiation South Surface, July 27th - Case 600 OR 900**



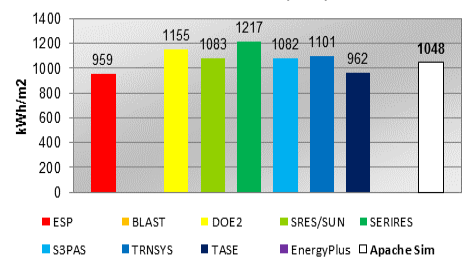
**Figure 313: Hourly Incident Solar Radiation West Surface, July 27th - Case 600 OR 900**



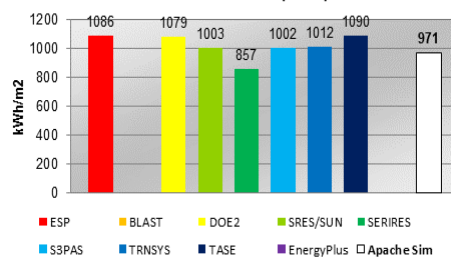
**Figure 314: Annual Incident Total Solar Radiation - Case 600 OR 900 (North)**



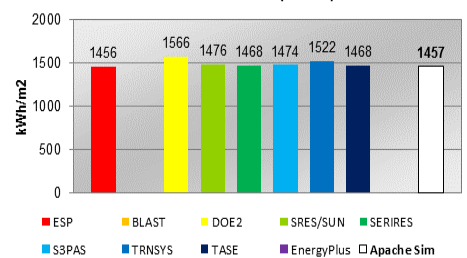
**Figure 315: Annual Incident Total Solar Radiation - Case 600 OR 900 (East)**



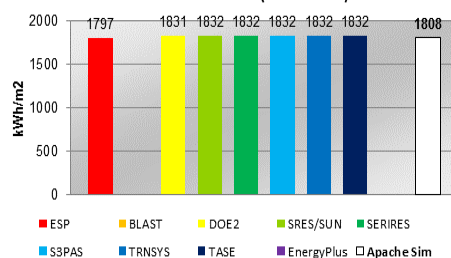
**Figure 316: Annual Incident Total Solar Radiation - Case 600 OR 900 (West)**



**Figure 317: Annual Incident Total Solar Radiation - Case 600 OR 900 (South)**



**Figure 318: Annual Incident Total Solar Radiation - Case 600 OR 900 (Horizontal)**



**Figure 319: Annual Unshaded Transmitted Solar Radiation - Case 920 (West)**

