DOMUS Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007

DOMUS – PROCEL EDIFICA Version Beta

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Prepared by:

M.O. Abadie

Thermal Systems Laboratory (LST), Pontifical Catholic University of Paraná (PUCPR) , Rua Imaculada Conceicão, 1155 Curitiba, PR 80215-901, Brazil.
http://www2.pucpr.br/

Coordinated by: Prof. Nathan Mendes

Preliminary Notes:

This report is based upon work supported by ELETROBRÁS/APC-PUCPR in the frame of the research project “DOMUS – Software for Supporting the National Building Energy Efficiency Code: Validation, Research and Dissemination” (Grant # ECV 283/2008).

The structure and parts of text of the present report are based on the validation of EnergyPlus v4.0.0.024 document (Henninger and Witte, 2009).

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1 TEST OBJECTIVES AND OVERVIEW

1.1 Introduction

This report describes the modeling methodology and results for testing done of building thermal envelope and fabric tests designated as Cases 195 through 960 of ANSI/ASHRAE Standard 140 – 2007 titled Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. The results of DOMUS are also compared with results from several other whole building energy analysis programs that simulated the same test cases.

1.2 Test Type: Comparative Loads

Comparative tests compare a program to other simulation programs. This type of testing accomplishes results on two different levels, both validation and debugging.

From a validation perspective, comparative tests will show that DOMUS is computing solutions that are reasonable compared to other energy simulation programs. As stated by Henninger and Witte (2009), this is a very powerful method of assessment, but it is no substitute for determining if the program is absolutely correct since it may be just as equally incorrect as the benchmark program or programs. The biggest strength of comparative testing is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation. The ANSI/ASHRAE Standard 140-2007 procedures discussed below take advantage of the comparative test method that has already been run by experts of the other simulation tools.

Comparative testing is also useful for field-by-field input debugging. Energy simulation programs have so many inputs and outputs that the results are often difficult to interpret. To ascertain if a given test passes or fails, engineering judgment or hand calculations are often needed. Field by field comparative testing eliminates any calculational requirements for the subset of fields that are equivalent in two or more simulation programs. The equivalent fields are exercised using equivalent inputs and relevant outputs are directly compared.

1.3 Test Suite: ANSI/ASHRAE Standard 140-2007

The tests described in Section 5.2 of ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI/ASHRAE, 2007), were performed. This suite of tests is based on work previously performed under an earlier project sponsored by the International Energy Agency (IEA) titled Building Energy Simulation Test (BESTEST) and Diagnostic Method (Judkoff and Neymark, 1995). As stated in its Foreword, Standard 140-2007 is a standard method of test that “can be used for identifying and diagnosing predictive differences from whole building energy simulation software that may possibly be caused by algorithmic differences, modeling limitations, input differences, or coding errors.”

The following tests were performed as specified with modeling notes and other reports generated as shown in the Standard:

- BASE Case (Case 600, Section 5.2.1 of Standard),

- BASIC Tests (Section 5.2.2 of Standard): Low mass tests (Cases 610 to 650), High mass tests (Cases 900 to 960) and Free float tests (Cases 600FF, 650FF, 900FF and 950FF),
- IN-DEPTH tests (Section 5.2.3 of Standard): Cases 195 to 320, Cases 395 to 440 and Cases 800 and 810.

The DOMUS test results are compared to the results of all programs that completed and reported test results, including ESP, BLAST-3-193, DOE2.1D, SRES/SUN, SERIRES, S3PAS, TRNSYS and TASE. Although not part of the original set of results, results for later version of EnergyPlus have also been added for completeness.

A brief description of the BASE Case, BASIC Test Cases and Case 195 are presented in the following sections. For details of the other test cases refer to Standard 140.

2 DESCRIPTION OF THE CASES

2.1 Low Mass Building Cases

2.1.1 Case 600 – Base Case Low Mass Building

The basic test building (Figure 2-1) is a rectangular single zone (8 m wide x 6 m long x 2.7 m high) with no interior partitions and 12 m^2 (2 windows of 3 m wide x 2 m high) of windows on the south exposure located at 0.2 m from the ground. The building is of lightweight construction with characteristics as described in the following Tables. The window glazing properties (Table 2-4) corresponds to the NFRC #102 ones (Window 5, 2009).

Infiltration equals 0.5 air change/hour. Internal heat gain of 200 W (60% radiative, 40% convective, 100% sensible) is applied at all time. The mechanical system is 100% convective air system, 100% efficient with no duct losses and no capacity limitation, no latent heat extraction, non-proportional-type dual setpoint thermostat with deadband (heating <20°C, cooling >27°C). The soil temperature is supposed to be 10°C.

For further details refer to Section 5.2.1 of ANSI/ASHRAE Standard 140-2007.

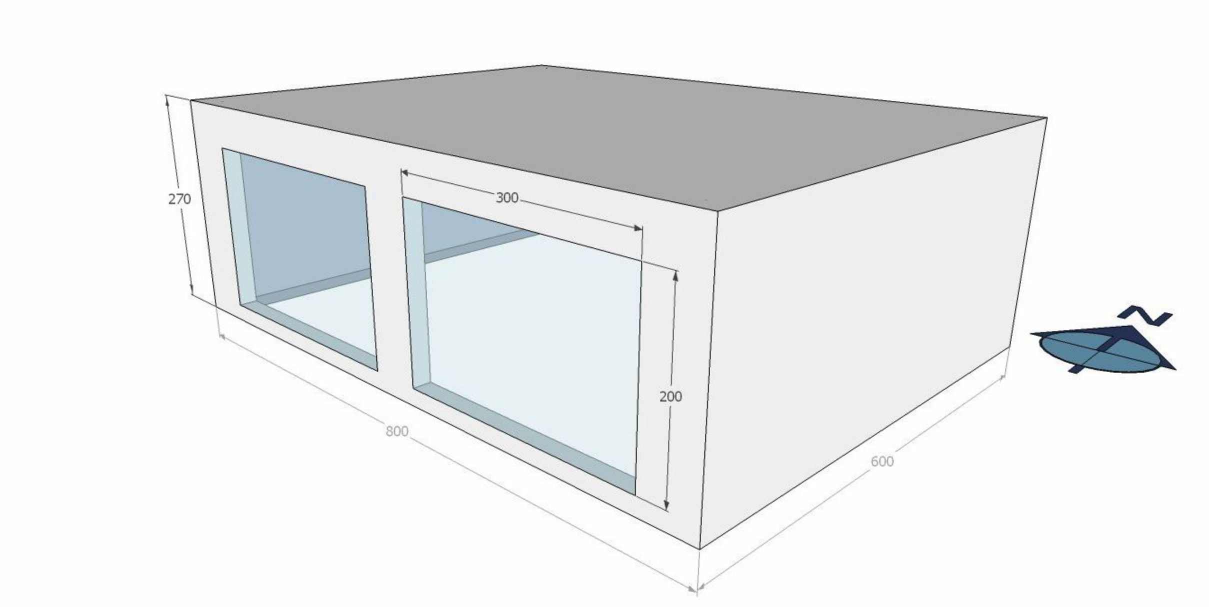

Figure 2-1: Base Building (Case 600).

Table 2-1: Wall Construction (light weight mass).

Element	k (W/m.K)	e (m)	U ($W/m^2.K$)	R ($m^2.K/W$)	ρ (kg/m^3)	c_p (J/kg.K)
Int. Surface Coefficient			8.290	0.121		
Plasterboard	0.160	0.012	13.333	0.075	950	840
Fiberglass Quilt	0.040	0.066	0.606	1.650	12	840
Wood Siding	0.140	0.009	15.556	0.064	530	900
Ext. Surface Coefficient			29.300	0.034		
Overall, air-to-air			0.514	1.944		

Table 2-2: Roof Construction (light weight mass).

Element	k (W/m.K)	e (m)	U ($W/m^2.K$)	R ($m^2.K/W$)	ρ (kg/m^3)	c_p (J/kg.K)
Int. Surface Coefficient			8.290	0.121		
Plasterboard	0.160	0.010	16.00	0.063	950	840
Fiberglass Quilt	0.040	0.1118	0.358	2.794	12	840
Roofdeck	0.140	0.019	7.368	0.136	530	900
Ext. Surface Coefficient			29.300	0.034		
Overall, air-to-air			0.514	1.944		

Table 2-3: Floor Construction (light weight mass).

Element	k (W/m.K)	e (m)	U ($W/m^2.K$)	R ($m^2.K/W$)	ρ (kg/m^3)	c_p (J/kg.K)
Int. Surface Coefficient			8.290	0.121		
Timber Flooring	0.140	0.025	5.600	0.179	650	1200
Insulation	0.040	1.003	0.040	25.075	12	840
Overall, air-to-air			0.039	25.374		

Table 2-4: Window properties.

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/m.K
Conductance of each glass pane	333 $W/m^2.K$
Combined radiative and convective coefficient of air gap	6.297 $W/m^2.K$
Exterior combined surface coefficient	21.00 $W/m^2.K$
Interior combined surface coefficient	8.29 $W/m^2.K$
U-value from interior air to ambient air	3.0 $W/m^2.K$
Hemispherical infrared emittance of ordinary uncoated glass	0.9
Density of glass	2500 kg/m^3
Specific heat of glass	750 J/kg.K
Interior shade devices	None
Double-pane shading coefficient at normal incidence	0.907
Double-pane solar heat gain coefficient at normal incidence	0.789

2.1.2 Case 610 – South Shading Test for Low Mass Building

Case 610 uses the Base Building modeled in Case 600 and adds a 1 m horizontal overhang across the entire length of south wall over the south facing windows at the roof level (Figure

2-2). All other characteristics of the building were identical to the Base Case building. This case tests the ability of a program to treat shading of a south exposed window.

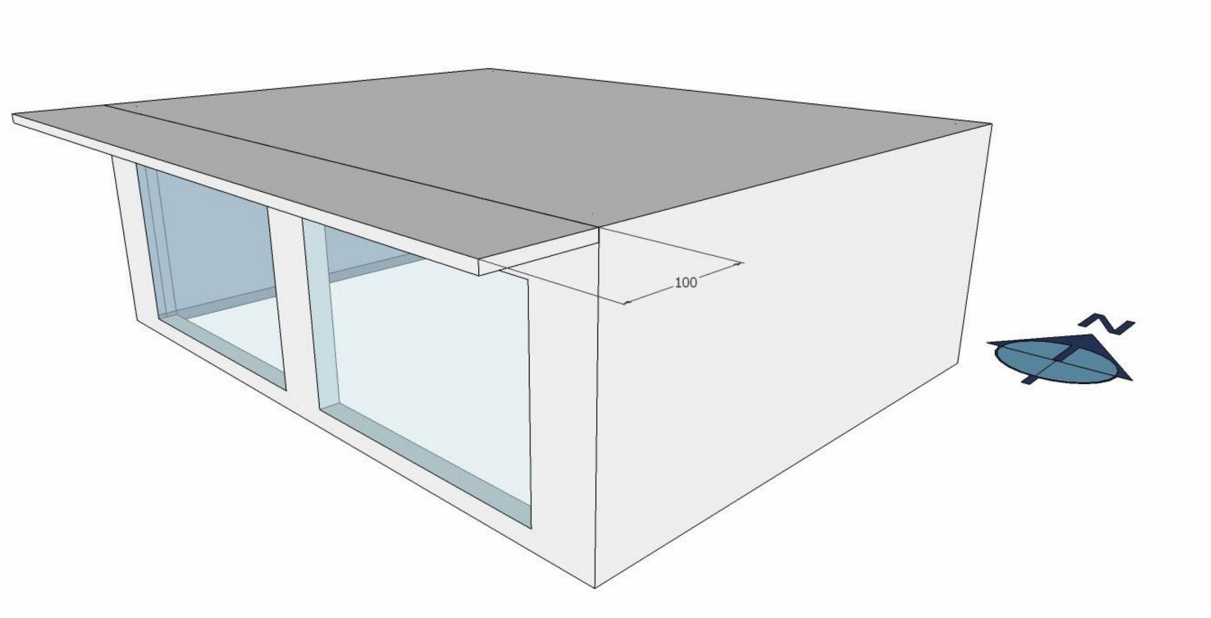

Figure 2-2: Base Building with South Shading (Case 610).

2.1.3 Case 620 – East/West Window Orientation Test for Low Mass Building

Case 620 uses the Base Building modeled in Case 600 with the following changes:

- The window orientation was modified such that 6 m^2 of window area was added to both the east and west walls (Figure 2-3). The window properties are exactly the same as in Case 600,
- The south windows were eliminated and replaced with the wall construction used throughout the building.

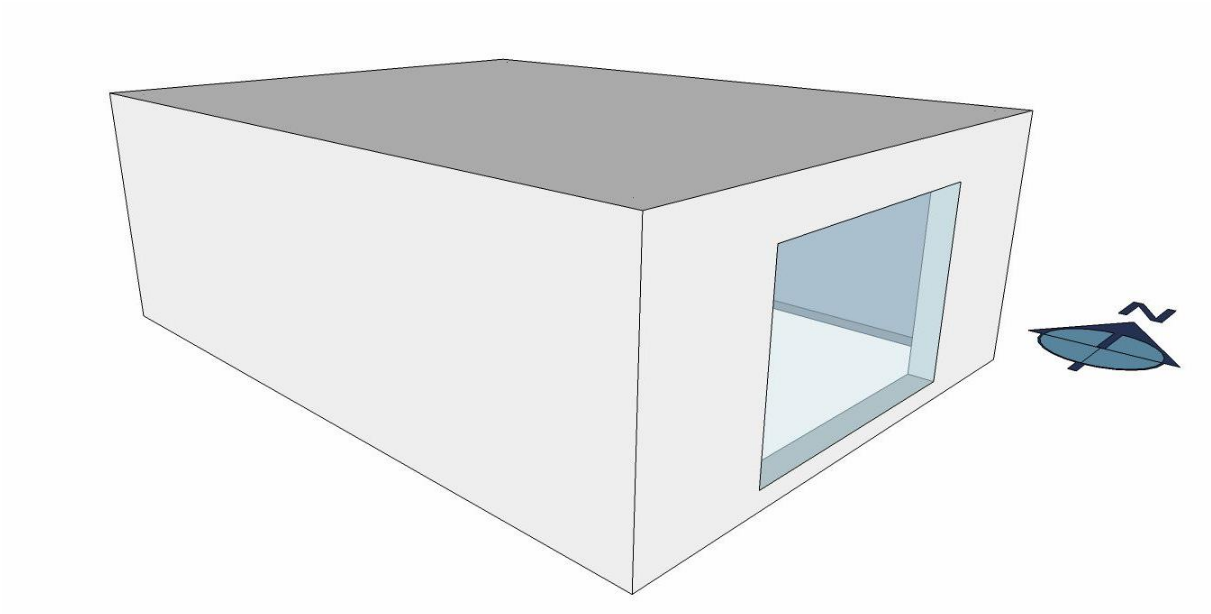

Figure 2-3: Building with East/West Window Orientation (Case 620).

2.1.4 Case 630 – East/West Shading Test for Low Mass Building

Case 630 is exactly the same as Case 620 except that a shade overhang and shade fins were added around the east and west window (Figure 2-4). A 1 m horizontal overhang is located at the roof level and extends across the 3 m width of each window. The 1 m wide right and left vertical shade fins are located at edge of each window and extend from the roof down to the ground.

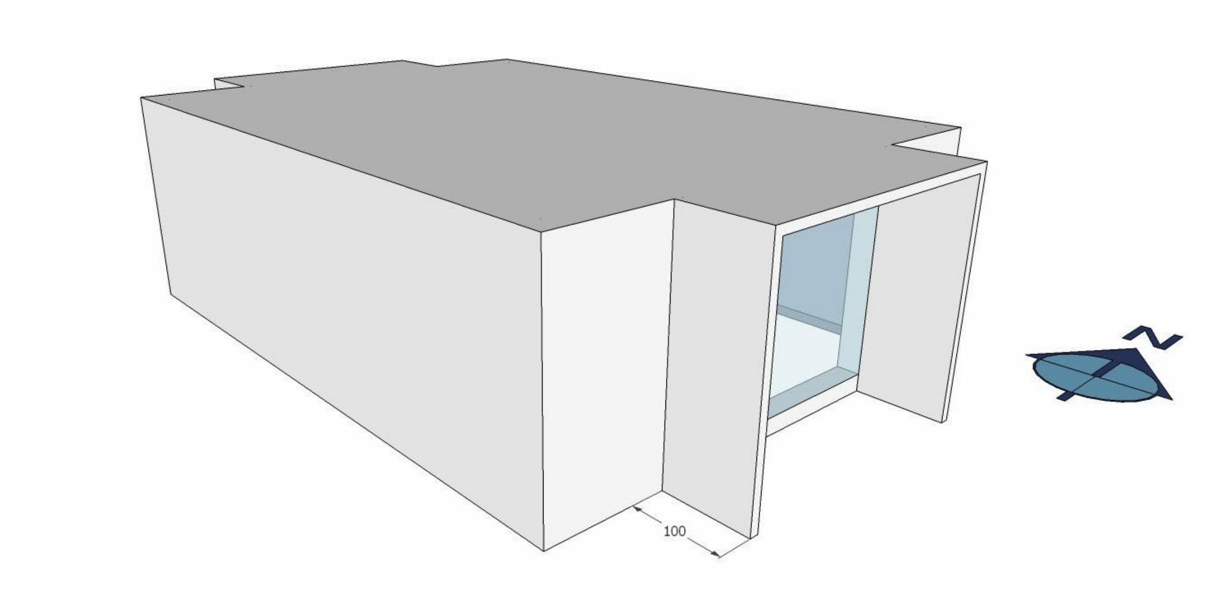

Figure 2-4: Building with East/West Window Orientation and Shade Overhang and Shade Fins added (Case 630).

2.1.5 Case 640 – Thermostat Setback Test for Low Mass Building

Case 640 is identical to the Base Case building of Case 600 except the following heating and cooling temperature setback schedule with a non-proportional thermostat was used:

- From 23:00 to 07:00, heat = on if zone temperature <10°C,
- From 07:00 to 23:00, heat = on if zone temperature <20°C,
- All hours, cool = on if zone temperature >27°C,
- Otherwise, mechanical equipment is off.

See Figure 2-1 for schematic of building.

2.1.6 Case 650 – Night Ventilation Test for Low Mass Building

Case 650 is identical to the Base Case building of Case 600 except the following scheduled night time ventilation and heating and cooling temperature control was used:

- From 18:00 to 07:00, vent fan = on,
- From 07:00 to 18:00, vent fan = off,
- Heating is always off,
- From 07:00 to 18:00, cool = on if zone temperature >27°C, otherwise cool = off,
- From 18:00 to 07:00, cool = off,
- Vent fan capacity = 1703.16 standard m^3/h (in addition to specified infiltration rate),

- Waste heat from fan = 0.

See Figure 2-1 for schematic of building.

2.2 High Mass Building Cases

2.2.1 Case 900 – Base Case High Mass Building

The 900 series of tests use the same building model as was used for the series 600 tests except that the wall and floor construction were changed to use heavier materials. Everything else with the building remained the same. The characteristics of the heavier mass wall and floor are as described in the following Tables.

Table 2-5: Wall Construction (heavy weight mass).

Element	k (W/m.K)	e (m)	U (W/m^2.K)	R (m^2.K/W)	ρ (kg/m^3)	c_p (J/kg.K)
Int. Surface Coefficient			8.290	0.121		
Concrete Block	0.510	0.100	5.100	0.196	1400	1000
Foam Insulation	0.040	0.0615	0.651	1.537	10	1400
Wood Siding	0.140	0.009	15.556	0.064	530	900
Ext. Surface Coefficient			29.300	0.034		
Overall, air-to-air			0.512	1.952		

Table 2-6: Floor Construction (heavy weight mass).

Element	k (W/m.K)	e (m)	U (W/m^2.K)	R (m^2.K/W)	ρ (kg/m^3)	c_p (J/kg.K)
Int. Surface Coefficient			8.290	0.121		
Concrete Slab	1.130	0.080	14.125	0.071	1400	1000
Insulation	0.040	1.007	0.040	25.075	12	840
Overall, air-to-air			0.039	25.366		

2.2.2 Case 910 – South Shading Test for High Mass Building

Case 910 uses the high mass Base Building modeled in Case 900 except that a 1 m horizontal overhang was added to the entire length of south wall over the south facing windows at the roof level (Figure 2-2). All other characteristics of the building were identical to the high mass Base Building of Case 900. This case tests the ability of a program to treat shading of a south exposed window. This case is identical to Case 610 except for high mass walls and floor.

2.2.3 Case 920 – East/West Window Orientation Test for High Mass Building

Case 920 is identical to Case 620 except for high mass walls and floor.

2.2.4 Case 930 – East/West Shading Test for High Mass Building

Case 930 is identical to Case 630 except for high mass walls and floor.

2.2.5 Case 940 – Thermostat Setback Test for High Mass Building

Case 940 is identical to Case 640 except for high mass walls and floor.

2.2.6 Case 950 – Night Ventilation Test for High Mass Building

Case 950 is identical to case 650 except for high mass walls and floor.

2.2.7 Case 960 – Sunspace Test

Case 960 simulates a passive solar building consisting of two zones (a back-zone and a sun-zone) separated by a common interior wall (Figure 5).

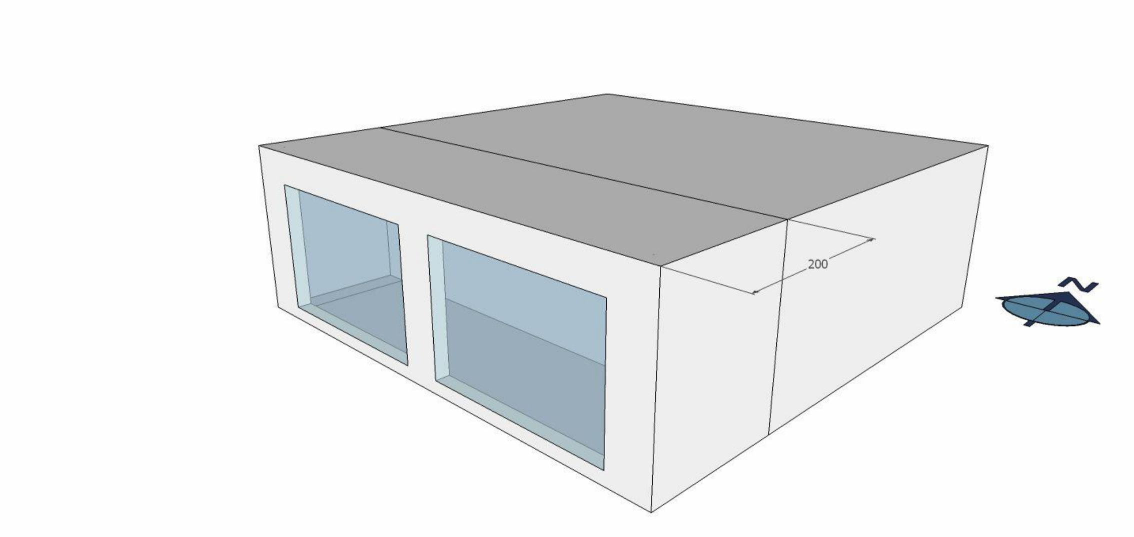

Figure 2-5: Sunspace Building with Back-Zone and Sun-Zone (Case 960).

Back Zone: The geometric and thermal properties of the back-zone are exactly the same as for Case 600 except that the south wall and windows are replaced with the common wall. Infiltration and internal load in the back-zone are also the same as in Case 600. The Back-zone is controlled the same as for case 600.

Common Wall: Material properties of the common wall are described in Table 2-7 .

Table 2-7: Common wall properties.

Element	k (W/m.K)	e (m)	U (W/m^2.K)	R (m^2.K/W)	ρ (kg/m^3)	c_p (J/kg.K)
Common Wall	0.510	0.200	2.55	0.392	1400	1000

Sun-Zone: The sun-zone is 2 m deep by 8 m wide by 2.7 m high. The back (north) wall of the sun-zone is the common wall. The south wall of the sun-zone contains two 6 m^2 windows that are identical to the windows in Case 900 except that they are raised to a level of 0.5 m above the ground. The thermal and physical properties of the sun-zone are the same as case 900 with the following exceptions:

- Infiltration rate is 0.5 air changes per hour.
- Internal heat gain = 0 W.
- Heating and cooling control strategy as follows:
- Sun-zone has no space conditioning system (free floating).

2.3 Other Cases

2.3.1 Free Floating Temperature Cases

The Free Floating Temperature cases are the ones with no mechanical heating or cooling system i.e. the zone temperature is varied according to the solicitations.

- Case 600FF – Free Floating Temperature Test for Base Case Low Mass Building: Case 600FF is the same as Case 600 except that there is no mechanical heating or cooling system.
- Case 650FF – Free Floating Temperature Test for Base Case Low Mass Building with Night Ventilation: Case 650FF is the same as Case 650 except that there is no mechanical heating or cooling system.
- Case 900FF – Free Floating Temperature Test for Base Case High Mass Building: Case 900FF is the same as Case 900 except that there is no mechanical heating or cooling system.
- Case 950FF – Free Floating Temperature Test for Base Case High Mass Building with Night Ventilation: Case 950FF is the same as Case 950 except that there is no mechanical heating or cooling system.

2.3.2 In-depth Cases

The In-depth cases (or Diagnostic cases) 195 to 320 aim at isolating the effects of individual algorithms by varying a single parameter from case to case. These cases are relatively primitive, to minimize the number of interacting heat transfer phenomena that can confound attempts at diagnosis. However, some programs will not be able to model some of these cases because of use of simplified algorithms or fixed assumptions. Diagnostic cases from 395 to 440 and 800 to 810 attempt to solve this problem by presenting alternative cases that are slightly more realistic than the primitive cases.

- Case 195: same as Case 600 with the following exceptions:
    - South wall contains no windows and is entirely constructed of the Lightweight mass exterior wall construction,
    - Infiltration Rate = 0,
    - Internal Gains = 0,
    - Thermostat control is “20,20 bang-bang” (Heating = on if temperature < 20°C, Cooling = on if temperature > 20°C),
    - Interior and exterior surface emissivity and absorptance set to 0.1.
- Case 200: same as Case 195 with 12 m^2 high conductance wall in the south wall.
- Case 210: same as Case200 with exterior surface emissivity set to 0.9.
- Case 215: same as Case200 with interior surface emissivity set to 0.9.
- Case 220: same as Case200 with exterior/interior surface emissivity set to 0.9.
- Case 230: same as Case220 with infiltration.
- Case 240: same as Case220 with internal heat gain.
- Case 250: same as Case220 with exterior surface absorptance set to 0.9.
- Case 270: same as Case220 with 12 m^2 windows in the south wall.
- Case 280: same as Case270 with interior surface absorptance set to 0.9.

- Case 290: same as Case280 with south horizontal overhang.
- Case 300: same as Case270 with East/West Solar windows.
- Case 310: same as Case300 with East/West Overhang and Fins.
- Case 320: same as Case270 with Thermostat Dead band 20°C/27°C.
- Case 395: same as Case 195 with Thermostat Dead band 20°C/27°C.
- Case 400: same as Case395 with exterior/interior surface emissivity set to 0.9.
- Case 410: same as Case400 with infiltration.
- Case 420: same as Case410 with internal heat gain.
- Case 430: same as Case420 with exterior surface absorptance set to 0.6.
- Case 440: same as Case600 with interior surface absorptance set to 0.6.
- Case 800: same as Case430 with heavy weight mass with and 12 m^2 high conductance wall.
- Case 810: same as Case900 with heavy weight mass with and 12 m^2 windows.

3 MODELING NOTES

3.1 Weather file

DRYCOLD.TMY weather file (solar time) has been converted to DRYCOLD.TM2 (legal time) with a third-party program. The TM2 file has then been converted to DOMUS weather file (DRYCOLD.DWF) using DOMUS weather converter.

3.2 Material thermal properties

BESTEST material thermal properties have been added to DOMUS material library.

3.3 Window

The window is double-glazed made up of two NFRC 102 glasses whose optical and thermal characteristics are similar to those described in the BESTEST documentation. The resistive model (DOMUS default model) has been used here.

3.4 Infiltration and Ventilation

Infiltration has been set up to 0.5 ACH using DOMUS "Direct ventilation" option. For cases that require more than one ventilation rate, DOMUS "HVAC Fan-coils" with one fan and no return air have been used instead.

3.5 Internal gain

Internal gain of 200W (40% convective, 60% radiative) has been added to the zone through DOMUS "Heat Gain" option.

3.6 Convective Heat Transfer Coefficients

DOMUS provides three options for the calculation of the Convective Heat Transfer Coefficient (CHTC):

1. Fixed value,
2. Automatic calculation according to the wind velocity and direction (Emmel *et al.*, 2007) for the external CHTC and to the surface temperature and local air velocity (Mc Adams, 1954) for the internal one,
3. Automatic calculation according to the surface temperature (Yazdanian and Klems, 1994) with adjustable coefficients.

Fixed values of 24.7 W/m^2.K and 3.2 W/m^2.K have been used throughout the cases for the external and internal CHTC, respectively. Note that those values are respectively imposed to all external and internal surfaces as there is no possibility to impose different values to different internal or external surfaces in the current version of DOMUS.

3.7 Internal long-wave radiation treatment

The "Mean Radiant Temperature/Balanced" algorithm developed by Walton (1980) has been used. The main advantage of this algorithm is that it does not require any calculation of view factors while it provides good results for simple shape zones (cubic and parallelepipedic zones).

3.8 Internal short-wave radiation treatment

The algorithm implemented in this DOMUS current version treats the absorption/reflection of short-wave radiation in a zone as follow:

1. Direct solar radiation initially hits the floor. The reflected portion is absorbed by the other surfaces in proportion to their area-absorptance products.
2. Diffuse solar radiation is absorbed by all the surfaces in proportion to their area-absorptance products.
3. Radiative part of the internal heat gain is absorbed by all the surfaces in proportion to their area-absorptance products.

This algorithm differs from the one described in the BESTEST documentation. The main difference is that it avoids the calculation of view factors that makes it faster but less precise for low-values of wall absorptance.

3.9 Simulation settings

All results presented here have been obtained using a time step of 1 minute and a spatial discretization of 1 volume/cm for the finite volume discretization of opaque walls. Note that for most cases, a time step of 10 min provides similar results. Results from the second year of simulation are presented in this report.

4 RESULTS

The following appendices present comparison charts and tables between DOMUS and other Whole Building Energy Simulation programs:

1. Appendix A – Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs is dedicated to the BASE cases presenting the comparison graphs,
2. Appendix B – Tables Comparing DOMUS Results with Other Whole Building Energy Simulation Programs presents the BASE cases comparison tables,
3. Appendix C – Delta Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs gives the Delta comparison charts for the BASE cases,
4. Appendix D – Solar Radiation Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs presents the Solar Radiation comparison charts, and
5. Appendix E – IN-DEPTH Test Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs is dedicated to the IN-DEPTH cases presenting the comparison graphs of the Absolute and Delta results.

Due to limitations of the 2010 version of DOMUS, Cases 640 and 940, that require 2 set-back temperatures for heating, cannot be simulated with DOMUS. DOMUS provides only one set-back temperature for heating and another one for cooling. Because of DOMUS simplified internal short-wave radiation treatment, Case 960 (sunspace test) has not been performed as the test consists in evaluating the solar distribution inside the zone.

From Appendix A and B, DOMUS results for the BASE cases are in good agreement with the other programs. Results regarding heating energy and peak (cooling energy and peak) are located in the upper (lower) limit of the other programs' intervals. Some results are slightly out of the range but still remain close to the limits. The main discrepancy lies in the prediction of the maximum temperature in the Free-Floating cases that tends to be underestimated, especially for the Low mass building. Results regarding the Low Mass Building with low absorptances and no windows (Figure 6-11) are very close to ESP-r (and EnergyPlus) results that are the only ones to be considered as valid from the original BESTEST validation round by ASHRAE.

By presenting the variation of the outputs from one BASE case to another, Appendix C reveals that DOMUS correctly reproduces those variations. It is an important point of the validation process because Building Energy Simulation programs aim at comparing the performance of different strategies regarding for example the building structure (surface area of window, wall structure, solar protections…). Results of one building are of second importance and are only used to roughly evaluate the energy consumption or thermal comfort of the final building.

Appendix D presents the DOMUS validations regarding the incident solar radiation on the building envelop. Results are in good agreement with the other programs. In particular, daily variations are closer to the ones given by TASE.

The almost 100 additional comparisons regarding the IN-DEPTH cases (Appendix E) illustrate DOMUS capabilities to model the following different simulated elements: no windows, opaque windows, exterior infrared emittance, interior infrared emittance, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, window orientation, shading devices, and thermostat set-points. Again, the case-by-case comparisons are very important here as they put into relief the effect of considering or not one physical process, so they help identifying the precision of the models used in a particular program. On the whole, DOMUS correctly reproduces both the absolute results and case-by-case variations. However, results tend to show problem of the cavity albedo treatment (comparison between 270 and 280) that can originate from DOMUS simplified treatment of the internal short-wave radiation.

Considering all results obtained by DOMUS for the BASE and IN-DEPTH test cases, DOMUS was within the range of spread of results for 77% of the cases (111/144), 90% of the cases (129/144) considering ranges only 20% wider. As previously pointed out, the main discrepancies seem to come from two DOMUS simplifications: the cavity albedo treatment and the use of constant value for the convective heat transfer coefficients. According to Henninger and Witte (2009), improving both the treatment of the window diffuse solar radiation within a zone and the convective heat transfer would imply a reduction of the annual and peak heating and an increase of the annual and peak cooling results. Applied to DOMUS, this would bring most of the results regarding the BASE cases inside the other programs' intervals, reducing to only 8 results out of the BESTEST intervals.

5 CONCLUSION

DOMUS was used to model a range of building specifications as specified in ANSI/ASHRAE Standard 140 – 2007 – Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.

The ability of DOMUS to predict thermal loads was tested using a test suite of 14 cases which included buildings with both low mass and high mass construction, without windows and with windows on various exposures, with and without exterior window shading, with and without temperature setback, with and without night ventilation, and with and without free floating space temperatures. The annual heating and cooling and peak heating and cooling results predicted by DOMUS were compared to results from 8 other whole building energy simulation programs that participated in an International Energy Agency (IEA) project conducted in February 1995 and from EnergyPlus Version 1.2.0.029 (Henninger and Witte, 2004). Maximum and minimum free-floating temperatures were compared for 4 different cases. A range of about 40 BASIC and IN-DEPTH test cases were also modeled.

When comparing results obtained by DOMUS for the BASE and IN-DEPTH test cases, DOMUS was within the range of spread of results for 77% of the cases (111/144), 90% of the cases (129/144) considering ranges only 20% wider. Moreover, DOMUS shows very good agreement with the other programs regarding the case-by-case comparisons. Those results demonstrate the capabilities of DOMUS to account for any alterations of the simulated problem and clearly validate the program as a candidate for supporting the National Building Energy Efficiency Code.

Future developments should focus on the treatment of internal short-wave radiation distribution by integrating the evaluation of view factor calculation and on the possibility of applying different convective heat transfer coefficient values or algorithm at every building internal and external surface.

6 Appendix A – Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs

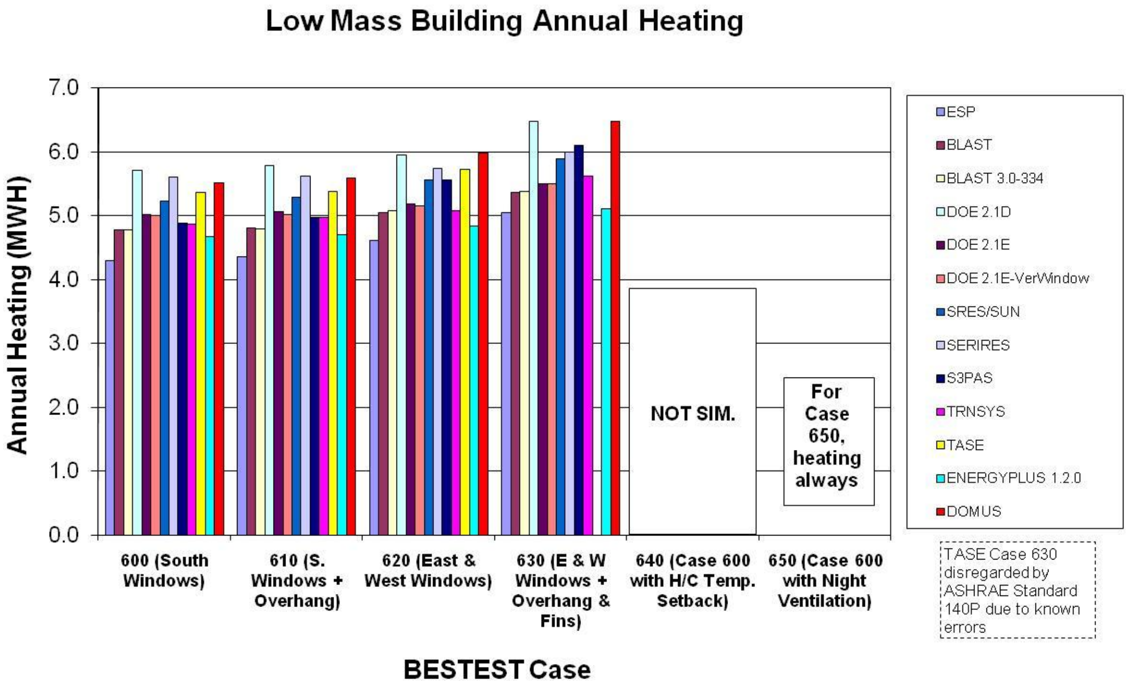

Figure 6-1: BASE Cases – Low Mass Building Annual Heating.

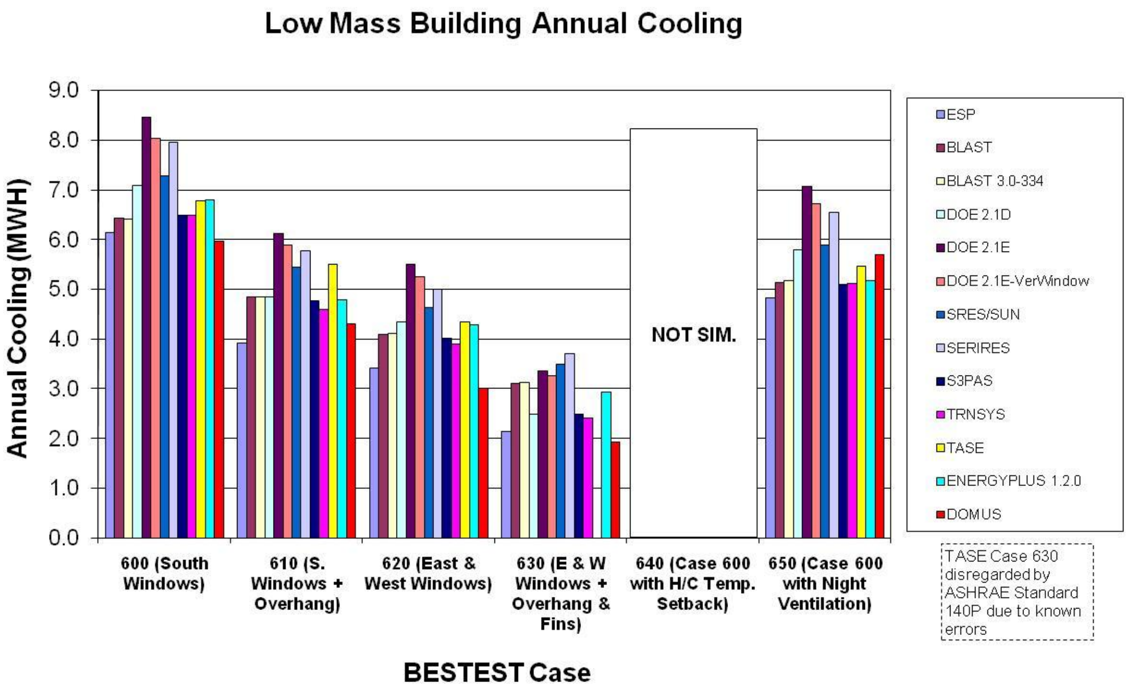

Figure 6-2: BASE Cases – Low Mass Building Annual Cooling.

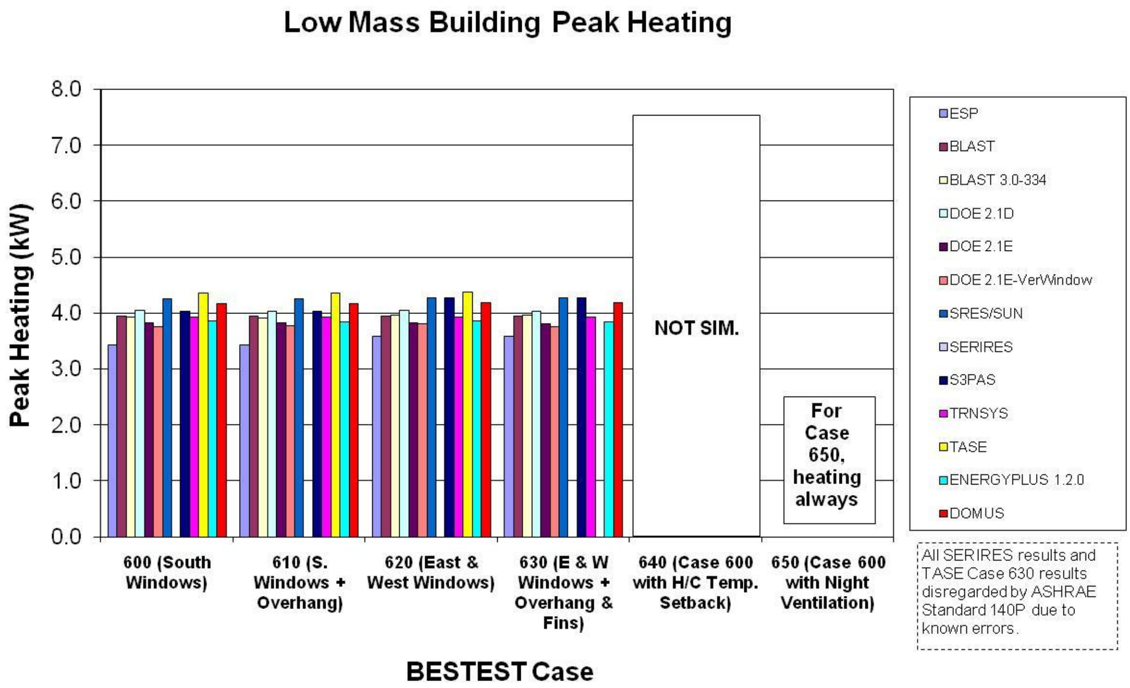

Figure 6-3: BASE Cases – Low Mass Building Peak Heating.

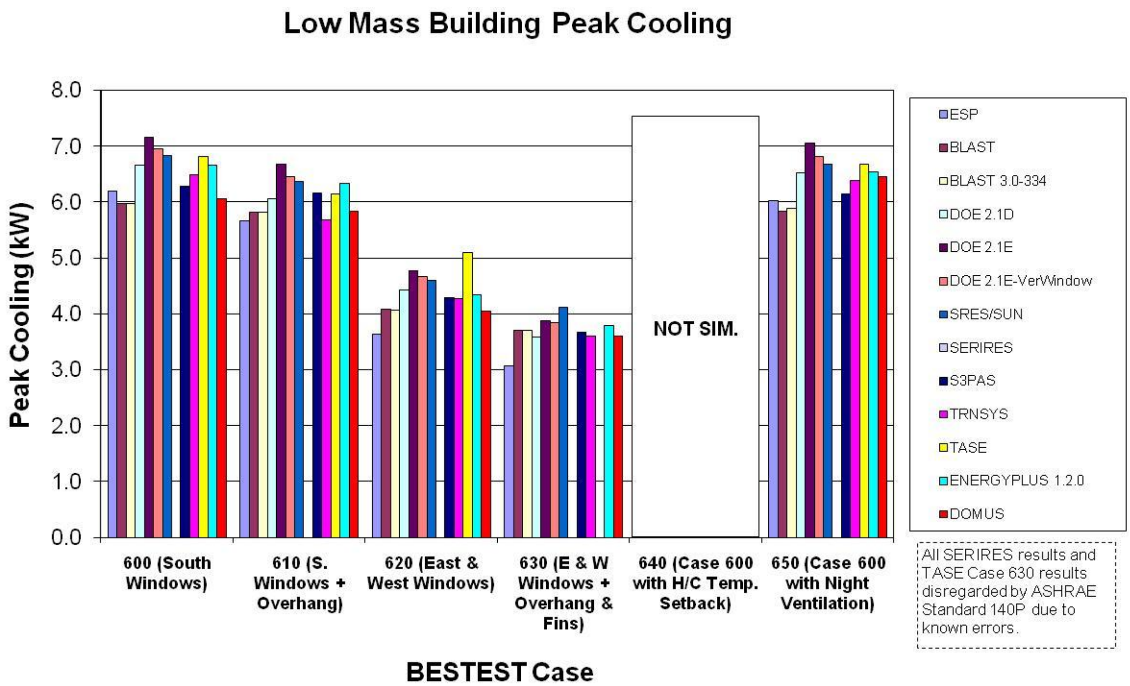

Figure 6-4: BASE Cases – Low Mass Building Peak Cooling.

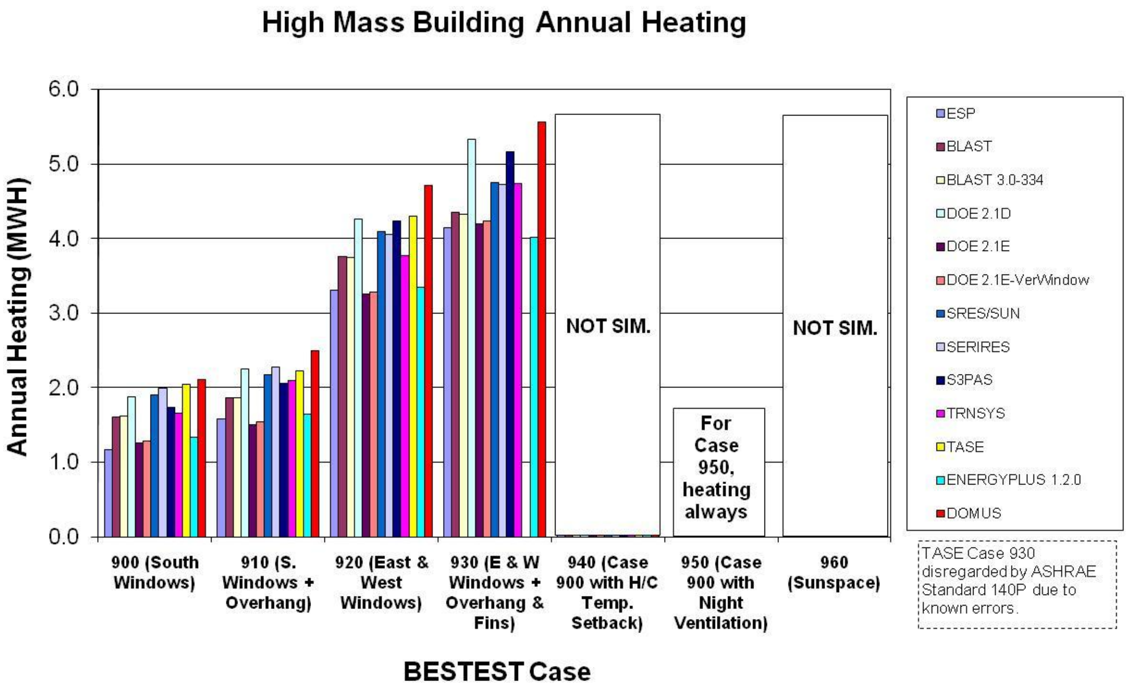

Figure 6-5: BASE Cases – High Mass Building Annual Heating.

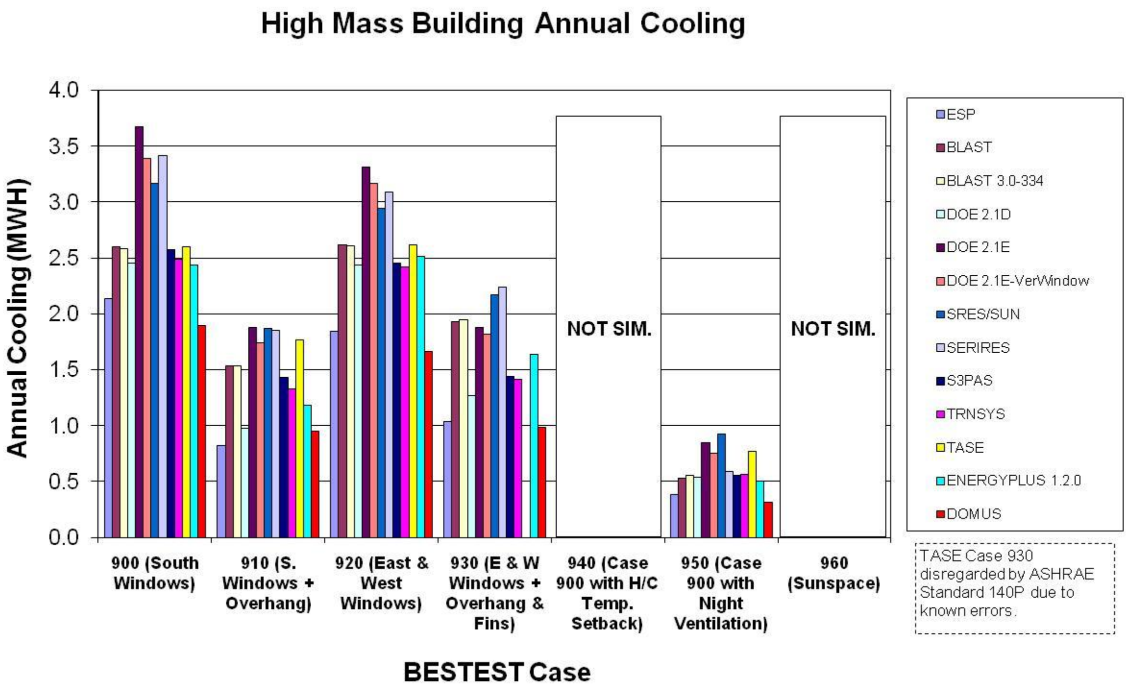

Figure 6-6: BASE Cases – High Mass Building Annual Cooling.

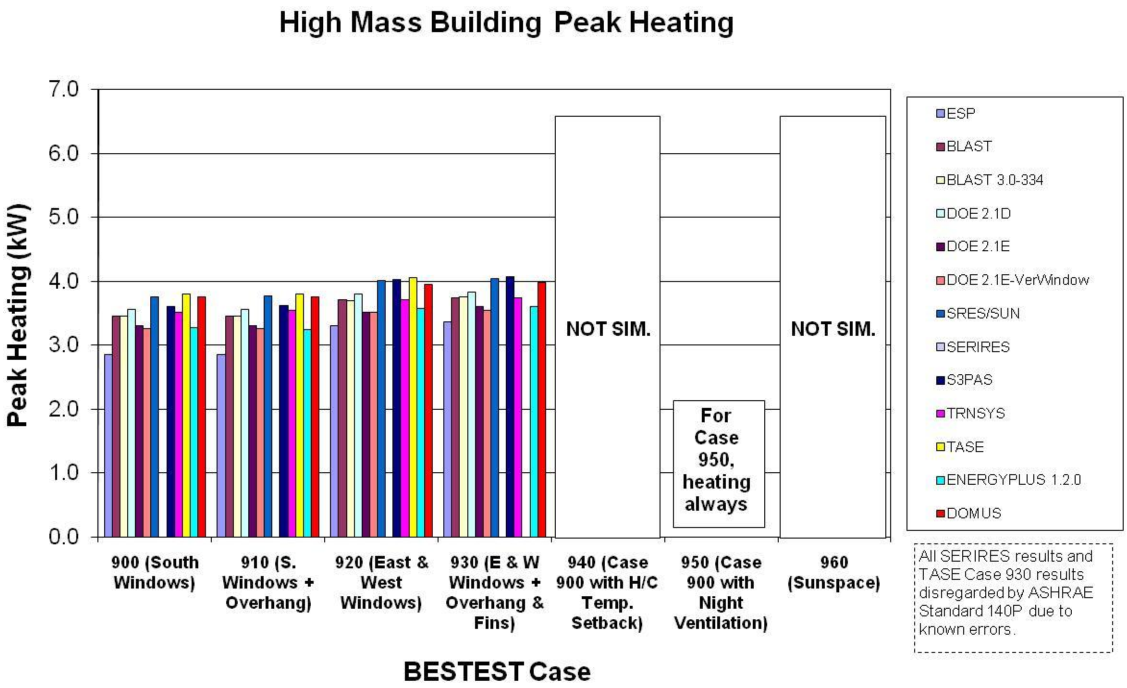

Figure 6-7: BASE Cases – High Mass Building Peak Heating.

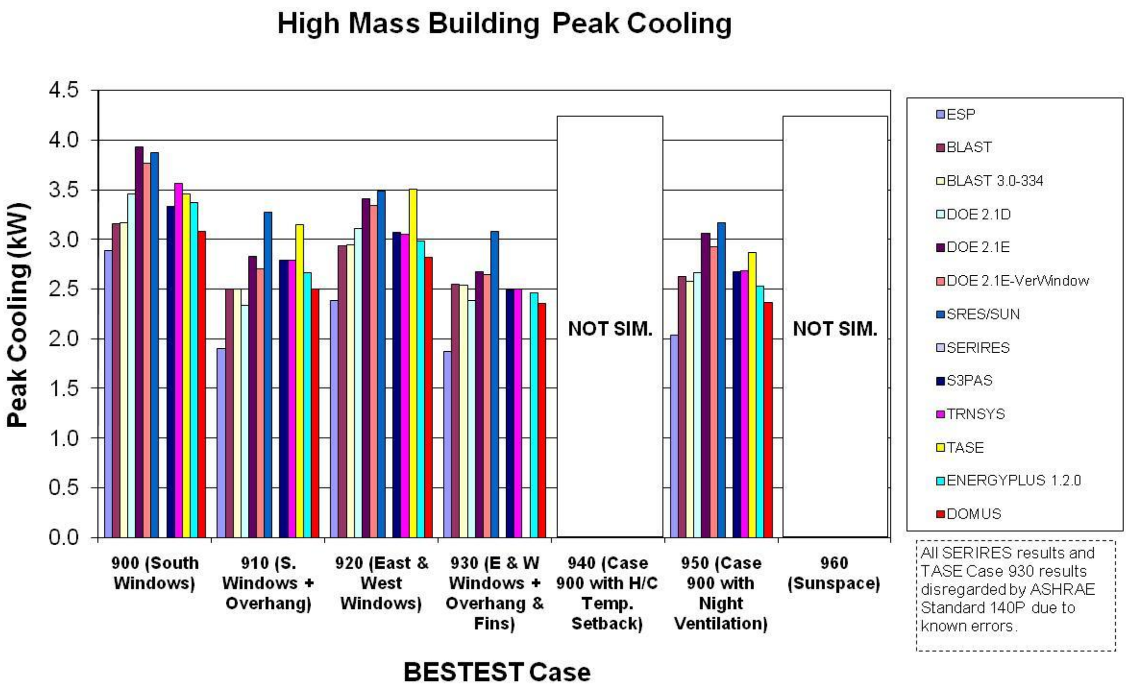

Figure 6-8: BASE Cases – High Mass Building Peak Cooling.

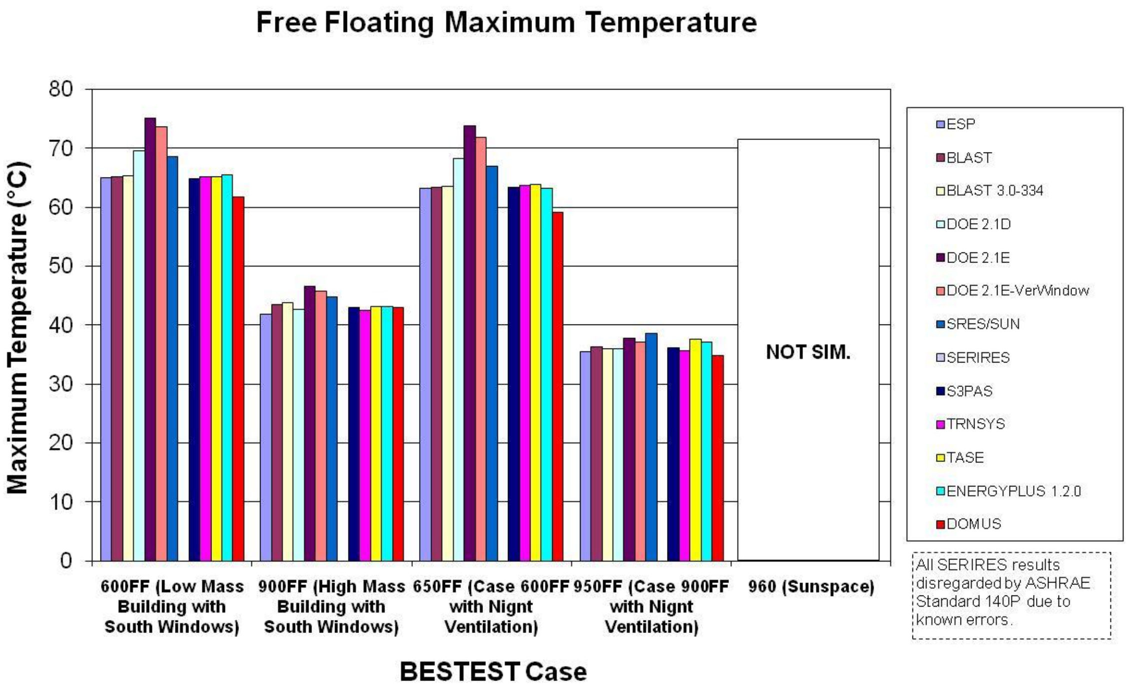

Figure 6-9: BASE Cases – Free Floating Maximum Temperature.

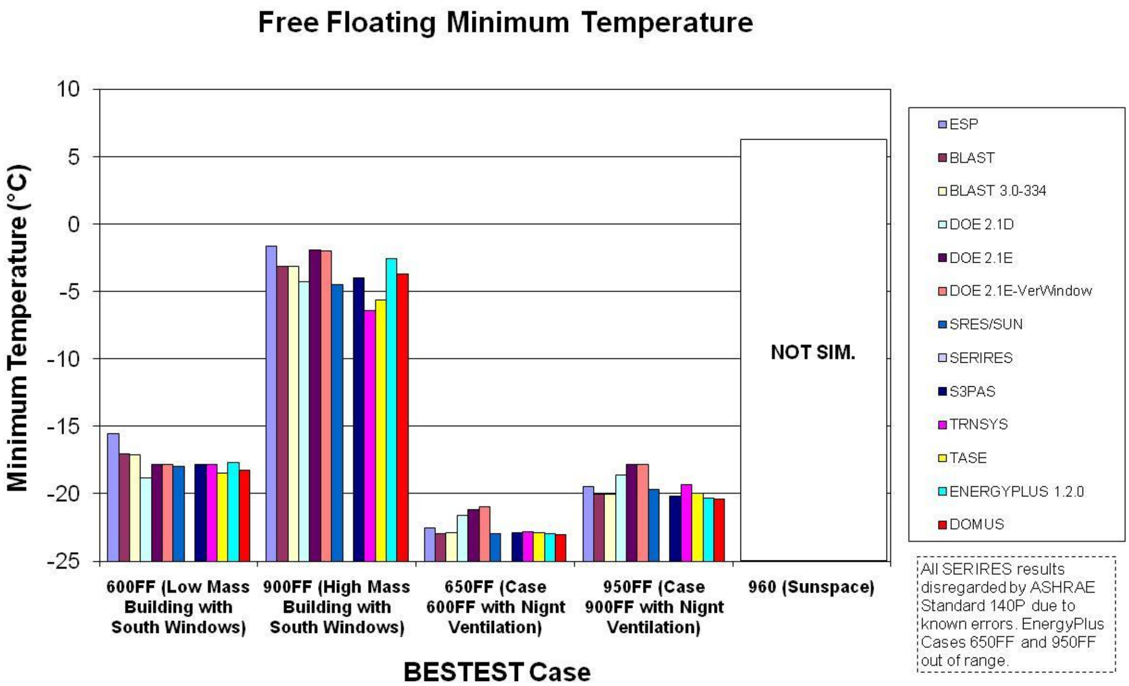

Figure 6-10: BASE Cases – Free Floating Minimum Temperature.

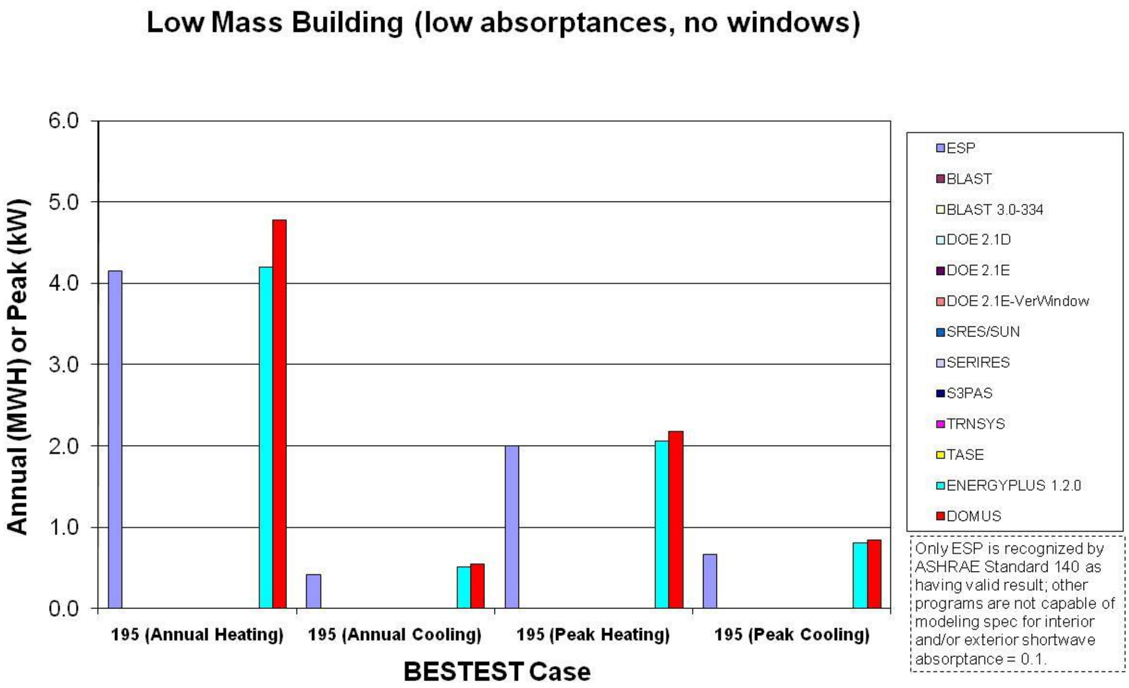

Figure 6-11: BASE Cases – Low Mass Building with low absorptances and no windows.

7 Appendix B – Tables Comparing DOMUS Results with Other Whole Building Energy Simulation Programs

BESTEST Case	600	610	620	630	640	650
Description	**Basic Heat Transfer Problem**	**South Shade Problem**	**East/West Incid./Trans. Problem**	**East/West Shade Problem**	**Setback Problem**	**Night Ventilation Problem**
	Windows on South wall	Same as 600 with	Windows on East & West wall	Same as 620 with	Same as 600	Same as 600
	200 w internal load	0.8M overhang on South Wall	200 w internal load	1.0M overhang & fins on	Setback Thermostat	Vent air 1800-700 hrs
	0.5 ACH infiltration		0.5 ACH infiltration	windows from roof to	Cooling 27C, all hours	Cooling 27C, 700-1800 hrs
	H/C Setpoint 20C/27C		H/C Setpoint 20C/27C	ground	Heating 10C, 2300 to 0700	Heating, always off
					Heating 20C, 0700 to 2300	
Annual Heating (MWh)						
BESTEST Minimum	4.296	4.355	4.613	5.050		0.000
BESTEST Maximum	5.709	5.786	5.944	6.469		0.000
BESTEST Average	5.090	5.146	5.407	5.783		0.000
DOMUS	5.515	5.591	5.982	6.471		0.000
Difference, %	8.36%	8.64%	10.63%	11.90%		0.00%
DOMUS within Range	YES	YES	NO	NO		YES
Annual Cooling (MWh)						
BESTEST Minimum	6.137	3.915	3.417	2.129		4.816
BESTEST Maximum	7.964	5.778	5.004	3.701		6.545
BESTEST Average	6.832	4.964	4.218	2.832		5.482
DOMUS	5.973	4.303	3.002	1.929		5.704
Difference, %	-12.57%	-13.32%	-28.83%	-31.90%		4.06%
DOMUS within Range	NO	YES	NO	NO		YES
Peak Heating (kW)						
BESTEST Minimum	3.437	3.437	3.591	3.592		0.000
BESTEST Maximum	4.354	4.354	4.379	4.280		0.000
BESTEST Average	4.000	3.998	4.062	4.006		0.000
DOMUS	4.173	4.176	4.187	4.188		0.000
Difference, %	4.33%	4.47%	3.07%	4.53%		0.00%
DOMUS within Range	YES	YES	YES	YES		YES
Peak Cooling (kW)						
BESTEST Minimum	5.965	5.669	3.634	3.072		5.831
BESTEST Maximum	6.827	6.371	5.096	4.116		6.679
BESTEST Average	6.461	5.988	4.343	3.626		6.321
DOMUS	6.062	5.844	4.056	3.610		6.451
Difference, %	-6.18%	-2.42%	-6.60%	-0.43%		2.05%
DOMUS within Range	YES	YES	YES	YES		YES

BESTEST Case	900	910	920	930	940	950	960
Description	**Basic Heat Transfer Problem**	**South Shade Problem**	**East/West Incid./Trans. Problem**	**East/West Shade Problem**	**Setback Problem**	**Night Ventilation Problem**	**Passive Solar Problem**
	Windows on South wall	Same as 900 with	Windows on East & West wall	Same as 920 with	Same as 900	Same as 900	Same as 900 but with
	200 w internal load	1.0M overhang on South Wall	200 w internal load	1.0M overhang & fins on	Setback Thermostat	Vent air 1800-700 hrs	sunspace and interior wall
	0.5 ACH infiltration		0.5 ACH infiltration	windows from roof to	Cooling 27C, all hours	Cooling 27C, 700-1800 hrs	Sunspace is uncontrolled
	H/C Setpoint 20C/27C		H/C Setpoint 20C/27C	ground	Heating 10C, 2300 to 0700	Heating, always off	and has two windows
					Heating 20C, 0700 to 2300		
Annual Heating (MWh)							
BESTEST Minimum	1.170	1.575	3.313	4.143		0.000	
BESTEST Maximum	2.041	2.282	4.300	5.335		0.000	
BESTEST Average	1.745	2.066	3.973	4.745		0.000	
DOMUS	2.102	2.490	4.716	5.564		0.000	
Difference, %	20.44%	20.53%	18.70%	17.26%		0.000	
DOMUS within Range	NO	NO	NO	NO		YES	
Annual Cooling (MWh)							
BESTEST Minimum	2.132	0.821	1.840	1.039		0.387	
BESTEST Maximum	3.415	1.872	3.092	2.238		0.921	
BESTEST Average	2.678	1.447	2.552	1.644		0.605	
DOMUS	1.891	0.947	1.660	0.982		0.315	
Difference, %	-29.38%	-34.58%	-34.97%	-40.24%		-47.98%	
DOMUS within Range	NO	YES	NO	NO		NO	
Peak Heating (kW)							
BESTEST Minimum	2.850	2.858	3.308	3.355		0.000	
BESTEST Maximum	3.797	3.801	4.061	4.064		0.000	
BESTEST Average	3.506	3.514	3.804	3.795		0.000	
DOMUS	3.749	3.752	3.954	3.984		0.000	
Difference, %	6.93%	6.78%	3.94%	4.97%		0.000	
DOMUS within Range	YES	YES	YES	YES		YES	
Peak Cooling (kW)							
BESTEST Minimum	2.888	1.896	2.385	1.873		2.033	
BESTEST Maximum	3.871	3.277	3.505	3.080		3.170	
BESTEST Average	3.390	2.676	3.077	2.479		2.674	
DOMUS	3.084	2.504	2.815	2.354		2.363	
Difference, %	-9.03%	-6.44%	-8.51%	-5.04%		-11.62%	
DOMUS within Range	YES	YES	YES	YES		YES	

BESTEST Case	600FF	900FF	650FF	950FF	960
Description	**Basic Heat Transfer Problem**	**Basic Heat Transfer Problem**	**Basic Heat Transfer Problem**	**Basic Heat Transfer Problem**	**Passive Solar Problem**
	Low Mass Building	**High Mass Building**	**Same as 600FF**	**Same as 900FF**	Same as 900 but with
	Windows on South wall	Windows on South wall	Vent air 1800-700 hrs	Vent air 1800-700 hrs	sunspace and interior wall
	200 w internal load	200 w internal load			Sunspace is uncontrolled
	0.5 ACH infiltration	0.5 ACH infiltration	Heating, always off	Heating, always off	and has two windows
	Free Float Temperature	Free Float Temperature	Free Float Temperature	Free Float Temperature	Free Float Temperature
Maximum Annual Hourly Zone Temperature (°C)					
BESTEST Minimum	64.90	41.81	63.24	35.54	48.88
BESTEST Maximum	69.50	44.80	68.20	38.50	55.34
BESTEST Average	66.22	43.05	64.68	36.50	50.33
DOMUS	61.70	42.94	59.16	34.81	65.61
Difference, %	-6.83%	-0.27%	-8.53%	-4.64%	30.37%
DOMUS within Range	NO	YES	NO	NO	NO
Minimum Annual Hourly Zone Temperature (°C)					
BESTEST Minimum	-18.80	-6.38	-23.00	-20.20	-2.82
BESTEST Maximum	-15.57	-1.65	-21.60	-18.60	3.90
BESTEST Average	-17.64	-4.23	-22.68	-19.62	1.36
DOMUS	-18.29	-3.70	-23.06	-20.41	-17.08
Difference, %	3.67%	-12.55%	1.67%	4.04%	-1352.07%
DOMUS within Range	YES	YES	NO	NO	NO
Average Annual Hourly Zone Temperature (°C)					
BESTEST Minimum	24.22	24.45	17.99	14.00	26.43
BESTEST Maximum	25.93	25.93	19.62	14.97	28.96
BESTEST Average	25.06	25.18	18.67	14.39	27.98
DOMUS	23.70	25.30	17.40	13.47	26.50
Difference, %	-5.42%	0.50%	-6.80%	-6.43%	-5.28%
DOMUS within Range	NO	YES	NO	NO	YES

8 Appendix C – Delta Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs

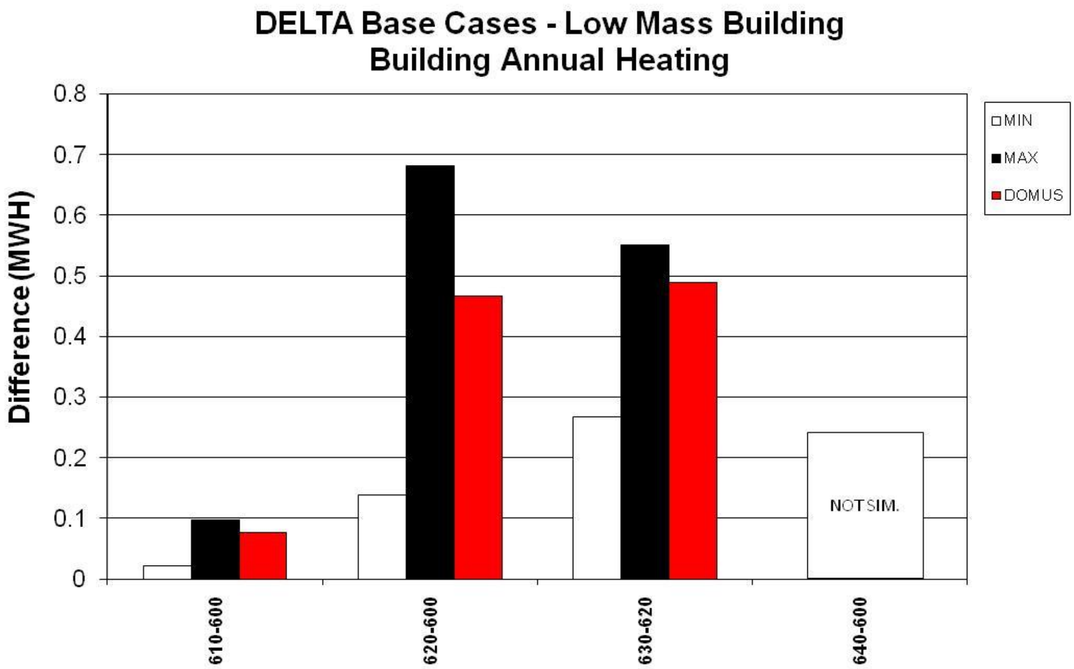

Figure 8-1: BASE Cases – DELTA – Low Mass Building Annual Heating.

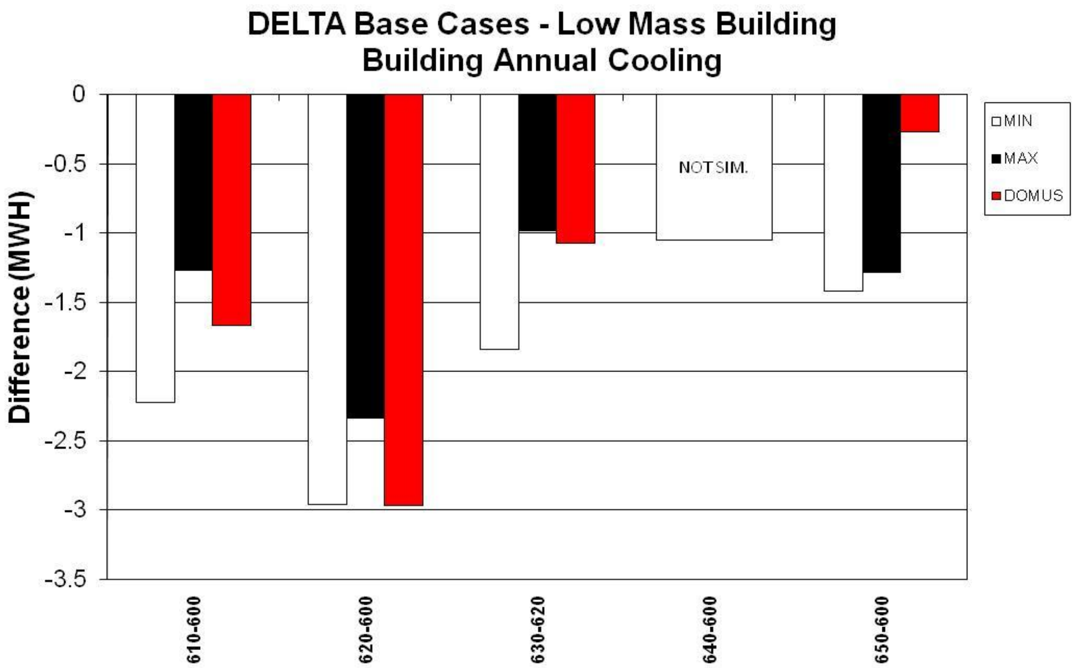

Figure 8-2: BASE Cases – DELTA – Low Mass Building Annual Cooling.

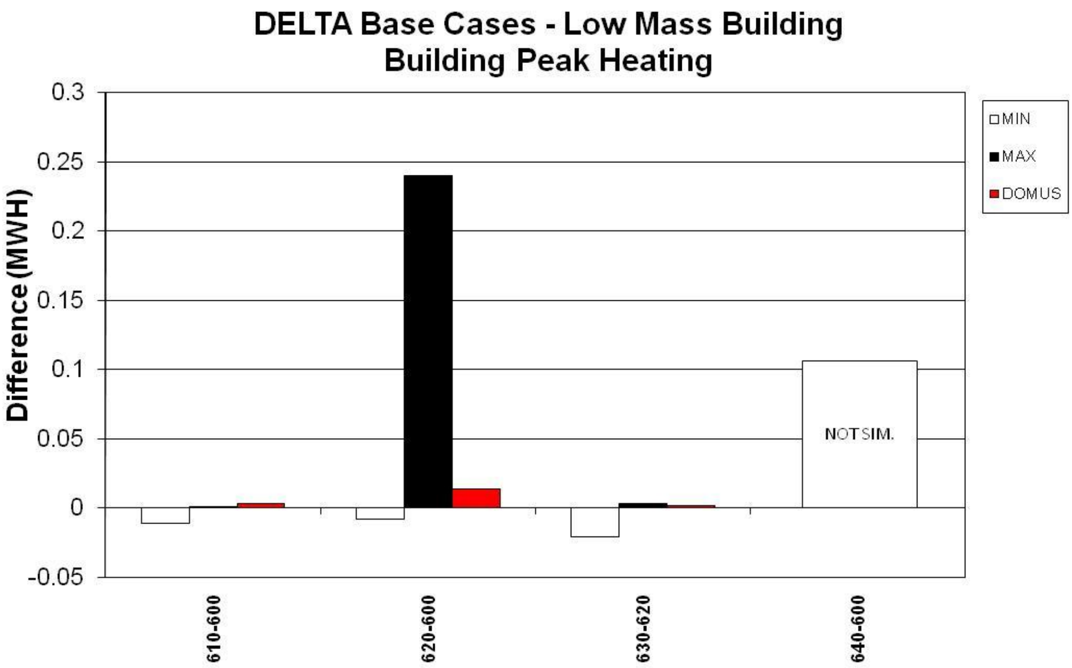

Figure 8-3: BASE Cases – DELTA – Low Mass Building Peak Heating.

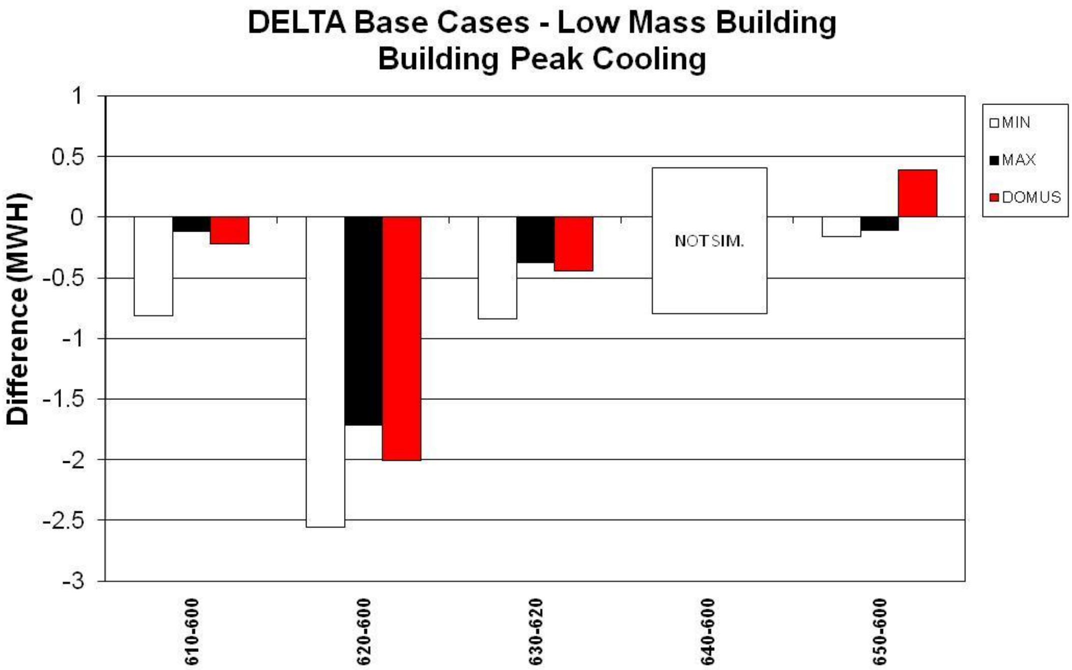

Figure 8-4: BASE Cases – DELTA – Low Mass Building Peak Cooling.

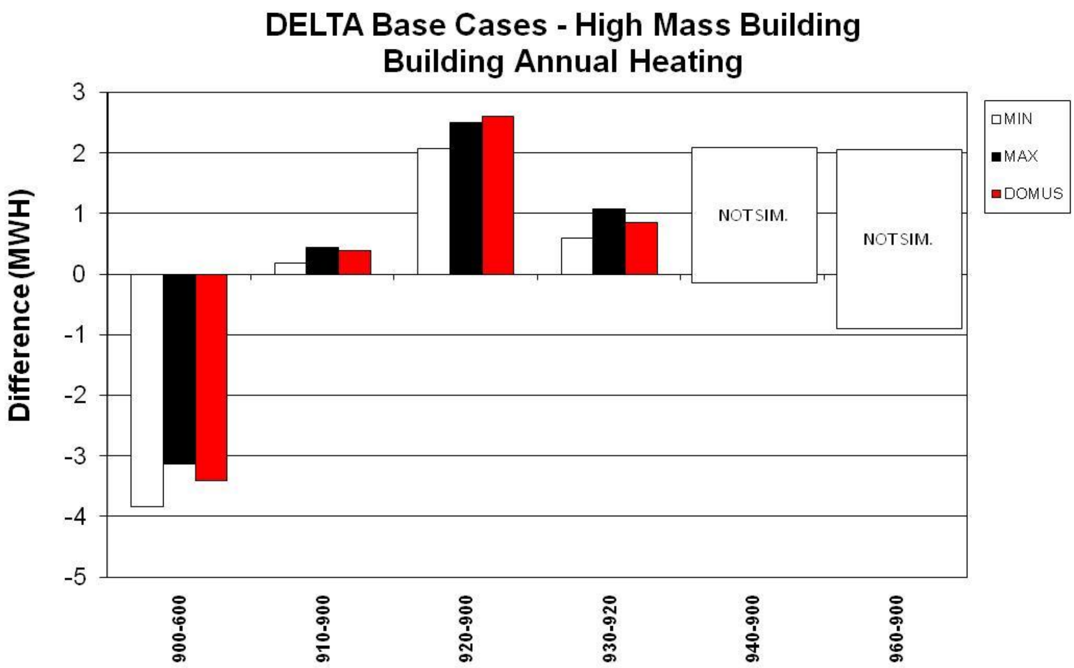

Figure 8-5: BASE Cases – DELTA – High Mass Building Annual Heating.

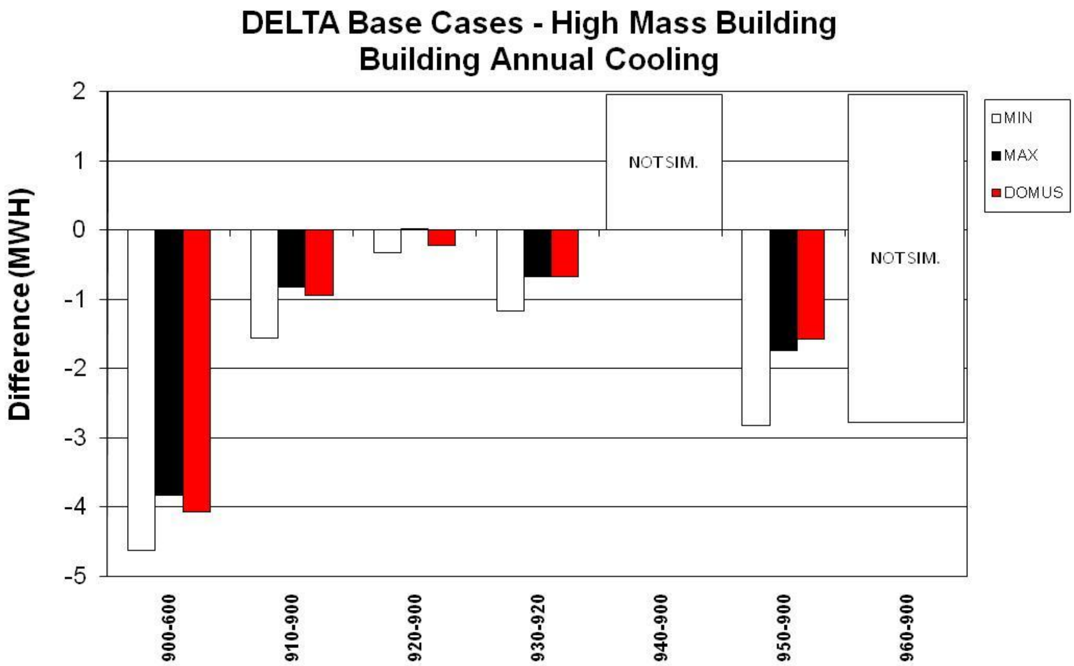

Figure 8-6: BASE Cases – DELTA – High Mass Building Annual Cooling.

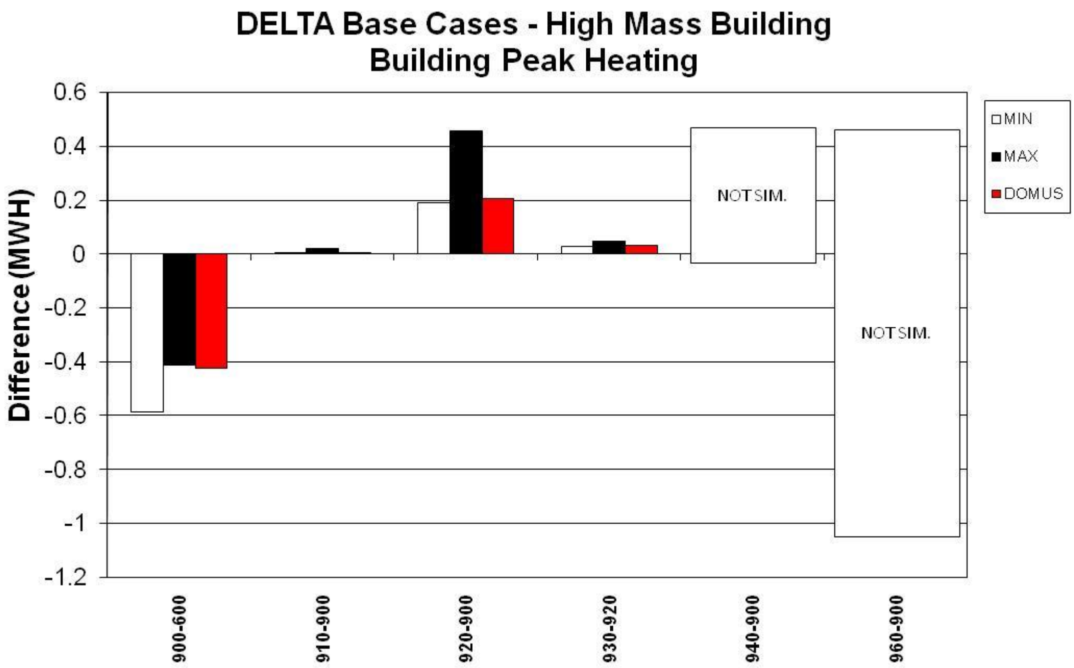

Figure 8-7: BASE Cases – DELTA – High Mass Building Peak Heating.

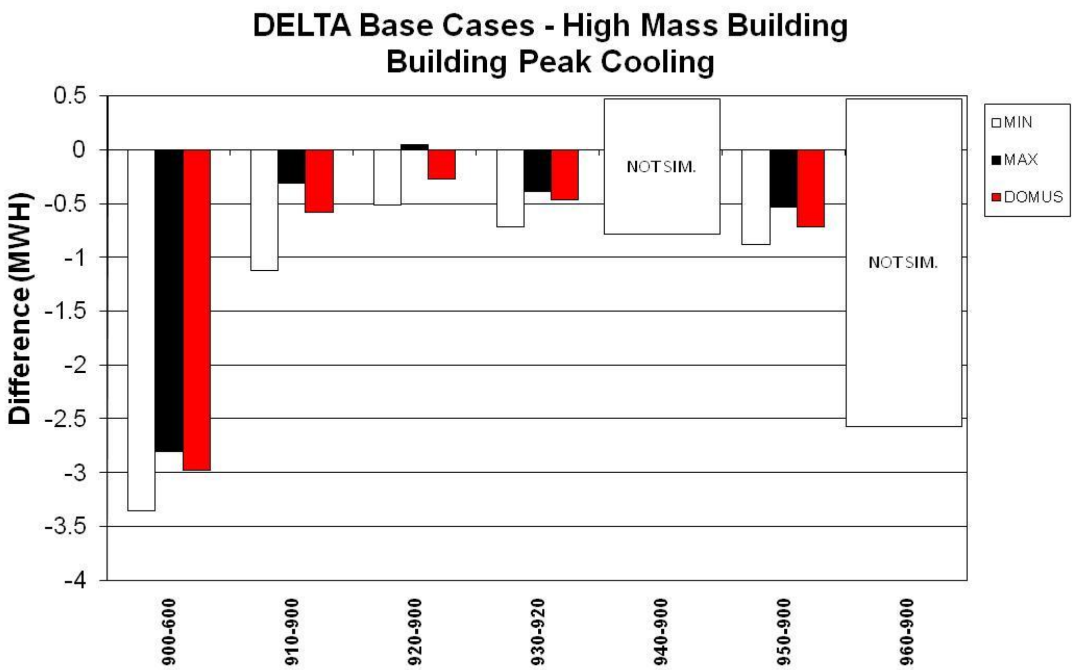

Figure 8-8: BASE Cases – DELTA – High Mass Building Peak Cooling.

9 Appendix D – Solar Radiation Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs

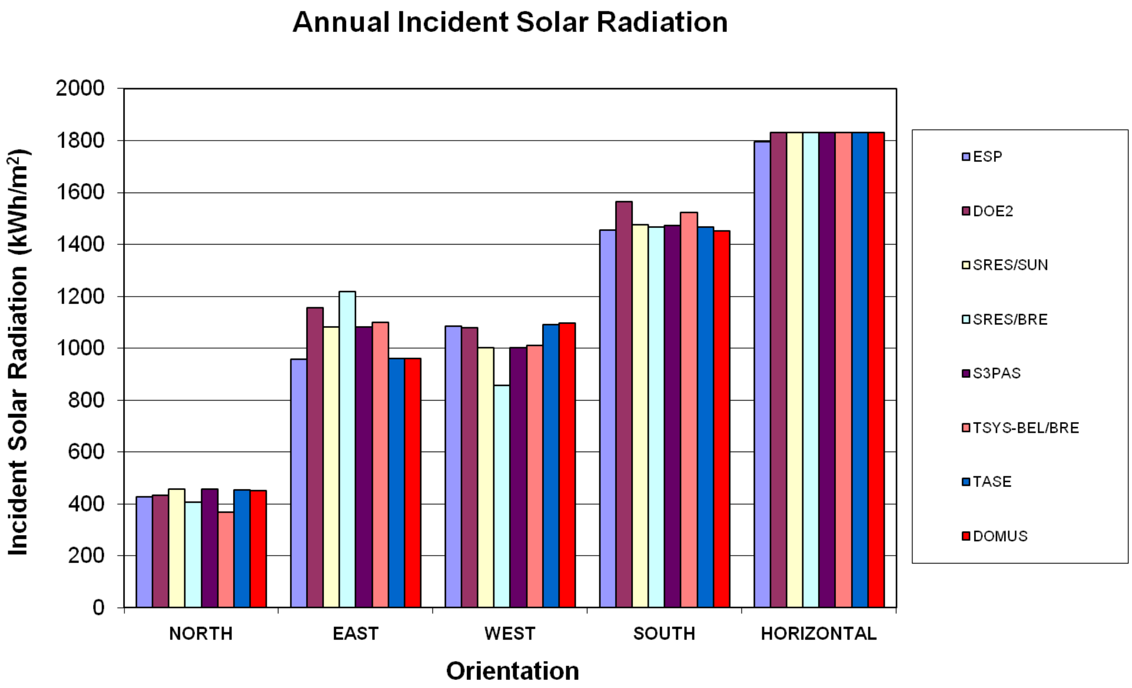

Figure 9-1: Annual Incident Solar Radiation.

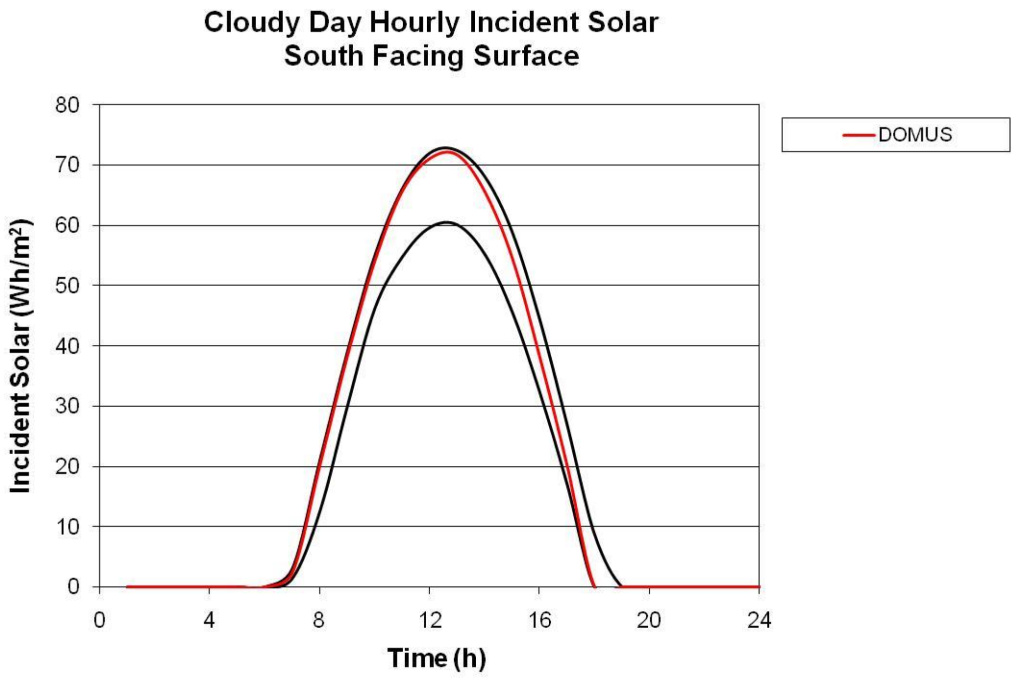

Figure 9-2: Cloudy Day Hourly Incident Solar – South Facing Surface.

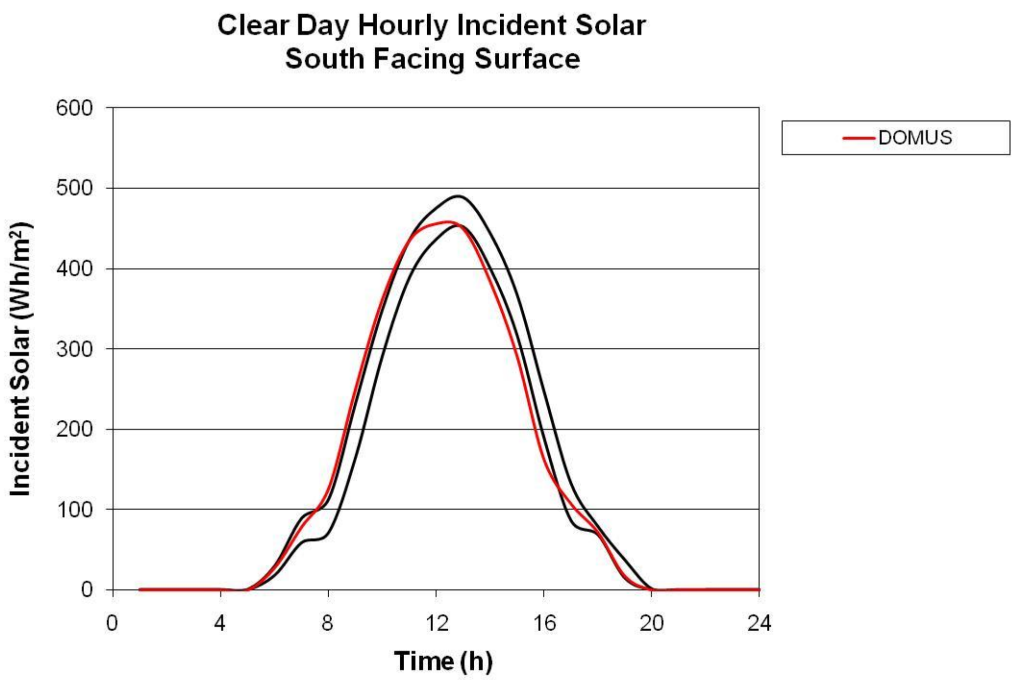

Figure 9-3: Clear Day Hourly Incident Solar – South Facing Surface.

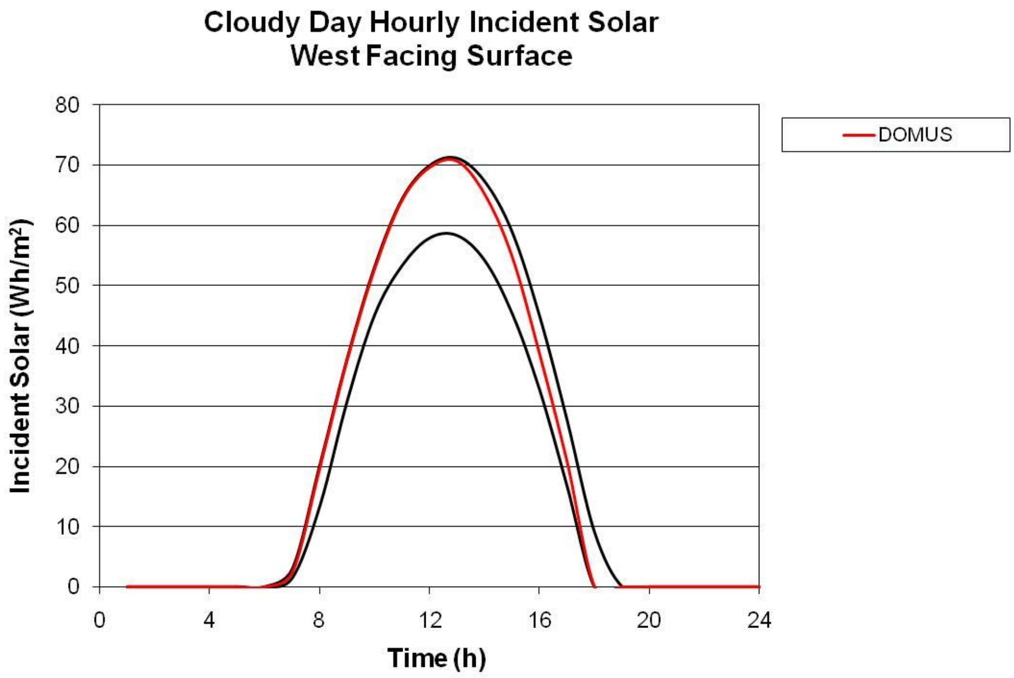

Figure 9-4: Cloudy Day Hourly Incident Solar – West Facing Surface.

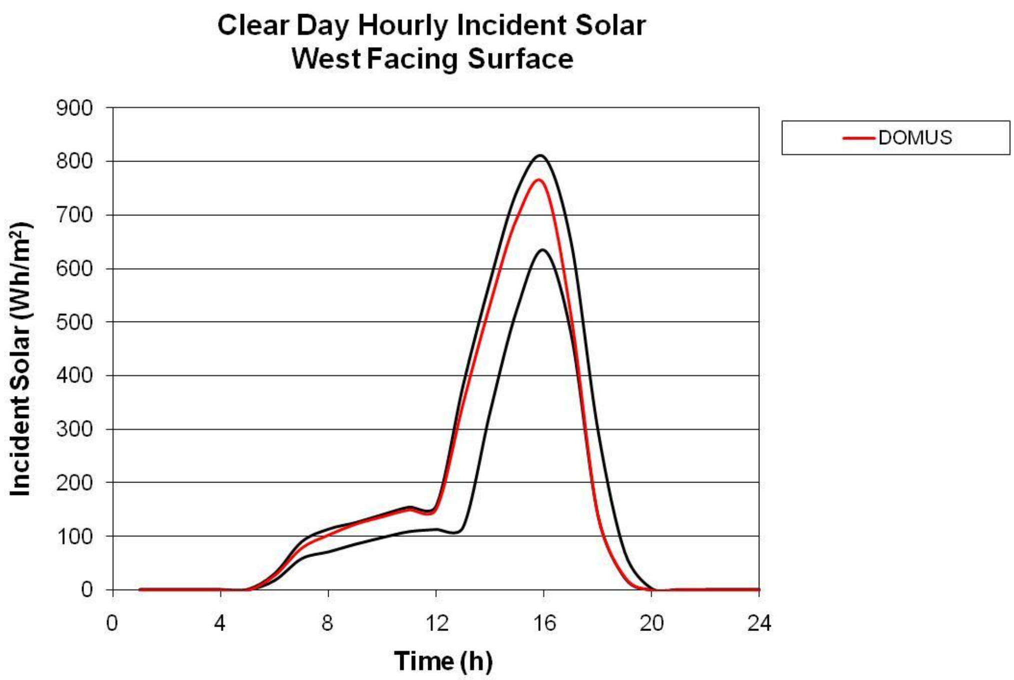

Figure 9-5: Clear Day Hourly Incident Solar – West Facing Surface.

10 Appendix E – IN-DEPTH Test Charts Comparing DOMUS Results with Other Whole Building Energy Simulation Programs

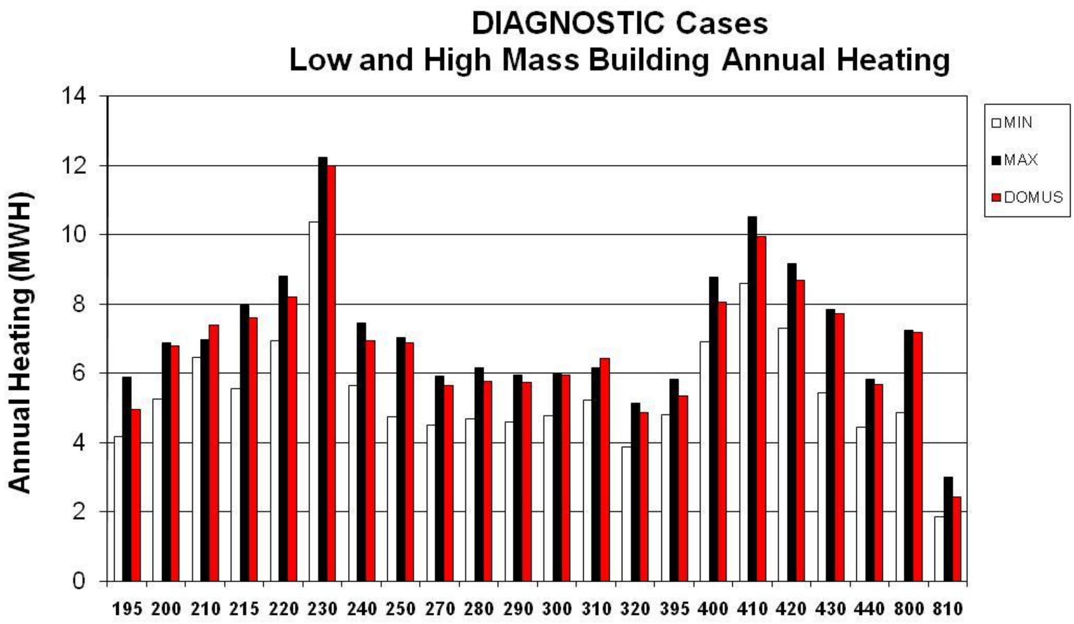

Figure 10-1: DIAGNOSTIC Cases – Low and High Mass Building Annual Heating.

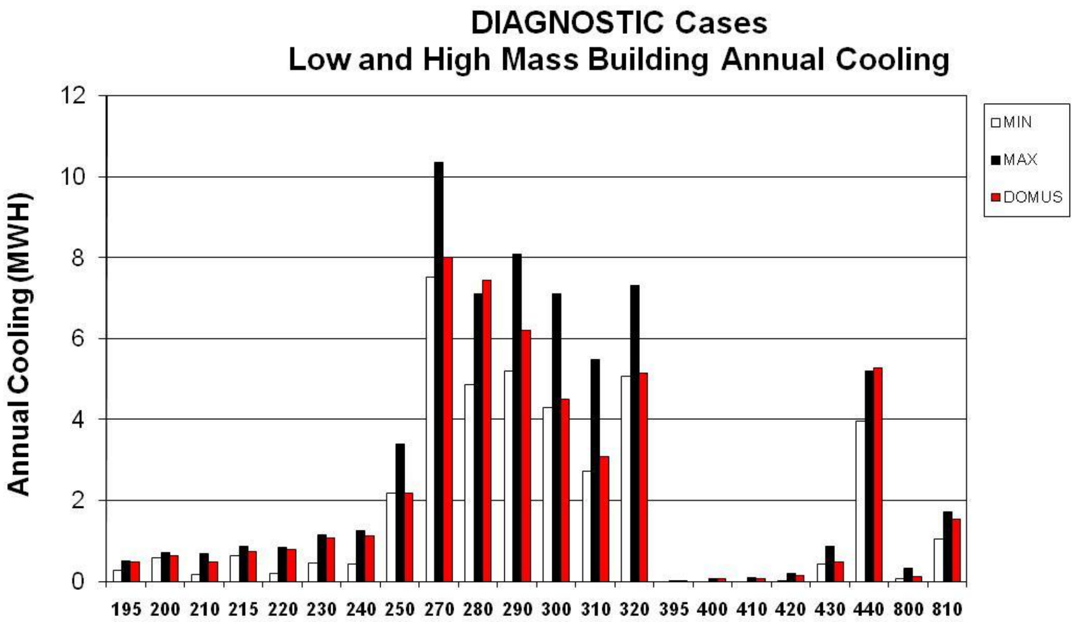

Figure 10-2: DIAGNOSTIC Cases – Low and High Mass Building Annual Cooling.

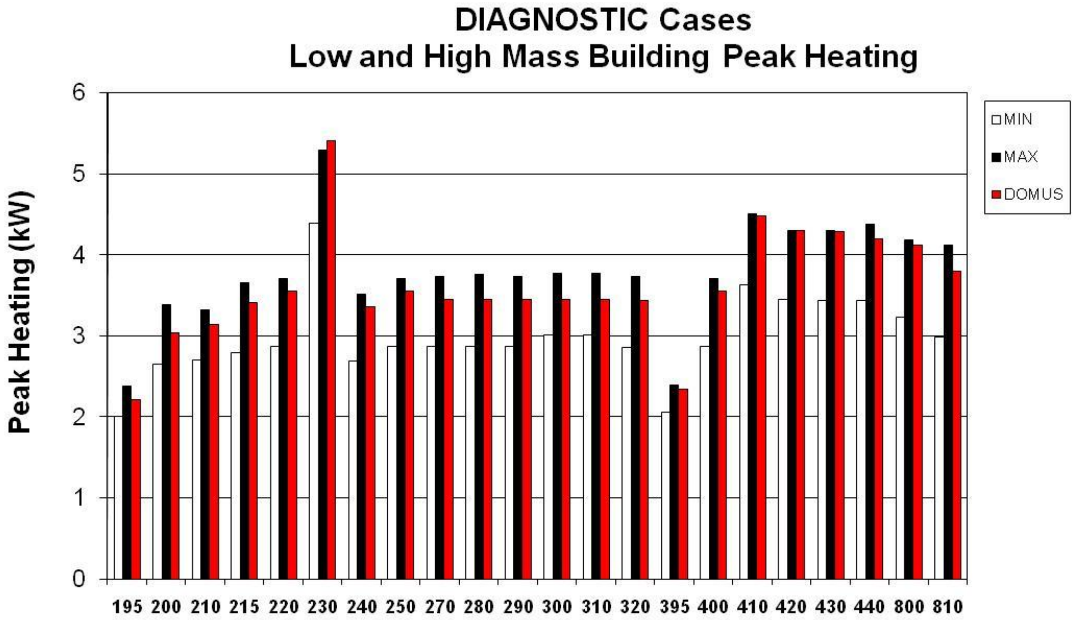

Figure 10-3: DIAGNOSTIC Cases – Low and High Mass Building Peak Heating.

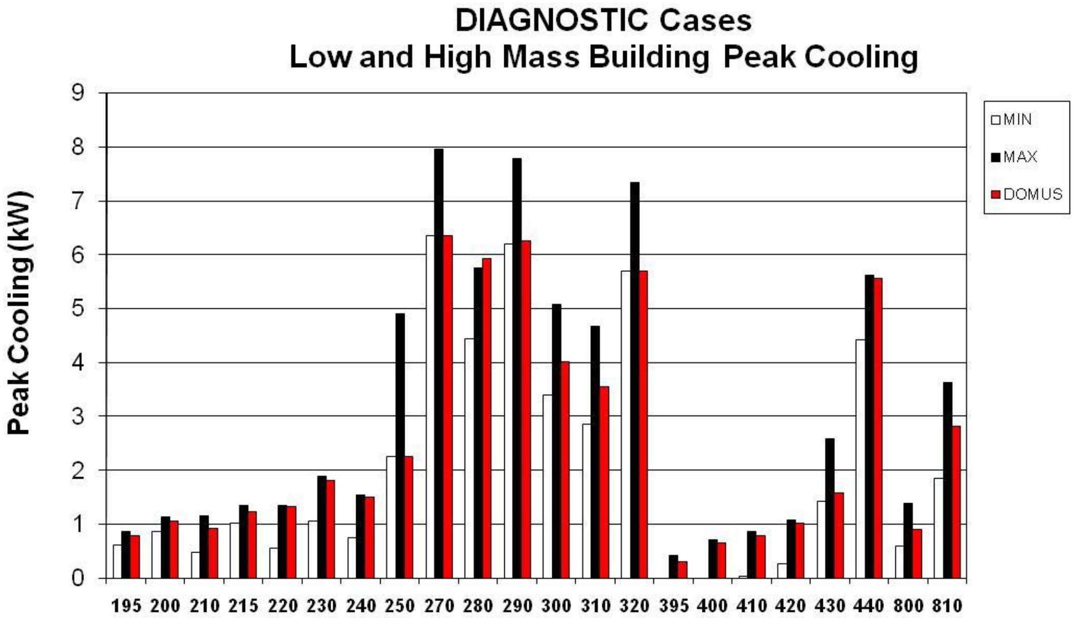

Figure 10-4: DIAGNOSTIC Cases – Low and High Mass Building Peak Cooling.

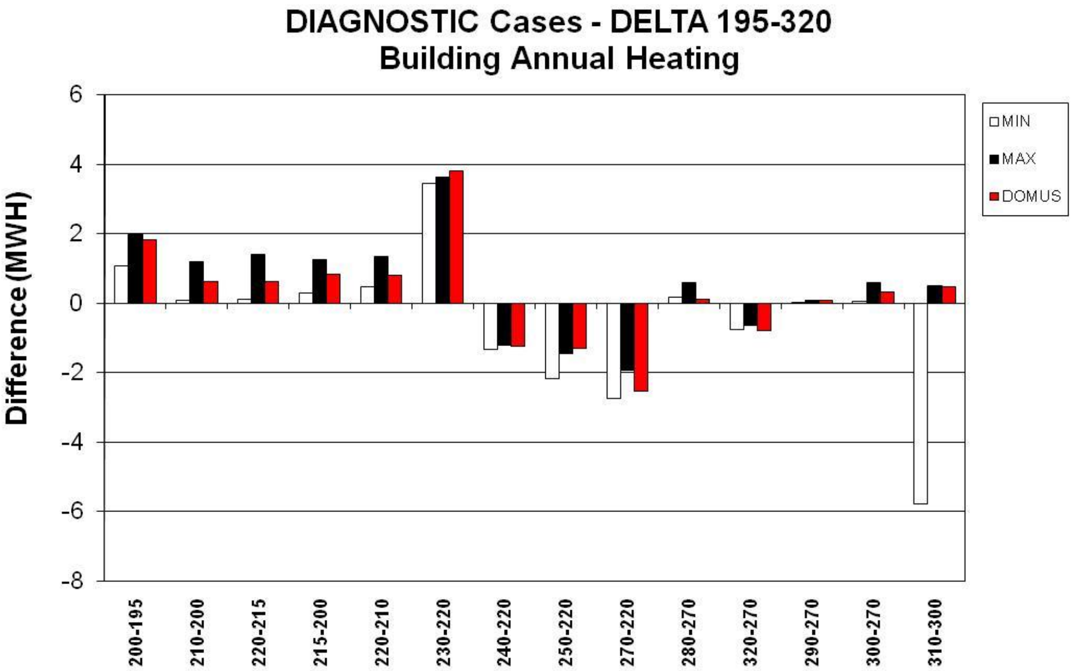

Figure 10-5: DIAGNOSTIC Cases – DELTA 195-320 – Building Annual Heating.

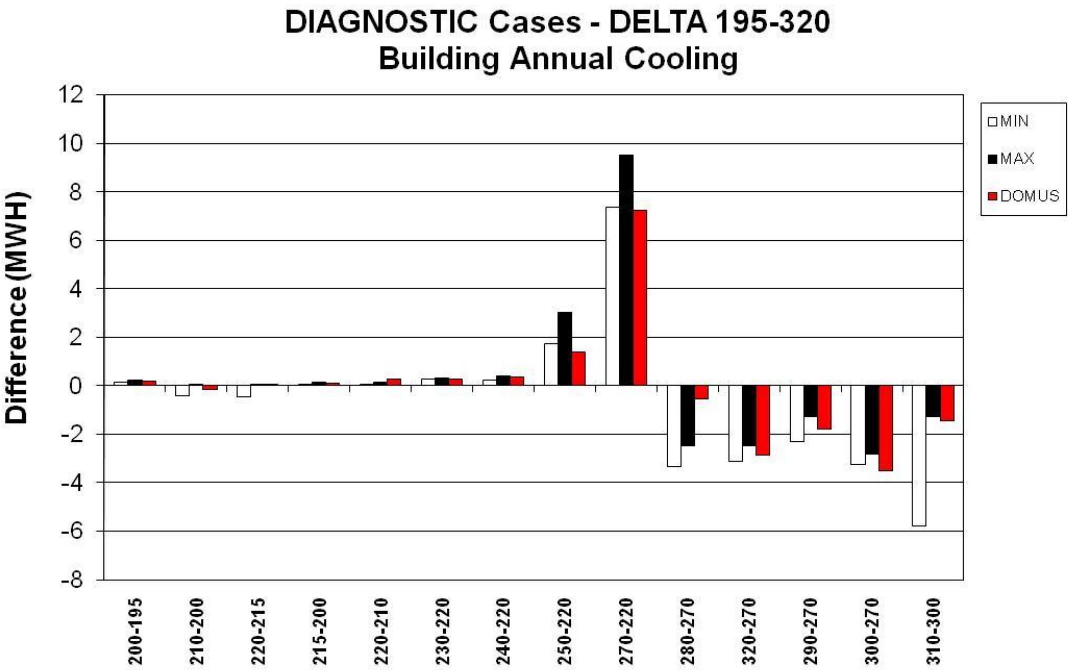

Figure 10-6: DIAGNOSTIC Cases – DELTA 195-320 – Building Annual Cooling.

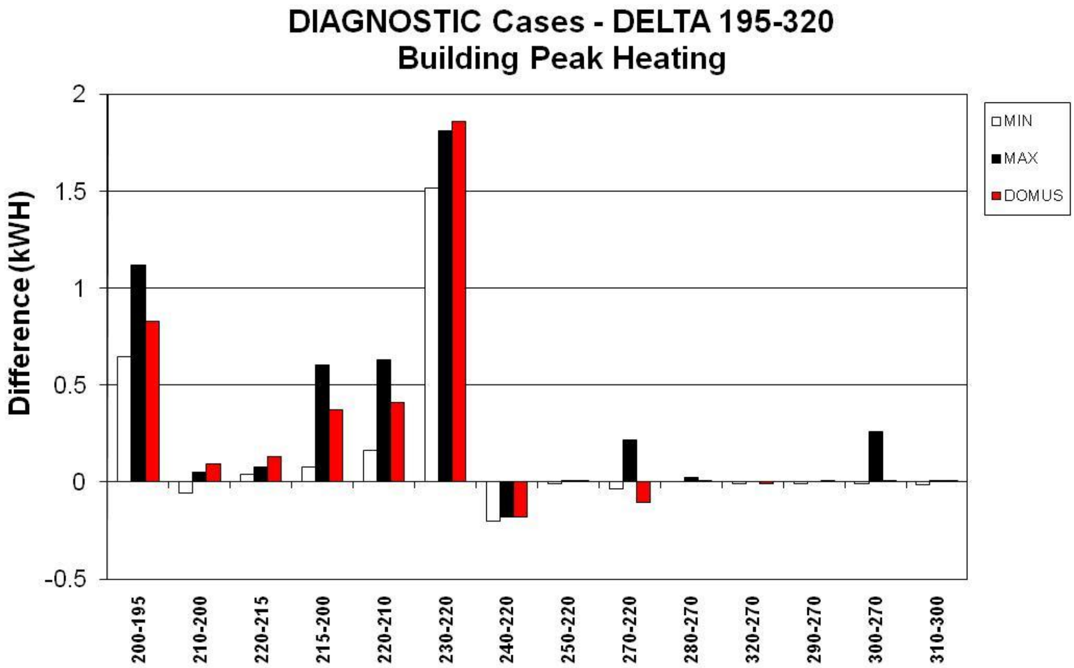

Figure 10-7: DIAGNOSTIC Cases – DELTA 195-320 – Building Peak Heating.

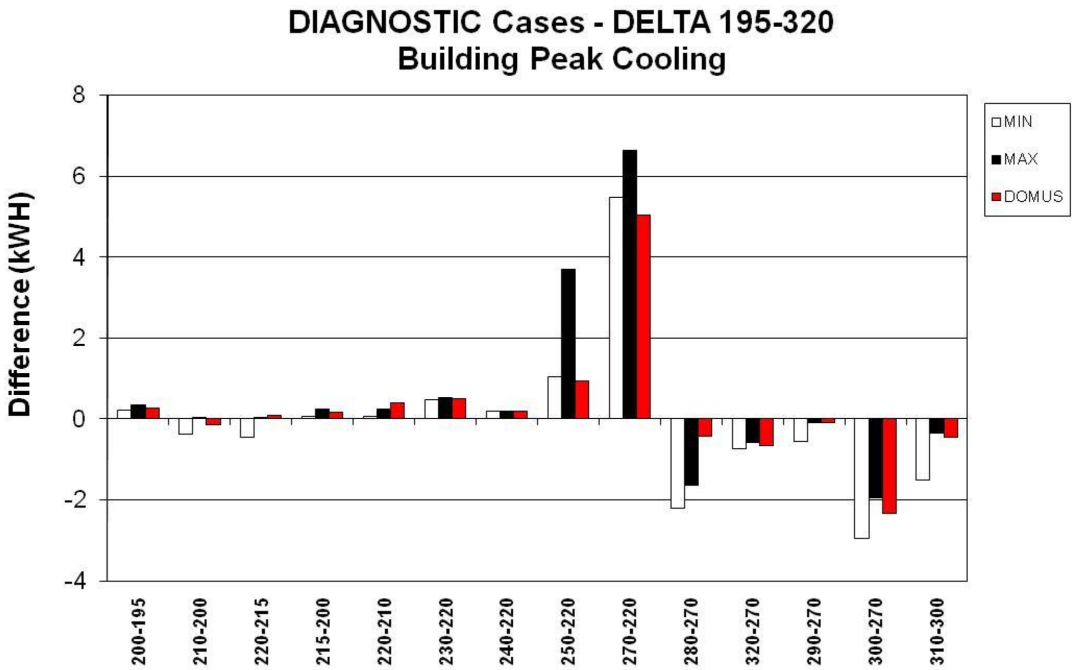

Figure 10-8: DIAGNOSTIC Cases – DELTA 195-320 – Building Peak Cooling.

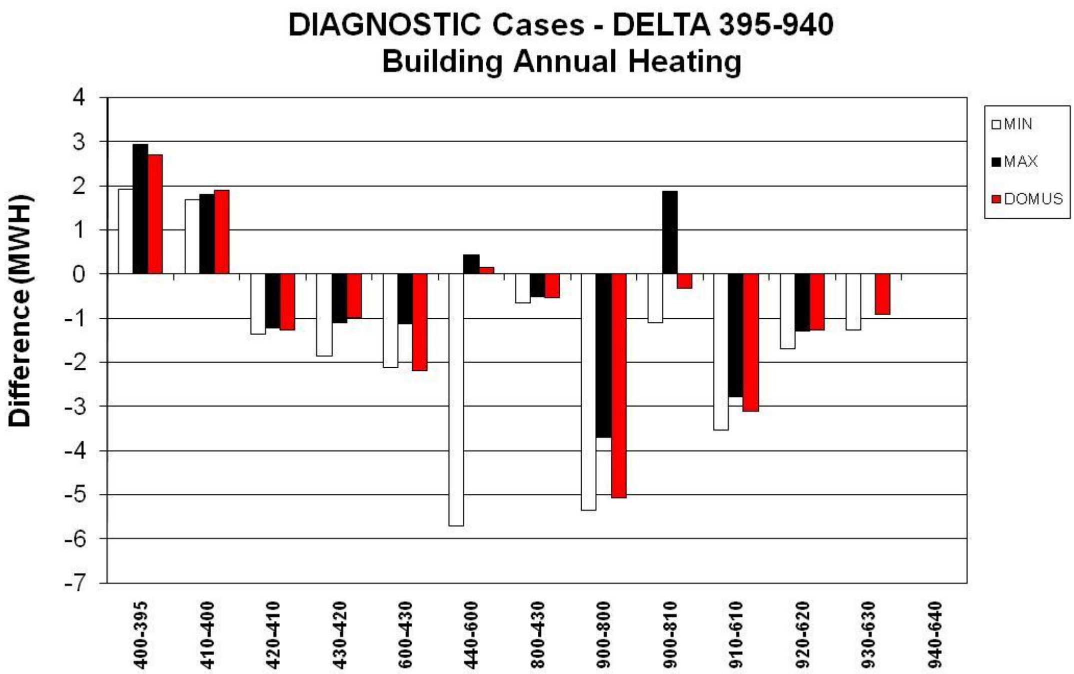

Figure 10-9: DIAGNOSTIC Cases – DELTA 395-940 – Building Annual Heating.

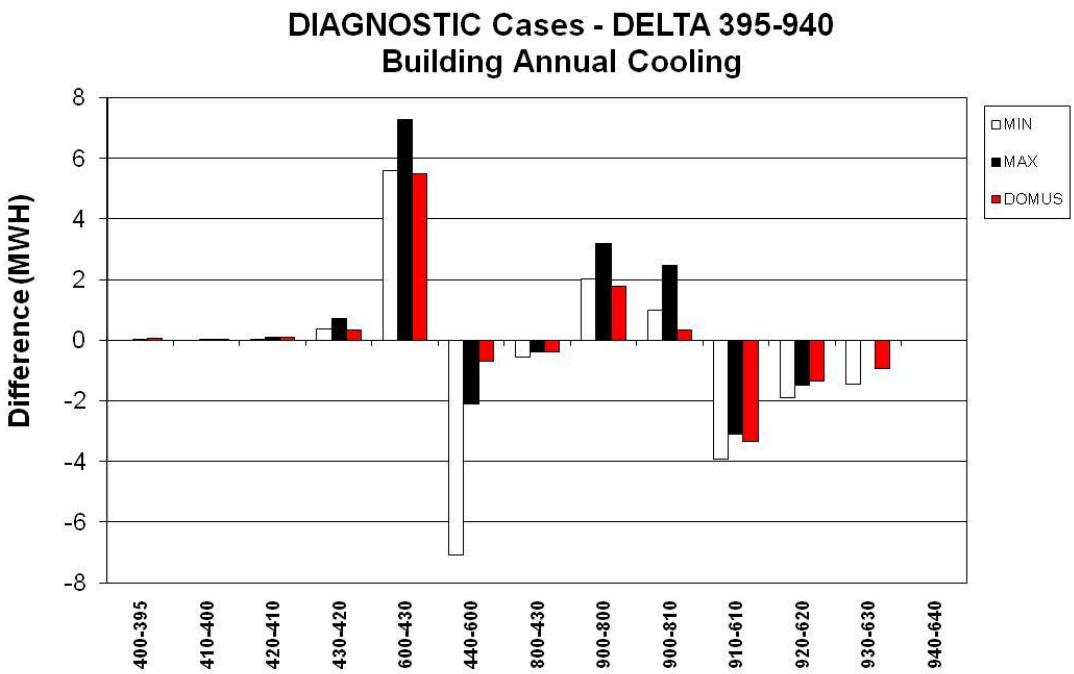

Figure 10-10: DIAGNOSTIC Cases – DELTA 395-940 – Building Annual Cooling.

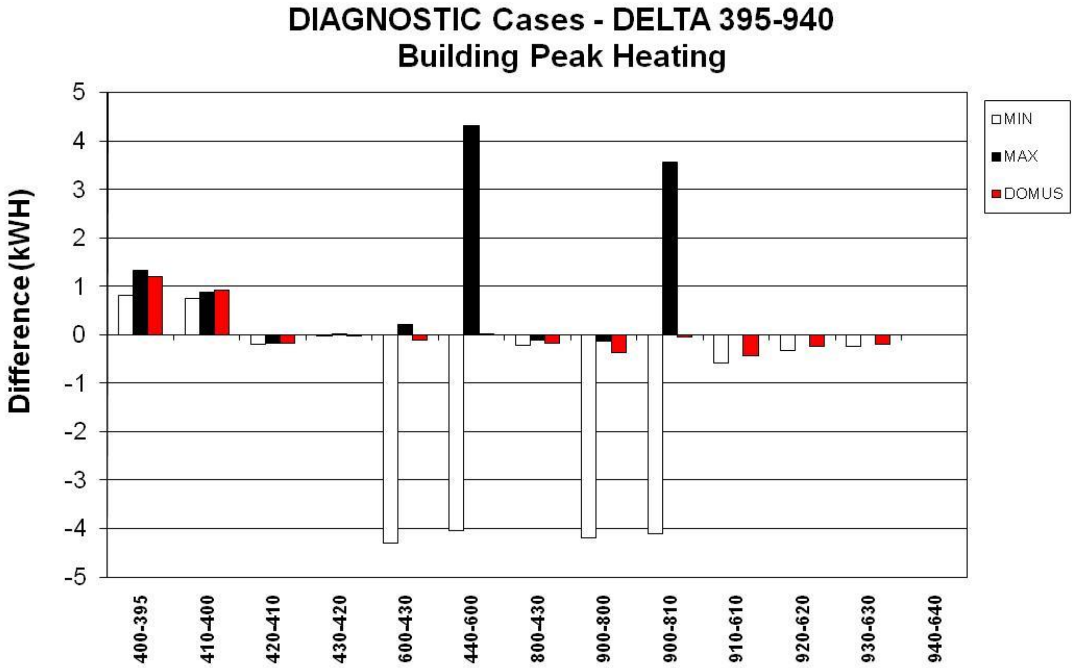

Figure 10-11: DIAGNOSTIC Cases – DELTA 395-940 – Building Peak Heating.

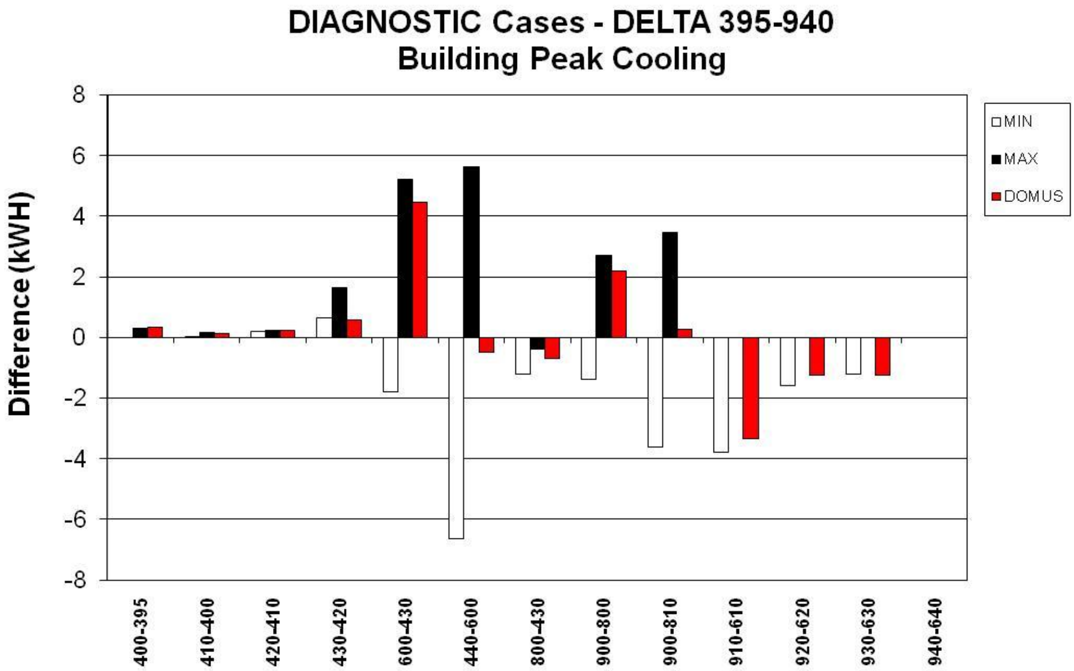

Figure 10-12: DIAGNOSTIC Cases – DELTA 395-940 – Building Peak Cooling.

11 References

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