A VALIDATION OF THE 'ACCURATE' SIMULATION ENGINE USING BESTEST

by

Angelo Delsante

April 2004

Report for
The Australian Greenhouse Office

A VALIDATION OF THE 'ACCURATE' SIMULATION ENGINE USING BESTEST

by

Angelo Delsante

April 2004

EXECUTIVE SUMMARY

The BESTEST protocol for evaluating building energy simulation software was developed by the International Energy Agency in 1995. It involves comparing a candidate program with the results from a set of "reference" programs, for a carefully chosen series of variations of a simple and meticulously described test building. Reference program results are provided for annual heating and cooling energy, peak heating and cooling demand, total annual incident and transmitted solar radiation, annual maximum and minimum temperatures for free-running buildings, and hourly temperatures and heating and cooling energies for selected days. BESTEST is a very powerful tool: if the candidate program differs significantly from the reference results for a particular building variation, it is very likely that the candidate program is deficient in some way, and the nature of the variation can give a good indication of where to start looking.

The BESTEST protocol was applied to the simulation engine used in the AccuRate software. This engine is a greatly enhanced version of the CHENATH simulation engine that is currently used in the NatHERS software.

BESTEST revealed one simple bug in the AccuRate simulation engine. After this was corrected, the conclusions obtained were:

1. In general, the AccuRate simulation engine agrees very well with the reference programs, and no major discrepancies were found. The results reported here are consistent with the BESTEST results previously obtained for CHENATH, the NatHERS simulation engine.

2. The engine's solar radiation model (incorporating the Perez model for anisotropic diffuse radiation) agrees very well with the reference programs in terms of annual total incident and transmitted solar radiation, and hourly incident solar radiation, on vertical surfaces.

3. Because the engine calculates and controls environmental temperature and not air temperature, it tends to predict somewhat high cooling energies and peak heating and cooling demands when compared with the reference programs. This is especially so for high-mass buildings and for thermostat setback.

1. INTRODUCTION

While comparison between simulations and measured data provides in principle the ultimate test of a program, it is not the only method of validation, and may not be the most revealing. Another technique, known as inter-program comparison, involves comparing the candidate program with the results from a set of "reference" programs, for a carefully chosen series of variations of a simple and meticulously described test building. If the candidate program differs significantly from the reference results for a particular building variation, it is likely (but not certain) that the candidate program is deficient in some way, and the nature of the variation can give a good indication of where to start looking.

Such a method, called BESTEST [1], was developed by the International Energy Agency in Task 12B/21C. The reference programs were: ESP (UK), BLAST (USA), DOE2 (USA), SUNCODE (USA), SERIRES (USA), S3PAS (Spain), TRNSYS (USA), and TASE (Finland). Reference program results are provided for annual heating and cooling energy, peak heating and cooling demand, total annual incident and transmitted solar radiation, annual maximum and minimum temperatures for free-running buildings, and hourly temperatures and heating and cooling energies for selected days.

This report gives the results of comparing the AccuRate engine with these programs using the BESTEST protocol. The engine alone rather than the AccuRate package (comprising a Windows user interface that drives the engine) was tested because the user interface imposes some limitations that are not present in the engine, which would have made it impossible to model the building as specified. One example of this is that in BESTEST heating and cooling is usually specified for 24 hours, whereas the AccuRate user interface specifies heating and cooling from 0700 to 2400.

2. MODELLING THE TEST BUILDING

The BESTEST test building is very simple: in its base form it is a 6 m x 8 m x 2.7 m box with a floor area of 48 m^2, two double-glazed windows either facing south (2 x 6 m^2) or east and west (6 m^2 on each facade), and either lightweight or heavyweight walls and floors. Except for one case, the building is not ground-coupled because the floor is very highly insulated. Although BESTEST does include a ground-coupled case, the ground-coupled case was omitted in ANSI/ASHRAE Standard 140-2001, which is a later version of BESTEST, no doubt reflecting the difficulties originally encountered in attempting to model the BESTEST case. Thus the ground-coupled case was not considered for this report.

BESTEST provides one year of hourly TMY weather data for Denver. The climate of Denver is such that extreme outdoor air temperatures are encountered (an annual minimum of –24.4°C and a maximum of 35.0°C). The weather data are based on solar time. Solar radiation totals are given for the hour ending on the solar hour specified (e.g. the total for hour 10 covers the period 0900 to 1000, solar time). As solar position was not provided, a separate program was written to calculate solar position at the midpoint of the solar hour, except where the solar hour included sunrise or sunset, in which case the solar position was calculated midway between sunrise and the end of the hour, or midway between the beginning of the solar hour and sunset. The time basis for the non-solar data (e.g. outdoor temperatures) was not stated, e.g. whether the values were spot values at the hour specified, or averages over the hour (i.e. centered on the half-hour), or averages centered on the hour. It is likely that the non-solar data are averages centered on the half hour. Unfortunately AccuRate assumes spot values on the hour. Nothing could be done about this mismatch, although the consequences are likely to be small for most cases, with the exception of the thermostat set-back and possibly the venting cases, where there is an irreconcilable discrepancy of half an hour between the AccuRate's interpretation and that of some of the other programs.

No difficulties were encountered in modelling the opaque elements. The specified thermal properties for each material were used, as the AccuRate engine permits material properties to be modified.

BESTEST specifies the double glazing as 3.175 mm clear glass with a refractive index of 1.526, an extinction coefficient of 0.0196, and a gap resistance of 0.1588 m^2.K/W, giving an overall U-value of 3.00 W/m^2.K when ASHRAE standard indoor and outdoor combined convective-radiative surface coefficients are used. The BESTEST specification also gives the transmittance and absorptances of each pane as a function of angle of incidence. The transmittance and absorptance data were used to create a special window data file for the AccuRate engine. However, because the engine calculates its own glazing surface heat transfer coefficients at each hour, the glazing U-value it calculates at each hour will usually differ from the specified value of 3.00 W/m^2.K (and in fact will be often lower). However this treatment is in accordance with the BESTEST guidelines.

The BESTEST specification gives the fractions of solar gain that are absorbed by each indoor surface and the fraction lost back through the window. These were used in the AccuRate engine input file.

3. COMPARISONS BETWEEN ACCURATE AND THE REFERENCE PROGRAMS

3.1 Description of cases simulated

There are 36 BESTEST cases (i.e. variations of the basic building) in all, plus four free-floating cases (i.e. no heating or cooling). These are classified as either “qualification” cases (14 in number) or “diagnostic” cases. The diagnostic cases are further divided into “realistic” or “primitive” diagnostic cases. A suggested procedure is to run the qualification cases first. If disagreements occur, the flow-charts supplied show how the diagnostic cases can then be used to try to identify the problem. Because it was recognised that some programs are not able to simulate the primitive diagnostic cases (e.g. because they cannot vary the outdoor surface emissivity), the realistic diagnostic cases are supplied as an alternative.

The AccuRate engine was run for all the qualification and realistic diagnostic cases.

Table 1. The BESTEST qualification cases. All are heated to 20°C and cooled to 27°C for 24 hours a day unless otherwise specified. The 600 series refers to lightweight walls and floor; the 900 series refers to heavyweight walls and floor.

Case no.	Description
600/900 600FF/900FF	South-facing 12m^2 window; no shading; exterior and interior solar absorptance 0.6; internal gains 200W; infiltration rate 0.5 air changes per hour. As for 600/900 but no heating or cooling.
610/910	As for 600/900, with 1 m full-width overhang on the south facade
620/920	As for 600/900, but with a 6 m^2 east window and a 6 m^2 west window, no shading.
630/930	As for 620/920, with 1 m overhang over windows only, plus 1 m reveals on both sides of each window.
640/940	As for 600/900, but heating thermostat set back to 10°C from 2300 to 0700.
650/950 650FF/950FF	As for 600/900, but no heating; cooling on from 0700 to 2300; vent fan on from 2300 to 0700 inducing 10.8 air changes per hour. As for 650/950, but no heating or cooling.
960	Sunspace: 2 m x 6 m heavyweight south-facing sunspace zone with 12 m^2 window; 6 m x 8 m lightweight back zone separated from sunspace zone by a mass wall. Back zone as for case 600.

Note that cases 650/950 are the only ones that test ventilation. However, they only test the effect of forced ventilation, where the air flow rate is specified and constant during the venting period, rather than natural ventilation, where the air flow rate varies depending on outdoor and indoor conditions. Nevertheless they are a useful test of the software’s ability to handle the effect of a sudden increase in ventilation rate.

Table 2. The BESTEST realistic diagnostic cases. All are heated to 20°C and cooled to 27°C for 24 hours a day. All are lightweight except 800 and 810.

Case no.	Description
395	No windows; exterior solar absorptance reduced to 0.1; zero internal gains and infiltration.
400	As for 395, but with 12 m^2 "high-conductance" south wall having the same thermal properties as the double-glazed window but not admitting or absorbing solar radiation.
410	As for 400, but with 0.5 ac/h infiltration.
420	As for 410, but with 200 W internal heat gain.
430	As for 420, but exterior solar absorptance increased to 0.6.
440	As for 600, but with interior solar absorptance reduced to 0.1.
800	As for 430, but heavyweight.
810	As for 440, but heavyweight.

3.2 Results for solar radiation

The AccuRate engine's calculation of incident solar radiation on tilted surfaces normally includes the Perez model [2] for anisotropic skies. This and similar models are based on the fact that diffuse radiation is anisotropic, because of the horizon-brightening effect and because some of the radiation recorded as diffuse comes from a circumsolar region and should in fact be treated as direct radiation. When converting radiation measured on a horizontal surface to that incident on a vertical surface, the change in intensity from the anisotropic regions should be taken into account. The effect of doing so is to usually increase the direct and decrease the diffuse radiation on the tilted surface.

Previous work [3] on empirical validation of CHENATH, the NatHERS simulation engine, showed that the Perez model give better agreement with measured values of incident radiation on an equator-facing vertical surface than did the isotropic model (although there was some indication that it may in fact slightly overestimate the incident radiation). Since then the Perez model has been incorporated into CHENATH and its successor, the AccuRate engine.

The annual total solar radiation incident on external surfaces or transmitted through the windows is shown in Table 3. Results for the isotropic sky model are also shown for comparison, but all subsequent AccuRate engine results are for the Perez model. Note that because the weather data are for Denver, the south façade faces the equator.

Table 3. Comparisons of annual total solar radiation.

Orientation	AccuRate (Perez anisotropic sky model)	AccuRate (Isotropic sky)	Range of reference programs and mean
Incident solar (kWh/m^2.annum)			
N	437	450	367 – 457 (429)
E	1156	1078	959 – 1217 (1080)
S	1565	1460	1456 – 1566 (1490)
W	1080	997	857 – 1090 (1018)
Horizontal	1832	1832	1797 – 1832 (1827)
Transmitted solar, unshaded (kWh/m^2.annum)			
W	712	655	563 – 735 (676)
S	1012	948	914 – 1051 (962)
Transmitted solar, shaded (kWh/m^2.annum)			
W	502	458	431 – 599 (488)
S	794	752	757 – 831 (792)
Transmissivity coefficient (unshaded transmitted/incident)			
W	0.659	0.657	0.641 – 0.687 (0.663)
S	0.647	0.649	0.623 – 0.671 (0.646)
Overhang and fin shading coefficients (1 - shaded transmitted/unshaded transmitted)			
W	0.295	0.301	0.182 – 0.346 (0.278)
S	0.215	0.207	0.115 – 0.209 (0.176)

The results show good agreement for either sky model (as might be expected since some of the reference programs use the isotropic sky model, while the rest use a variety of anisotropic models), and also clearly show the increase in incident solar when the Perez anisotropic model is used. The only value out of range for the Perez model is the south overhang fin shading coefficient, which is slightly high. The overshoot is too small to be of concern, but nevertheless the shading-related code was carefully checked and no errors were found.

Figures 1 and 2 show the hourly incident solar radiation on the south and west facades for a cloudy spring day (March 5), while figures 3 and 4 are for a clear summer day (July 27) (note that BLAST results were not available). The agreement is good in all cases.

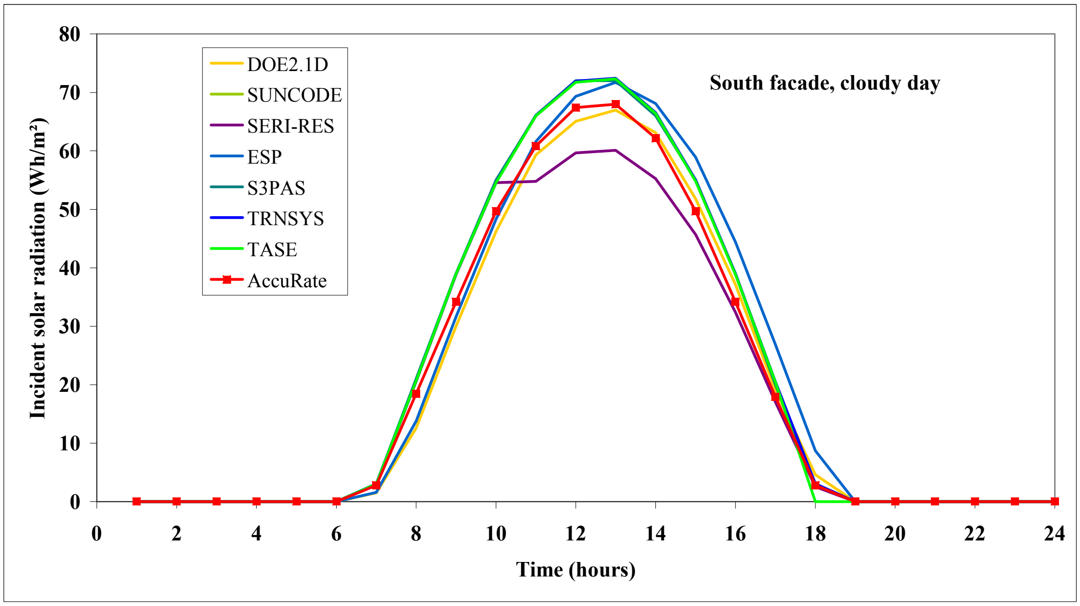

Figure 1. Hourly incident solar radiation on the south façade for a cloudy day (March 5)

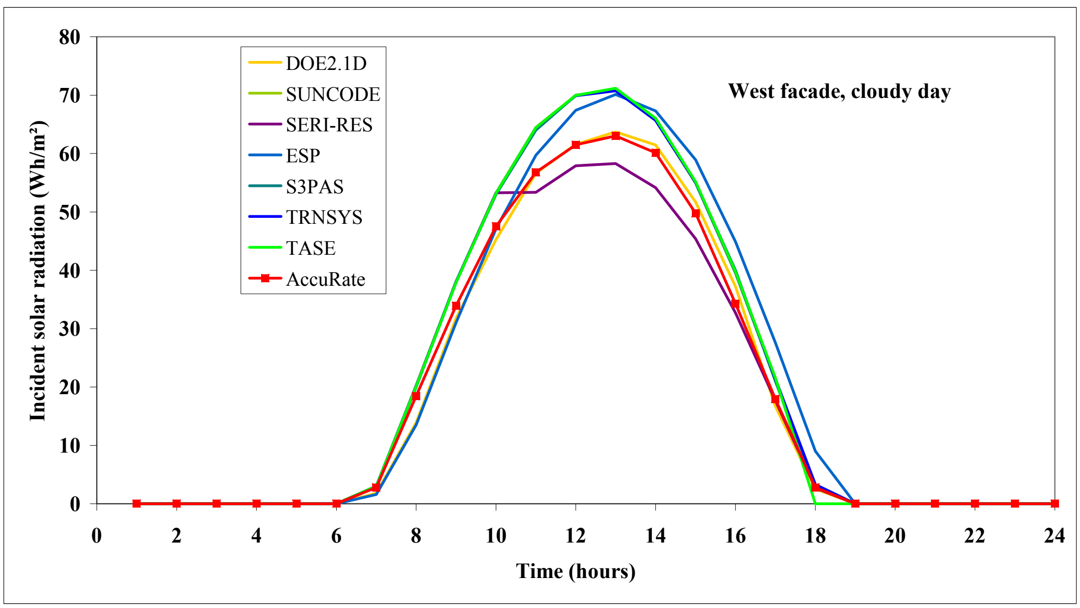

Figure 2. Hourly incident solar radiation on the west façade for a cloudy day (March 5)

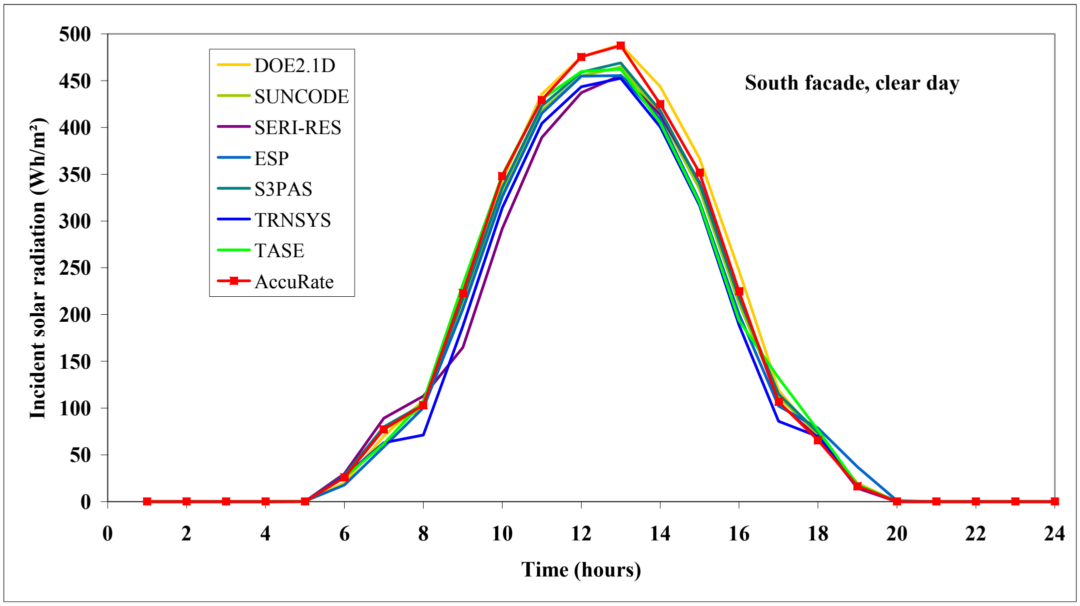

Figure 3. Hourly incident solar radiation on the south façade for a clear day (July 27)

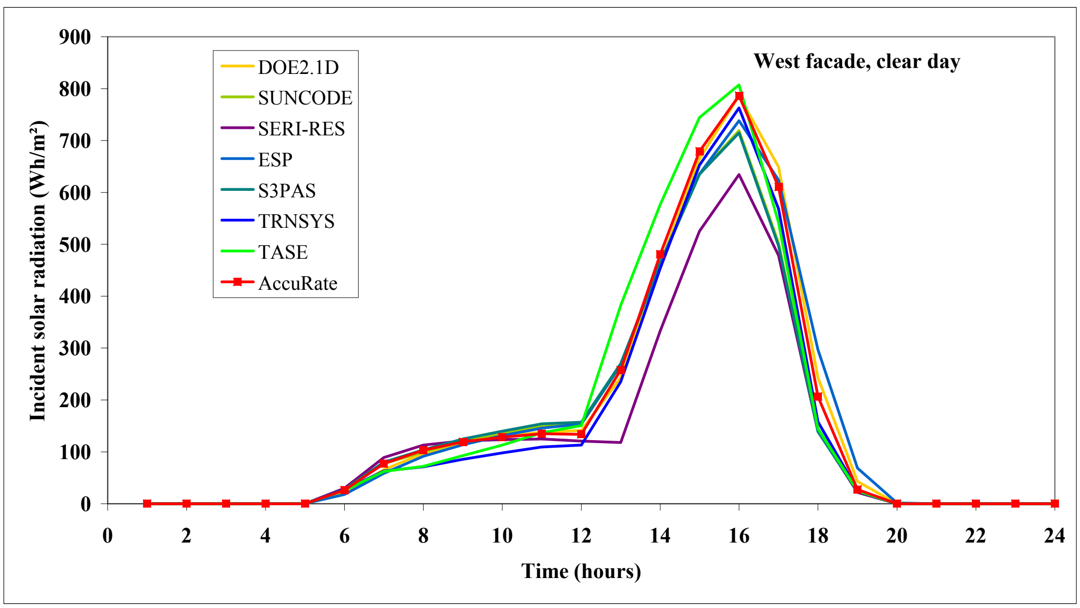

Figure 4. Hourly incident solar radiation on the west façade for a clear day (July 27)

3.3 Results for qualification cases

In comparing the AccuRate results with the reference programs, it should be borne in mind that the BESTEST protocol simply requires that the candidate program show "reasonable" agreement with the reference programs, and that "anomalous" results be corrected. However, the manual states that "We provide no exact definition for 'anomalous results' here. In general, any result very different from the example results .... should be scrutinized."

The first runs for the qualification cases gave anomalous results for cases 630/930 (east and west windows shaded by overhangs and fins). This was traced to a bug in the calculation of the shading effect of a right-hand fin. The bug was corrected and all the results reported here are with this bug fixed. Table 4 shows the effect of the bug on annual energy for case 630, and on the energy difference between cases 630 and 620.

Table 4. Effect of fin bug in the AccuRate simulation engine.

	Heating energy (MWh)			Cooling energy (MWh)		
Case	With bug	Without bug	Range of reference programs	With bug	Without bug	Range of reference programs
630	6.142	5.864	5.050 – 6.469	2.274	3.185	2.129 – 3.701
630-620	0.763	0.485	0.267 – 0.551	-2.562	-1.650	-1.845 – -0.984

While the absolute results were within the reference program ranges even with the bug present, the differences showed the anomaly clearly.

Table 5 and figures 5-8 give the results for annual heating energy and peak demands (in the figures, the cases on the horizontal axis are further identified by a brief description). In the tables and figures, the reference program range for each case is given. These ranges were determined by the BESTEST developers. Normally they were simply set by the lowest and highest results from the reference programs. However, in some cases one or more of the reference programs was excluded for the purposes of range setting (e.g. in figure 5, program TASE was excluded from setting the upper limit for case 630, because its results were judged to be unreliable for this case), while in others no ranges were set.

Table 5. Qualification cases: results for heating.

	Heating energy (MWh)		Peak heating demand (kW)	
Case	AccuRate	Range of reference programs	AccuRate	Range of reference programs
600	5.208	4.296 – 5.709	4.209	3.437 – 4.354
610	5.312	4.355 – 5.786	4.210	3.434 – 4.354
620	5.379	4.613 – 5.944	4.216	3.591 – 4.379
630	5.864	5.050 – 6.469	4.216	3.592 – 4.278
640	3.133	2.751 – 3.803	6.958	5.232 – 6.954
900	1.830	1.170 – 2.041	4.018	2.850 – 3.797
910	2.234	1.575 – 2.282	4.023	2.858 – 3.801
920	3.911	3.313 – 4.300	4.092	3.308 – 4.061
930	4.830	4.143 – 5.335	4.106	3.355 – 4.064
940	1.155	0.793 – 1.411	8.174	3.980 – 6.428
960	2.845	2.311 – 3.373	2.867	2.410 – 2.896

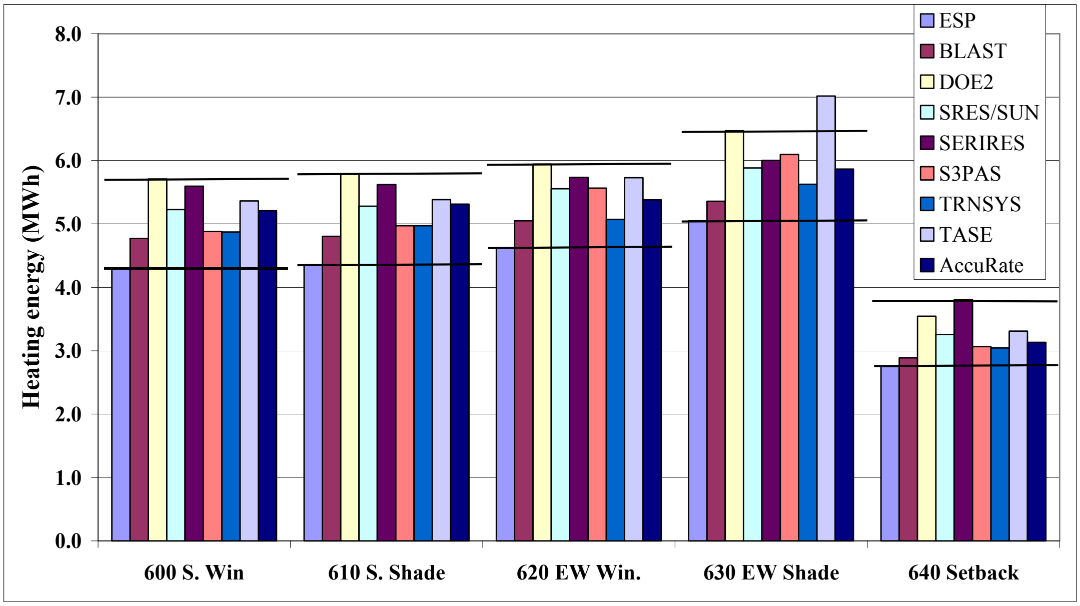

Figure 5. Low-mass annual heating energy. The reference program ranges are shown as horizontal lines.

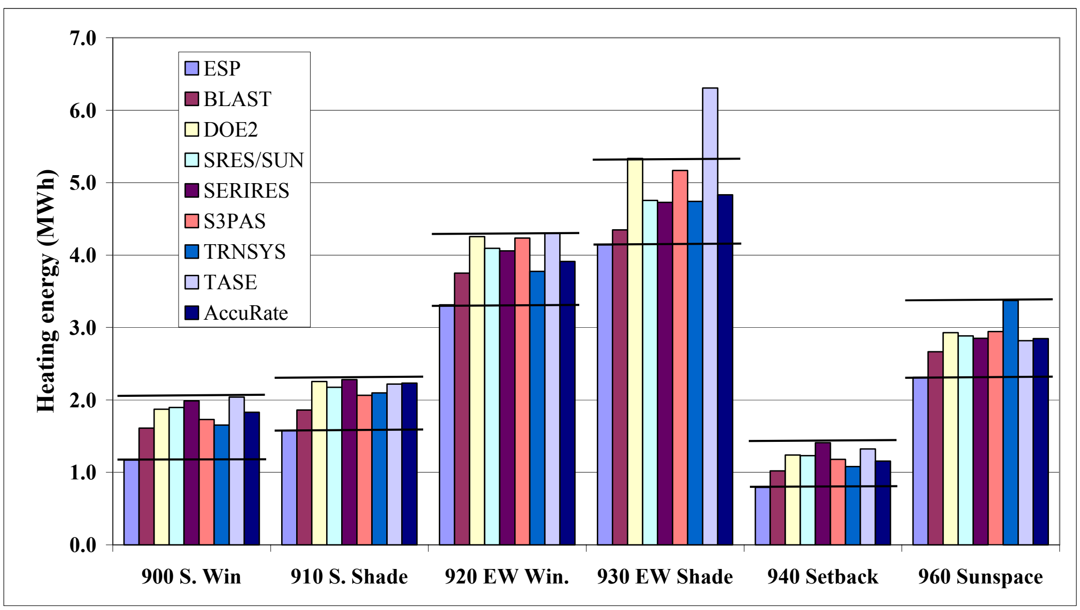

Figure 6. High-mass annual heating energy. The reference program ranges are shown as horizontal lines.

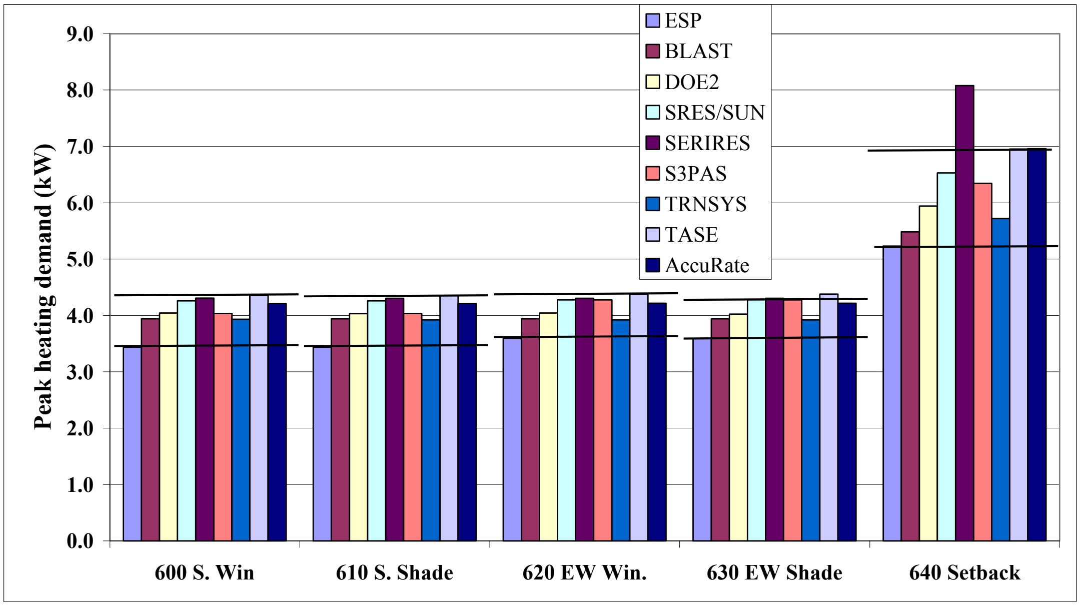

Figure 7. Low-mass peak heating demand. The reference program ranges are shown as horizontal lines.

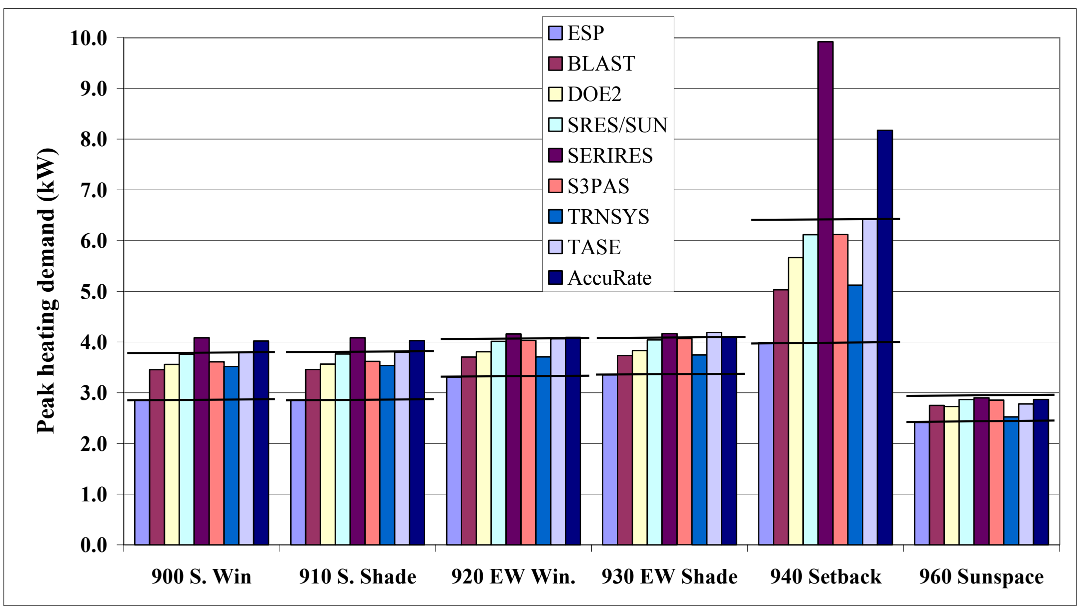

Figure 8. High-mass peak heating demand. The reference program ranges are shown as horizontal lines.

Table 6 and figures 9-12 give the results for annual cooling energy and peak demand.

Table 6. Qualification cases: results for cooling. A range in brackets indicates that a reference range was not set, in which case the values given are simply the lowest and highest values of the reference programs.

	Cooling energy (MWh)		**Peak cooling demand (kW)**	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
600	7.512	6.137 – 7.964	7.210	5.965 – 6.812
610	5.213	3.915 – 5.778	6.501	5.669 – 6.146
620	4.836	3.417 – 5.004	4.939	3.634 – 5.096
630	3.185	2.129 – 3.701	4.297	3.072 – 3.704
640	7.108	(5.952 – 7.811)	7.164	(7.537 – 6.161)
650	5.918	4.816 – 6.545	7.081	5.831 – 6.679
900	3.321	2.132 – 3.415	4.781	2.888 – 3.567
910	1.685	0.821 – 1.872	3.876	1.896 – 3.147
920	3.155	1.840 – 3.092	4.144	2.385 – 3.505
930	1.996	1.039 – 2.238	3.511	1.873 – 2.546
940	3.132	(2.079 – 3.241)	4.781	(2.888 – 3.567)
950	0.603	0.387 – 0.921	3.742	2.033 – 2.867
960	0.817	0.411 – 0.803	1.474	0.953 – 1.403

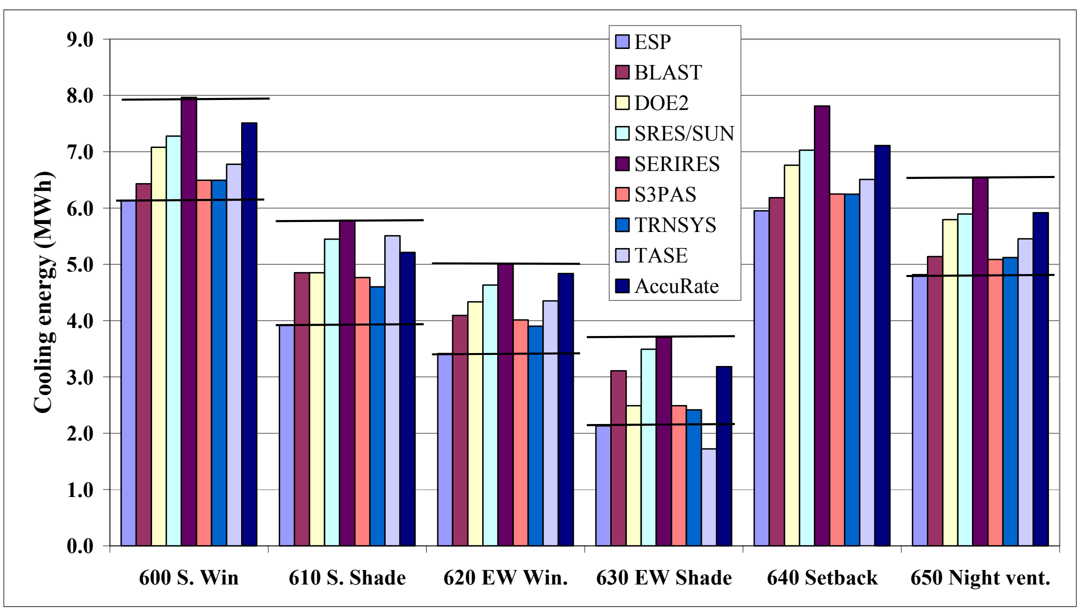

Figure 9. Low-mass annual cooling energy. The reference program ranges (where set) are shown as horizontal lines.

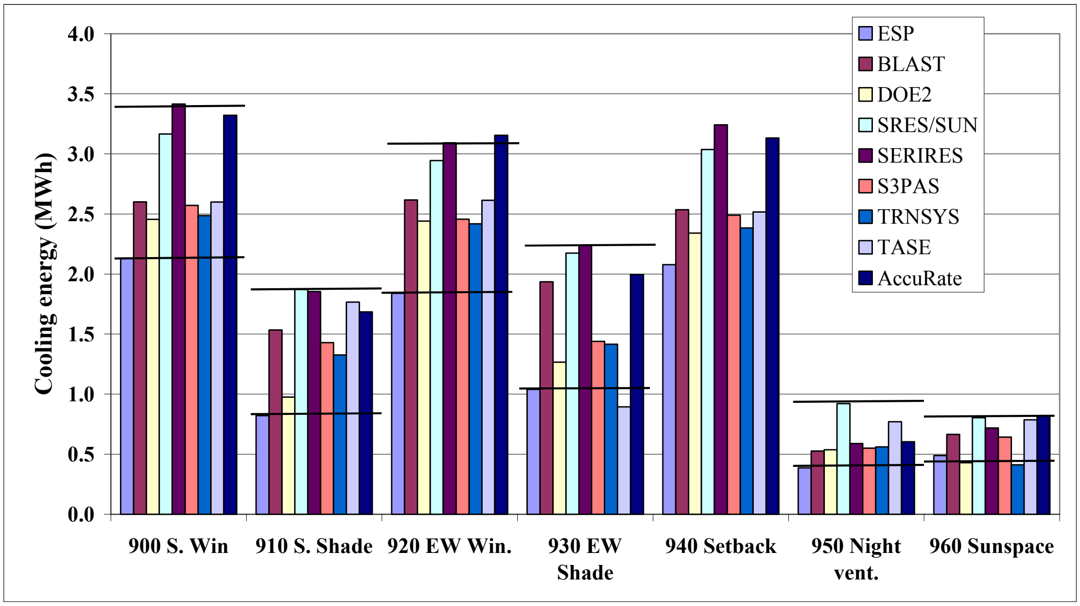

Figure 10. High-mass annual cooling energy. The reference program ranges (where set) are shown as horizontal lines.

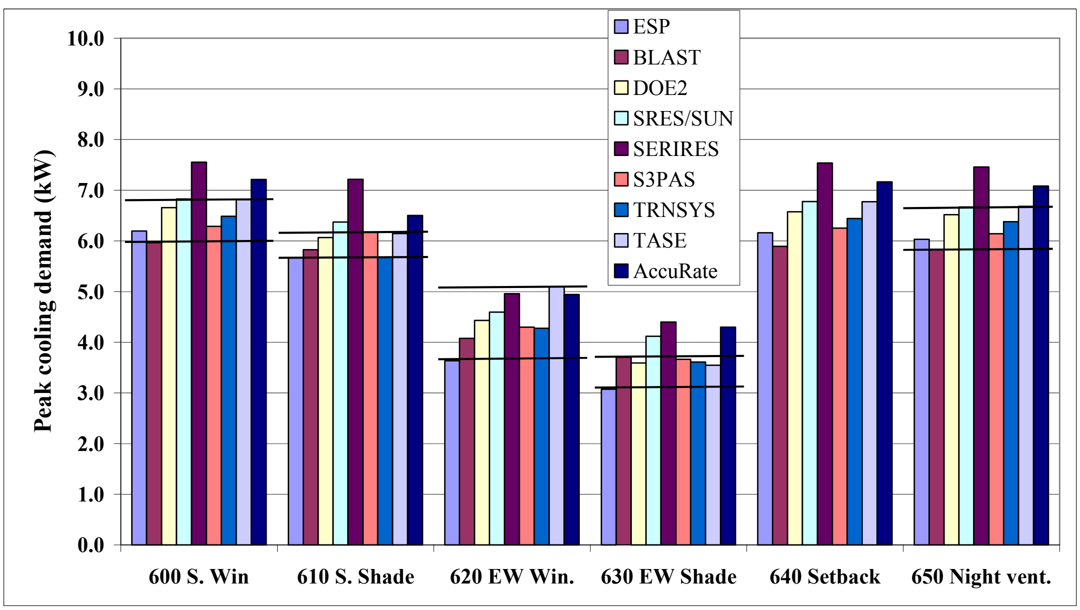

Figure 11. Low-mass peak cooling demand. The reference program ranges (where set) are shown as horizontal lines.

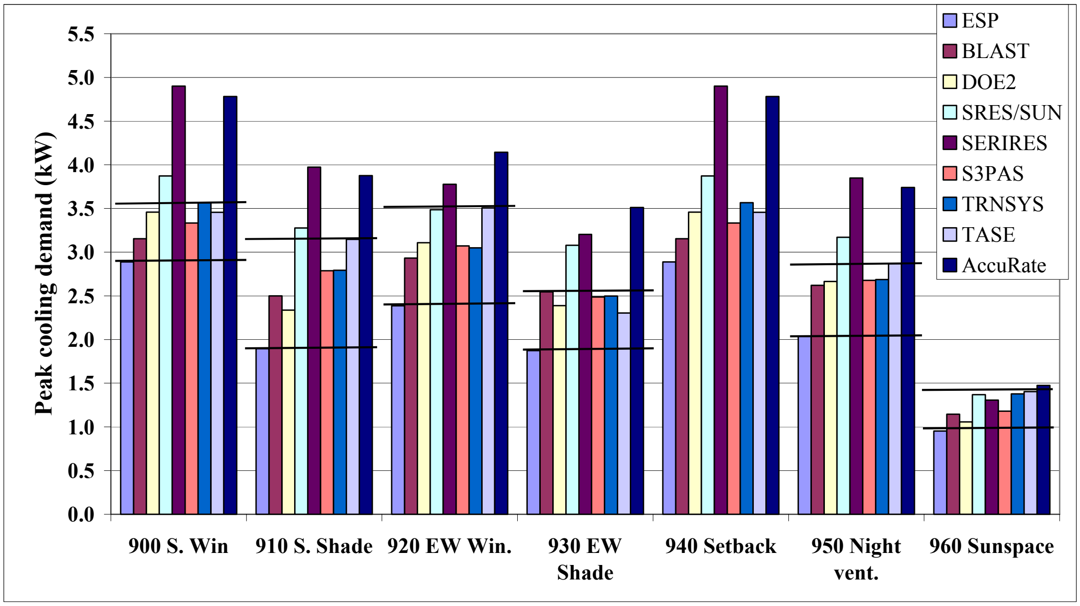

Figure 12. High-mass peak cooling demand. The reference program ranges (where set) are shown as horizontal lines.

Table 7 and figures 13-16 give the results for the annual heating energy and demand differences.

Table 7. Qualification differences - heating; 610-600 means the difference between the energies for cases 610 and 600, and so on.

	Heating energy (MWh)		Peak heating demand (kW)	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
610-600	0.104	0.021 – 0.098	0.001	-0.011 – 0.000
620-600	0.171	0.138 – 0.682	0.007	-0.008 – 0.240
630-620	0.485	0.267 – 0.551	0.000	-0.021 – 0.003
640-600	-2.075	-2.166 – -1.545	2.749	1.546 – 2.600
900-600	-3.378	-3.837 – -3.126	-0.191	-0.587 – -0.414
910-900	0.404	0.179 – 0.442	0.005	0.003 – 0.019
920-900	2.081	2.070 – 2.505	0.074	0.192 – 0.458
930-920	0.919	0.595 – 1.080	0.014	0.027 – 0.127
940-900	-0.675	-0.718 – -0.377	4.156	1.130 – 2.631
960-900	1.015	0.775 – 1.718	-1.151	-1.018 – -0.440

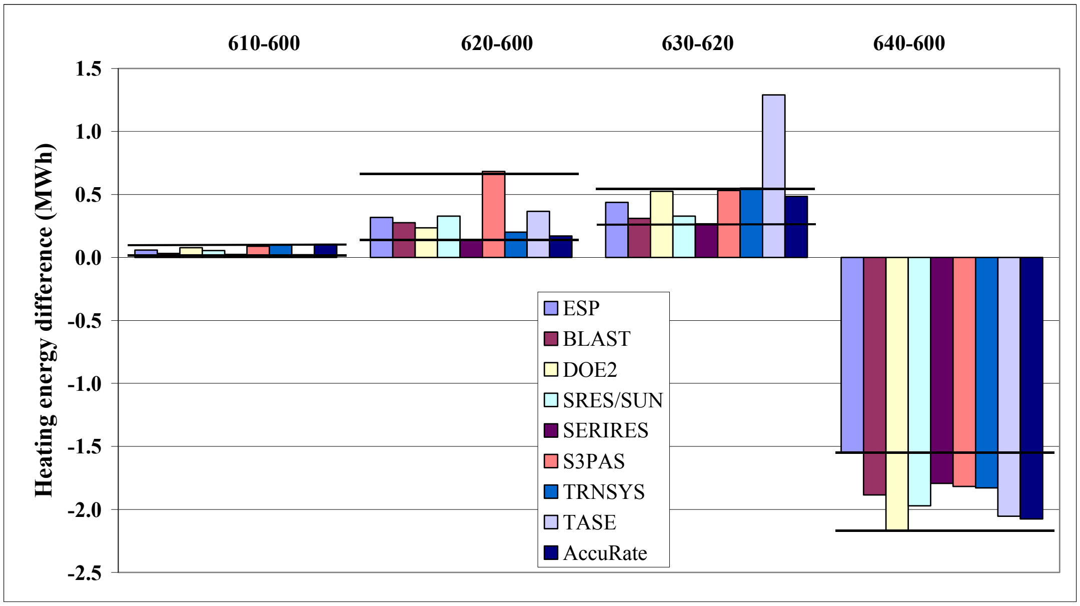

Figure 13. Low-mass annual heating energy differences. The reference program ranges are shown as horizontal lines.

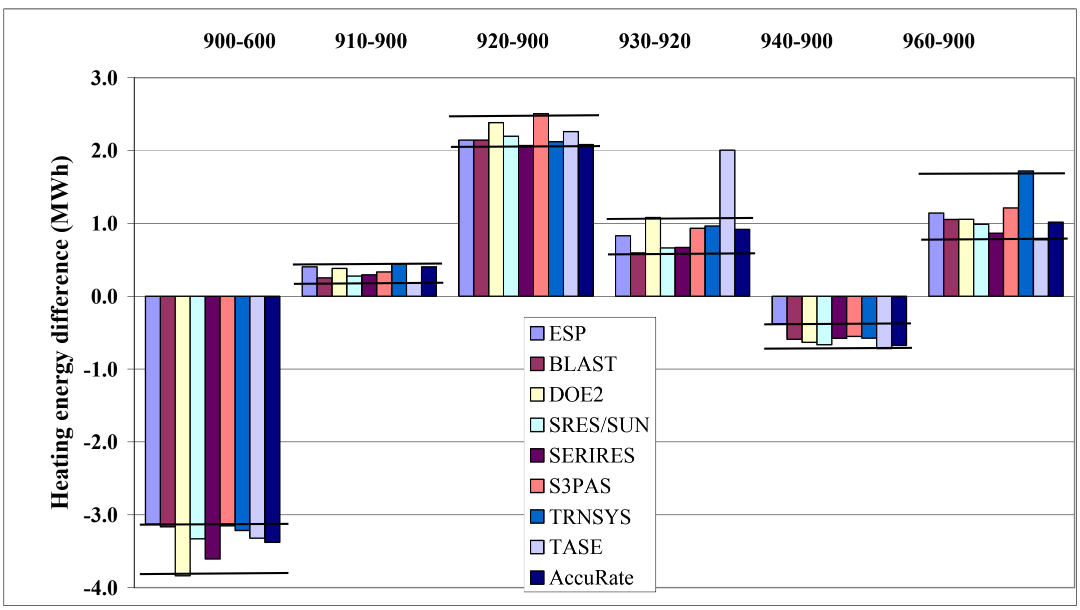

Figure 14. High-mass annual heating energy differences. The reference program ranges are shown as horizontal lines.

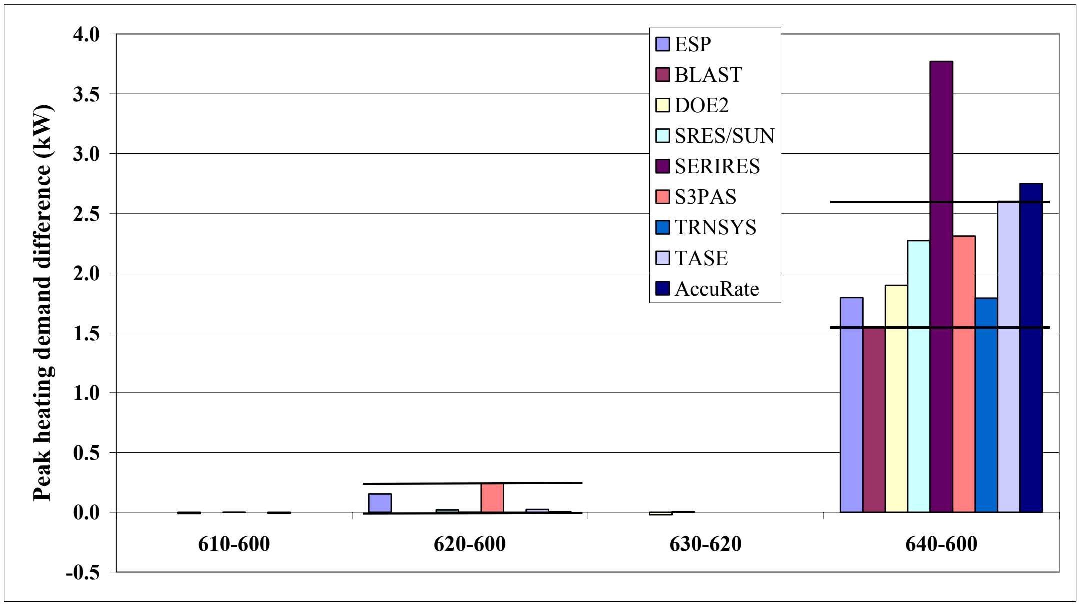

Figure 15. Low-mass peak heating demand differences. The reference program ranges are shown as horizontal lines.

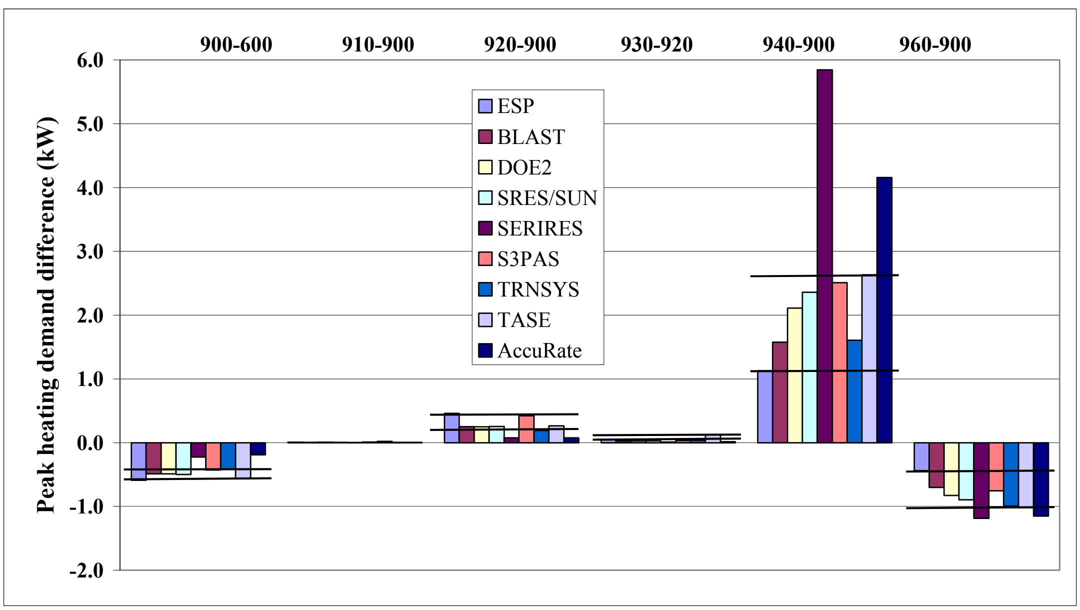

Figure 16. High-mass peak heating demand differences. The reference program ranges are shown as horizontal lines.

Table 8 and figures 17-20 give the results for the annual cooling energy and demand differences.

Table 8. Qualification differences - cooling; 610-600 means the difference between the energies for cases 610 and 600, and so on. A range in brackets indicates that a reference range was not set, in which case the values given are simply the lowest and highest values of the reference programs.

	Cooling energy (MWh)		Peak cooling demand (kW)	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
610-600	-2.299	-2.227 – -1.272	-0.709	-0.811 – -0.116
620-600	-2.676	-2.960 – -2.341	-2.271	-2.560 – -1.716
630-620	-1.651	-1.845 – -0.984	-0.642	-0.842 – -0.371
640-600	-0.404	(-0.320 – -0.153)	-0.046	(-0.080 – -0.014)
650-600	-1.594	-1.419 – -1.284	-0.129	-0.163 – -0.108
900-600	-4.191	-4.624 – -3.833	-2.429	-3.355 – -2.810
910-900	-1.636	-1.561 – -0.832	-0.905	-1.122 – -0.310
920-900	-0.166	-0.323 – 0.016	-0.637	-0.517 – 0.048
930-920	-1.159	-1.174 – -0.682	-0.633	-0.721 – -0.387
940-900	-0.189	(-0.174 – -0.053)	0.000	(0.000)
950-900	-2.718	-2.826 – -1.745	-1.039	-0.881 – -0.534
960-900	-2.504	-2.697 – -1.644	-3.307	-2.401 – -1.935

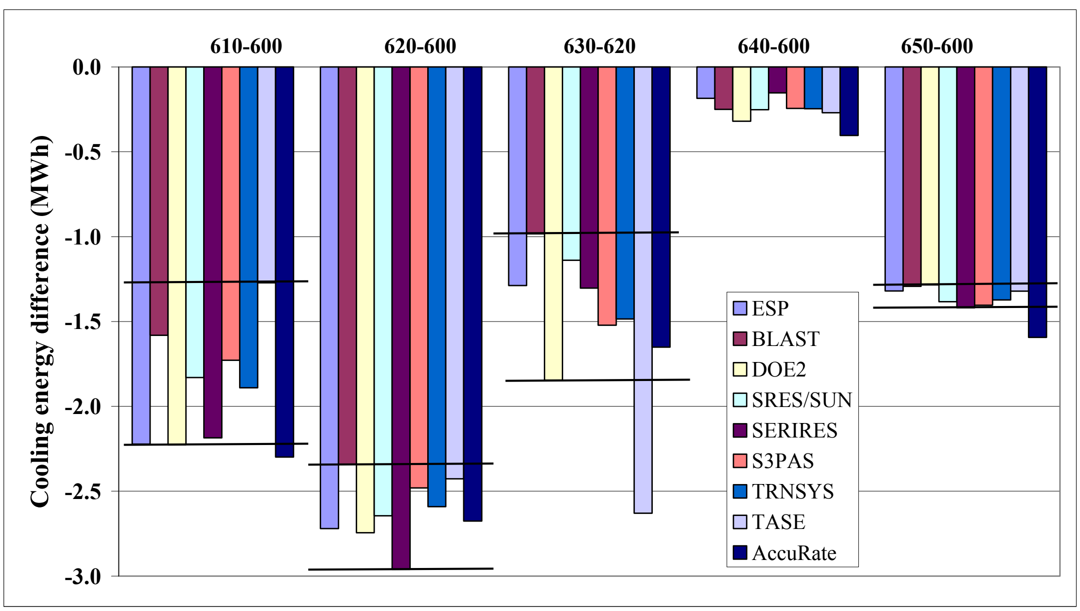

Figure 17. Low-mass cooling energy differences. The reference program ranges (where set) are shown as horizontal lines.

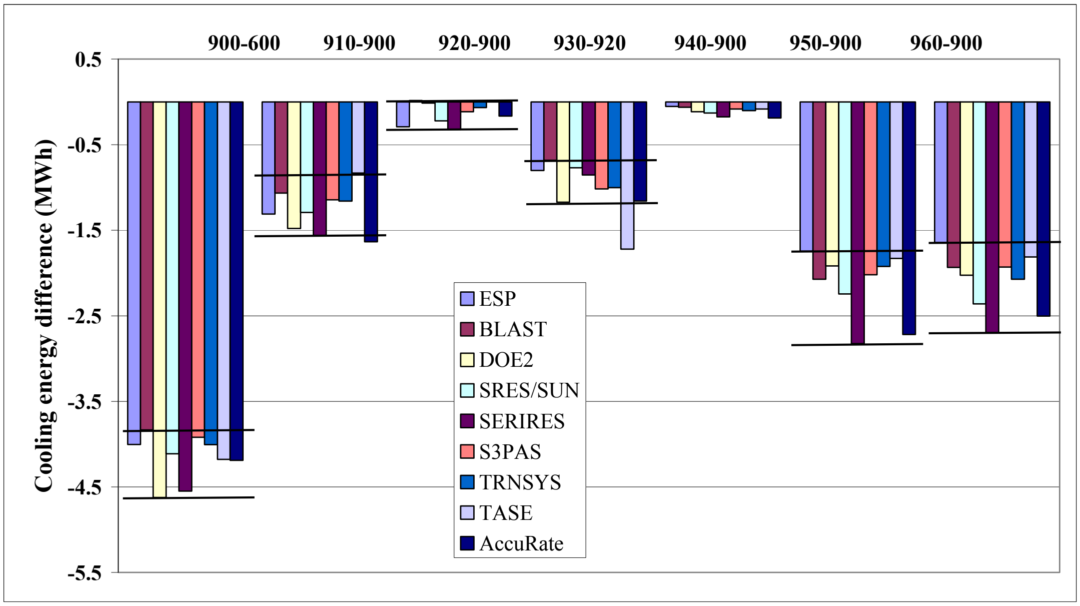

Figure 18. High-mass cooling energy differences. The reference program ranges (where set) are shown as horizontal lines.

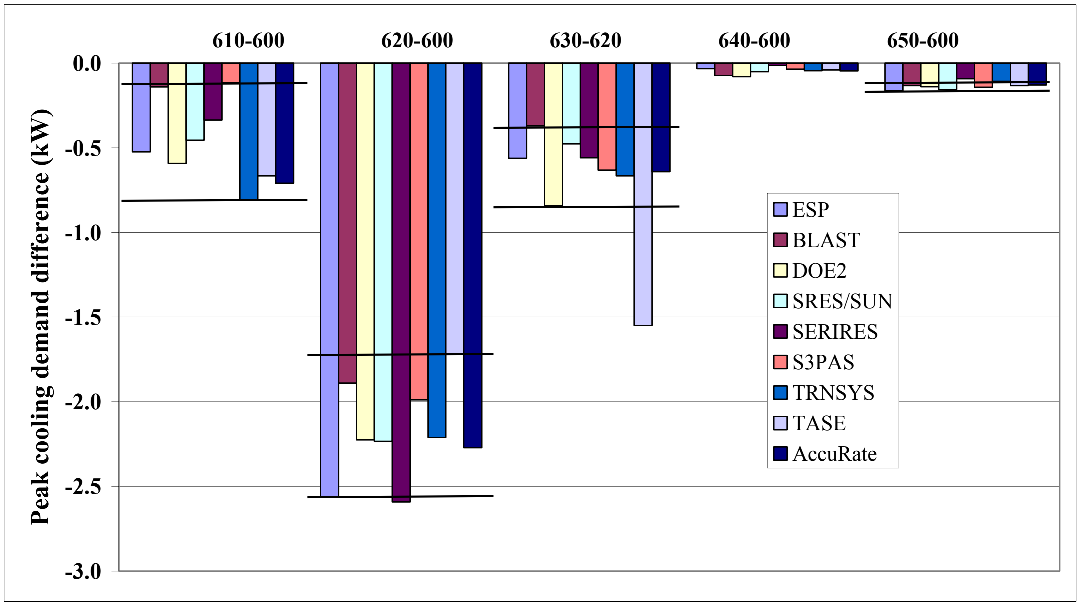

Figure 19. Low-mass peak cooling demand differences. The reference program ranges (where set) are shown as horizontal lines.

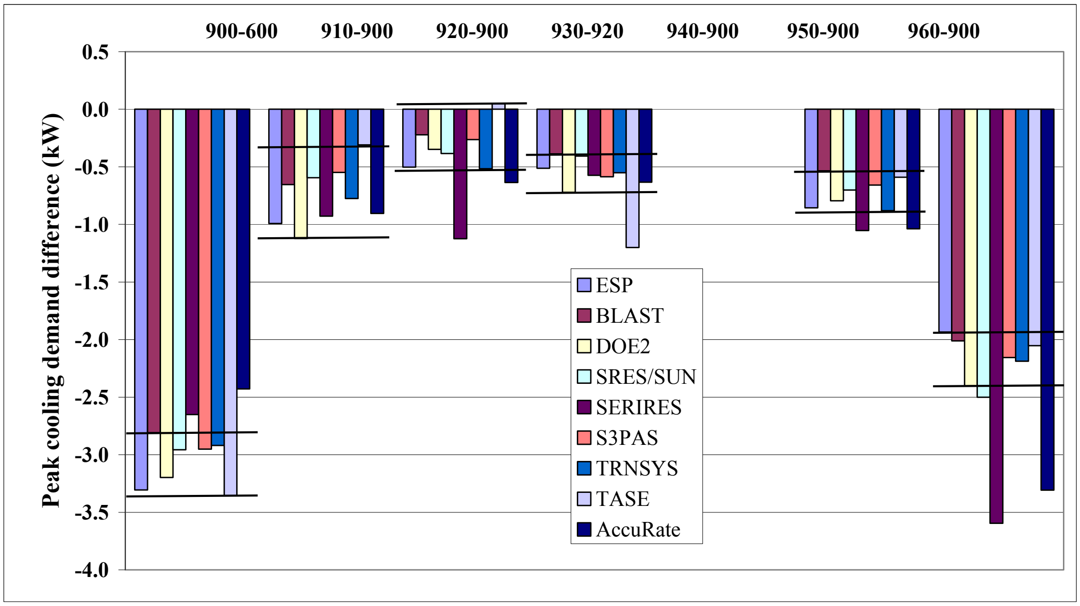

Figure 20. High-mass peak cooling demand differences. The reference program ranges (where set) are shown as horizontal lines.

3.4 Results for realistic diagnostic cases

The realistic diagnostic cases, the results for which are given in tables 9-12, were only run for completeness as they do not reveal anything that was not revealed by the qualification cases. Note that the ranges given are simply the lowest and highest values of the reference programs, as reference program ranges were not set.

Table 9. Realistic diagnostic cases: heating.

	Heating energy (MWh)		Peak heating demand (kW)	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
395	5.317	4.799 – 5.835	2.424	2.062 – 2.391
400	8.197	6.900 – 8.770	3.777	2.867 – 3.709
410	9.934	8.596 – 10.506	4.545	3.625 – 4.501
420	8.570	7.298 – 9.151	4.345	3.443 – 4.301
430	7.260	5.429 – 7.827	4.345	3.442 – 4.301
440	5.463	4.449 – 5.811	4.215	3.439 – 4.376
800	6.670	4.868 – 7.228	4.233	3.227 – 4.188
810	2.680	1.839 – 3.004	4.055	2.979 – 4.115

Table 10. Realistic diagnostic cases: cooling.

	Cooling energy (MWh)		Peak cooling demand (kW)	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
395	0.011	0.000 – 0.016	0.400	0.000 – 0.421
400	0.048	0.000 – 0.058	0.716	0.000 – 0.712
410	0.071	0.000 – 0.084	0.854	0.035 – 0.863
420	0.170	0.011 – 0.189	1.077	0.258 – 1.078
430	0.754	0.422 – 0.875	2.187	1.427 – 2.578
440	4.947	3.967 – 5.204	5.435	4.424 – 5.615
800	0.275	0.055 – 0.325	1.511	0.585 – 1.382
810	1.758	1.052 – 1.711	3.597	1.852 – 3.624

Table 11. Realistic diagnostic differences: heating.

	Heating energy (MWh)		Peak heating demand (kW)	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
400-395	2.880	1.916 – 2.935	1.353	0.805 – 1.318
410-400	1.737	1.696 – 1.798	0.768	0.757 – 0.885
420-410	-1.364	-1.361 – -1.222	-0.200	-0.200 – -0.180
430-420	-1.310	-1.869 – -1.112	0.000	-0.001 – 0.011
600-430	-2.052	-2.118 – -1.133	-0.136	-0.029 – 0.217
440-600	0.255	0.153 – 0.426	0.006	-0.001 – 0.022
800-430	-0.590	-0.649 – -0.501	-0.112	-0.215 – -0.113
900-800	-4.840	-5.356 – -3.698	-0.215	-0.378 – -0.107
900-810	-0.850	-1.107 – -0.669	-0.037	-0.166 – -0.034
910-610	-3.078	-3.632 – -2.780	-0.187	-0.579 – -0.223
920-620	-1.468	-1.689 – -1.297	-0.124	-0.318 – -0.150
930-630	-1.034	-1.273 – -0.884	-0.110	-0.238 – -0.141
940-640	-1.978	-2.392 – -1.867	1.216	-1.252 – 1.845

Table 12. Realistic diagnostic differences: cooling.

	Cooling energy (MWh)		**Peak cooling demand (kW)**	
Case	**AccuRate**	**Range of reference programs**	**AccuRate**	**Range of reference programs**
400-395	0.037	0.000 – 0.045	0.316	0.000 – 0.291
410-400	0.023	0.000 – 0.026	0.138	0.035 – 0.151
420-410	0.099	0.011 – 0.105	0.223	0.195 – 0.233
430-420	0.584	0.371 – 0.732	1.110	0.637 – 1.657
600-430	6.758	5.595 – 7.280	5.023	4.193 – 5.772
440-600	-2.565	-2.760 – -2.094	-1.775	-1.936 – -1.534
800-430	-0.479	-0.550 – -0.367	-0.676	-1.220 – -0.397
900-800	3.046	2.019 – 3.193	3.270	2.099 – 3.519
900-810	1.563	1.080 – 1.707	1.184	0.595 – 3.458
910-610	-3.528	-3.924 – -3.094	-2.625	-3.773 – -2.883
920-620	-1.681	-1.912 – -1.476	-0.795	-1.591 – -1.106
930-630	-1.189	-1.463 – -0.827	-0.786	-1.242 – -1.031
940-640	-3.976	-4.570 – -3.647	-2.383	-3.314 – -2.636
950-650	-5.315	-5.956 – -4.429	-3.339	-3.998 – -3.210

3.5 Summary and discussion for energy results

3.5.1 Annual energy

The results for heating energy are quite satisfactory. The results for cooling energy are on the high side but also satisfactory, except for case 920 (unshaded east and west windows), which is slightly above the reference range.

The results for energy differences are also generally satisfactory, except for a few cases when the cooling difference is slightly above the reference range.

3.5.2 Peak demands

The heating peak demands are on the high side but satisfactory except for cases 910 (shaded south window), which is slightly above the reference range, and 940 (high-mass setback), which is significantly high.

The low-mass peak cooling demands are mostly slightly above the reference range, while the high-mass peak cooling demands are mostly significantly above the reference range.

The peak heating demand differences are often outside the reference program ranges, although except for cases 640 and 940 (setback), the actual values are very small. For case 940 the peak heating demand difference is significantly high.

The low-mass peak cooling demand differences are satisfactory, but the high-mass differences are significantly low for 900-600 and significantly high for 960-900.

3.5.3 Discussion

When BESTEST was being developed, bugs in some of the reference programs resulted in very large differences (sometimes of the order of several hundred percent) between a program with bugs and the other reference programs. None of the AccuRate comparisons revealed differences of anywhere near this magnitude. Nevertheless, a pattern is apparent in the peak demands: apart from all peak demands being generally on the high side, peak cooling demands are often above the reference range, and the peak heating demand for the setback cases is above the reference range. This pattern suggests at least a difference in approach between AccuRate and most of the reference programs.

Such a difference is in fact obvious: only AccuRate and SERIRES use combined radiative and convective surface heat transfer coefficients, and thus calculate and control an environmental room temperature, not a pure air temperature. The other programs separate the radiative and convective networks. Combined coefficients couple the environmental temperature more closely to a surface than a convective coefficient couples an air temperature to a surface. The effect of this will be most apparent in the peak demands, in high-mass cases, and in setback cases. For example, in the setback case the zone temperature must be raised from 10°C to 20°C at 0800, a large increase. The energy required to do this will be greater if the temperature is more closely coupled to the surfaces, especially high-mass surfaces which have a high conductivity and a high heat capacity.

3.6 Other comparisons: free-floating cases and hourly results

3.6.1 Annual free-floating results

Hourly temperatures were calculated for cases 600 and 900 (basic low-mass and basic high-mass) and 650 and 950 (vented), without heating and cooling. Table 13 compares maximum, minimum and mean temperatures. The results are quite satisfactory.

Table 13. Annual results for free-floating cases. Note that the reference program range excludes the SERIRES minima for 600 and 650, as these appear to be anomalous (both are -10.0°C).

Case	AccuRate	Reference program range
600, max	66.7	64.9 – 69.8
600, min	-16.7	-18.8 – -15.6
600, mean	25.7	24.2 – 25.9
900, max	43.5	41.8 – 44.8
900, min	-2.4	-6.4 – -1.6
900, mean	25.9	24.5 – 25.9
650, max	64.7	63.2 – 68.5
650, min	-22.8	-23.0 – -21.6
650, mean	18.6	18.0 – 19.6
950, max	35.5	35.5 – 38.5
950, min	-19.6	-20.2 – -9.8
950, mean	14.0	14.0 – 15.0
960, max	51.1	48.9 – 55.3
960, min	-3.7	-2.8 – 3.9
960, mean	27.5	27.5 – 29.0

3.6.2 Hourly results

Figures 21-24 compare free-floating hourly temperatures for cases 600 and 900 on a cold clear day, and for cases 650 and 950 on a hot day. AccuRate's predictions for the high mass building on a cold clear day tend to be high. Again this is what would be expected from the fact that AccuRate calculates an environmental temperature. On the other hand, AccuRate's predictions for the high mass vented building on a hot day are on the high side at night but a little on the low side during the day. It is not easy to understand this case in detail as there are a number of factors involved: thermal storage, the switching off of the venting at 0700, solar gains, and indoor-outdoor temperature differences. However none of the results in figures 21-24 suggest a problem.

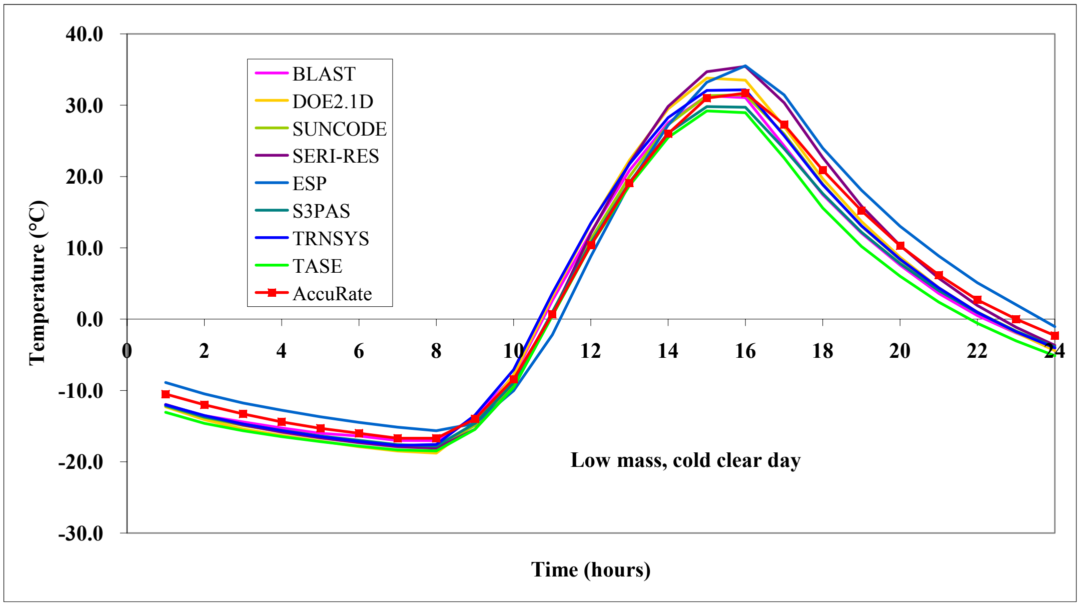

Figure 21. Hourly temperatures for the low-mass base case (600) for a cold clear day (January 4)

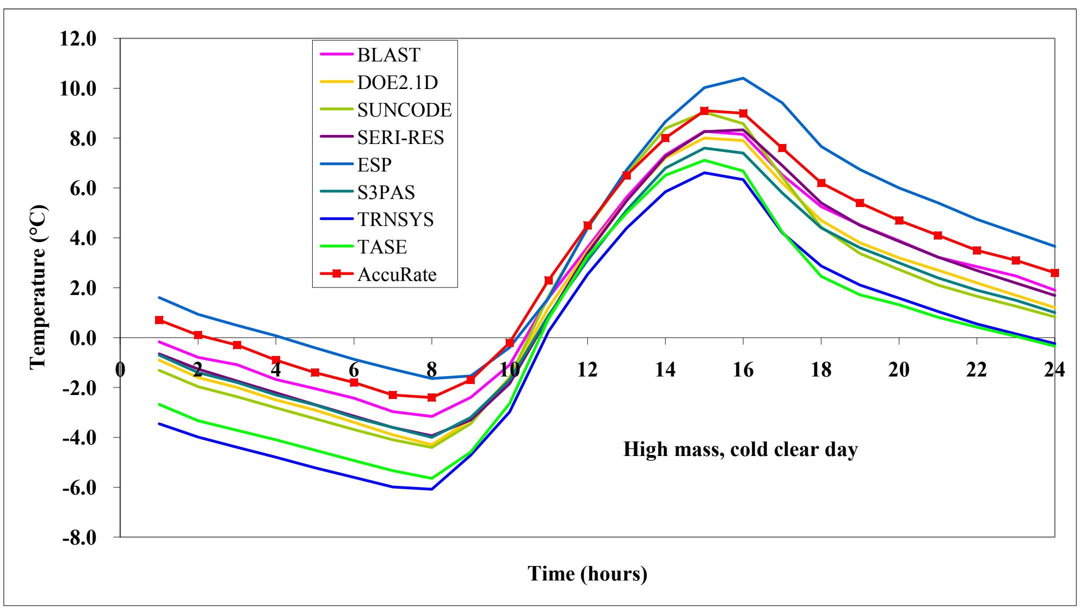

Figure 22. Hourly temperatures for the high-mass base case (900) for a cold clear day (January 4)

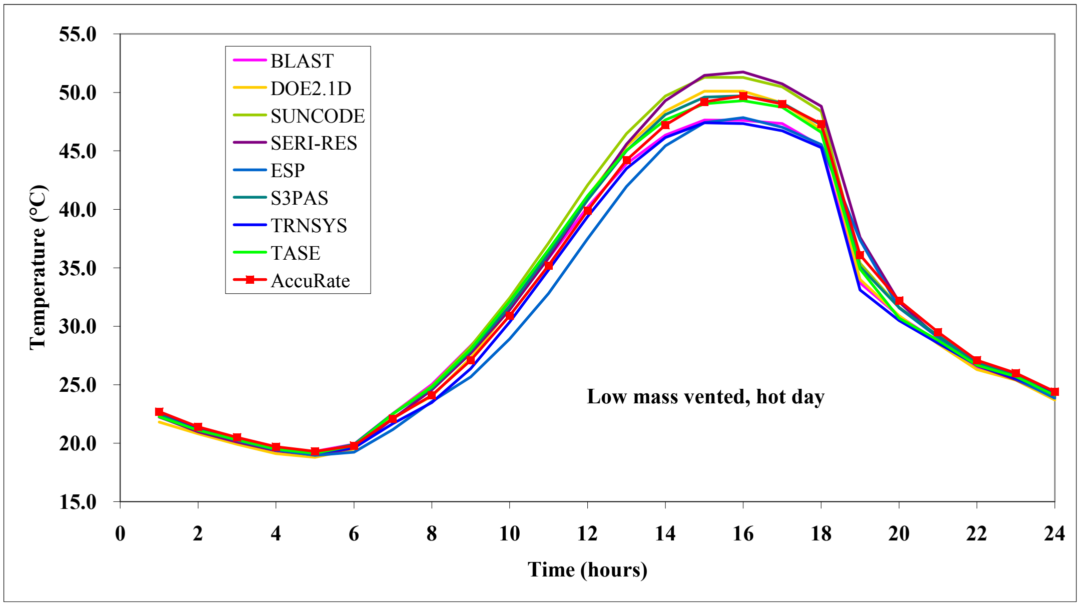

Figure 23. Hourly temperatures for the low-mass vented case (650) for a hot day (July 27)

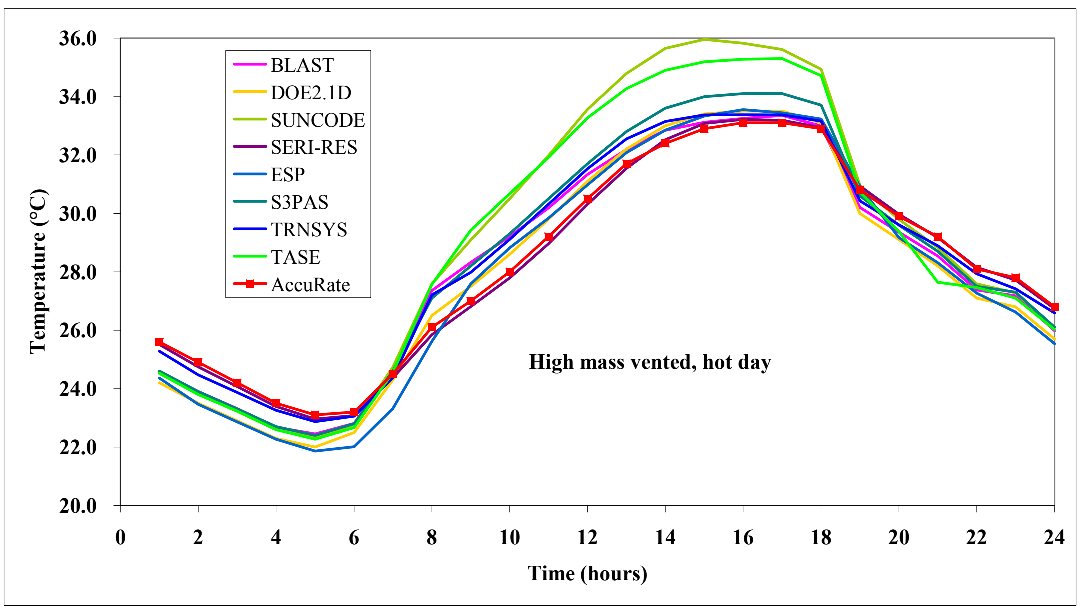

Figure 24. Hourly temperatures for the high-mass vented case (950) for a hot day (July 27)

Figures 25 and 26 compare hourly heating and cooling energy for cases 600 and 900 on a cold clear day (heating is shown as positive, cooling as negative). AccuRate's somewhat high cooling energy can be seen for the low-mass case. For the high-mass case, the similarity in the shape of the hourly heating energy curve between AccuRate and SERI-RES, and the difference between these two and the other programs, can be clearly seen.

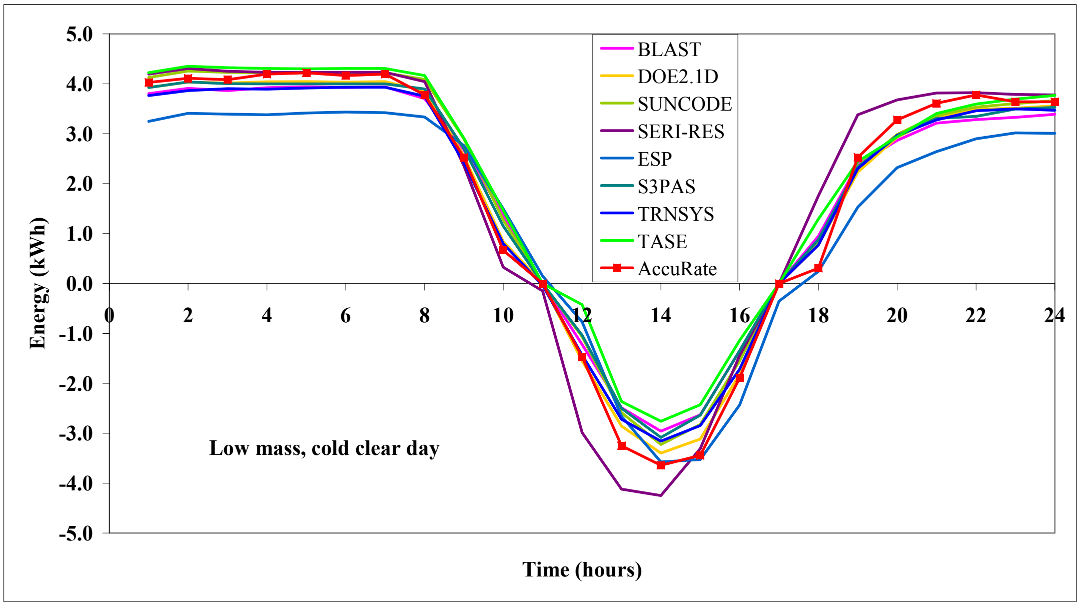

Figure 25. Hourly heating and cooling energy for the low-mass base case (600) for a cold clear day (January 4). Heating is positive and cooling is negative.

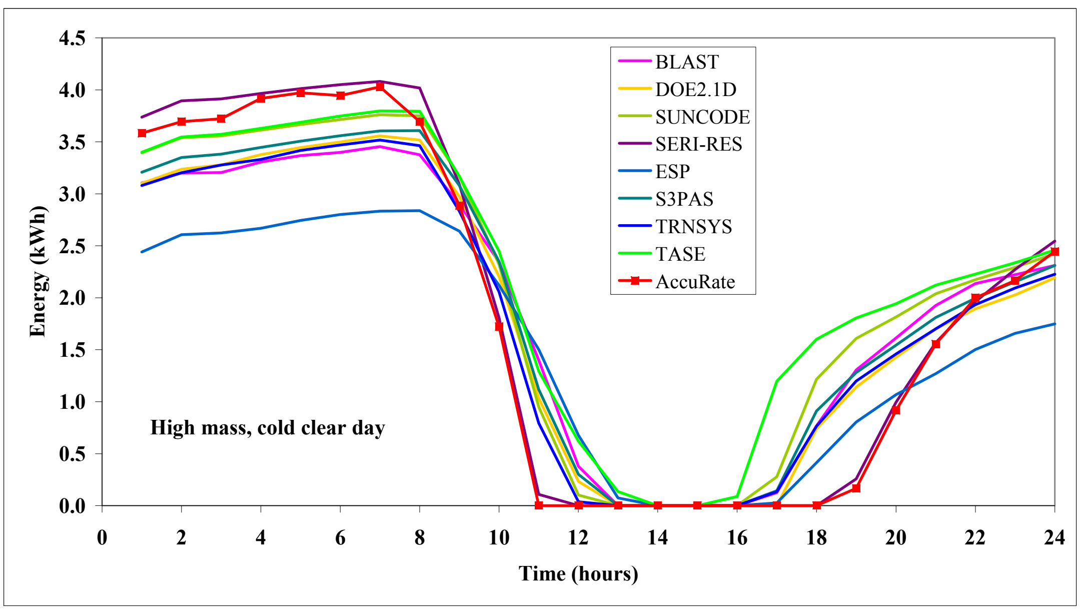

Figure 26. Hourly heating and cooling energy for the high-mass base case (900) for a cold clear day (January 4). Heating is positive and cooling is negative.

Finally, figure 27 shows the annual occurrences of hourly temperatures in 1-degree bins for the free-floating base high-mass case (900). The agreement is very good.

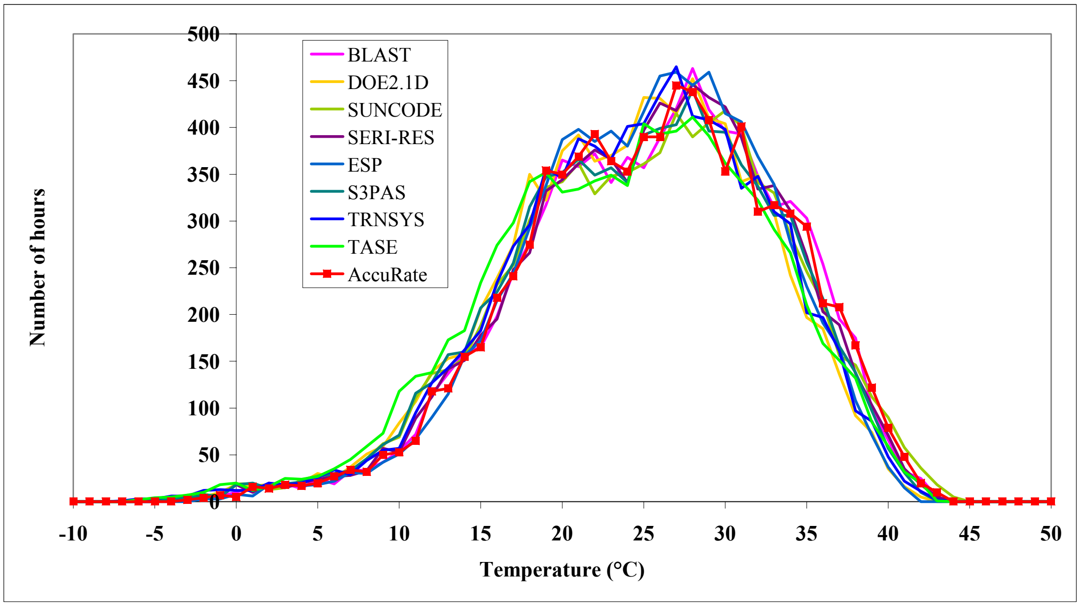

Figure 27. Annual occurrences of hourly temperatures in 1-degree bins for the free-floating high-mass base case (900).

4. SOME FURTHER ANALYSIS

Given that the AccuRate engine's predictions of cooling energy and peak cooling demand tend to be somewhat high relative to the reference programs, it was of interest to examine its internal consistency, i.e. whether its predictions of the relative effect of changes to a building agree with those of the reference programs. Accordingly, the ratios of annual energy or peak demand to the base case (600 or 900) were calculated and are shown in figures 28-31 for heating energy, peak heating demand, cooling energy, and peak cooling demand respectively. These comparisons are not part of BESTEST.

In all cases the AccuRate engine agrees very well with the other programs. The peak heating results for night setback (cases 640 or 940) show considerable variability, but it should be remembered that in addition to the effect of combined radiative and convective coefficients, there may be a timing problem for this case, as discussed in section 2.

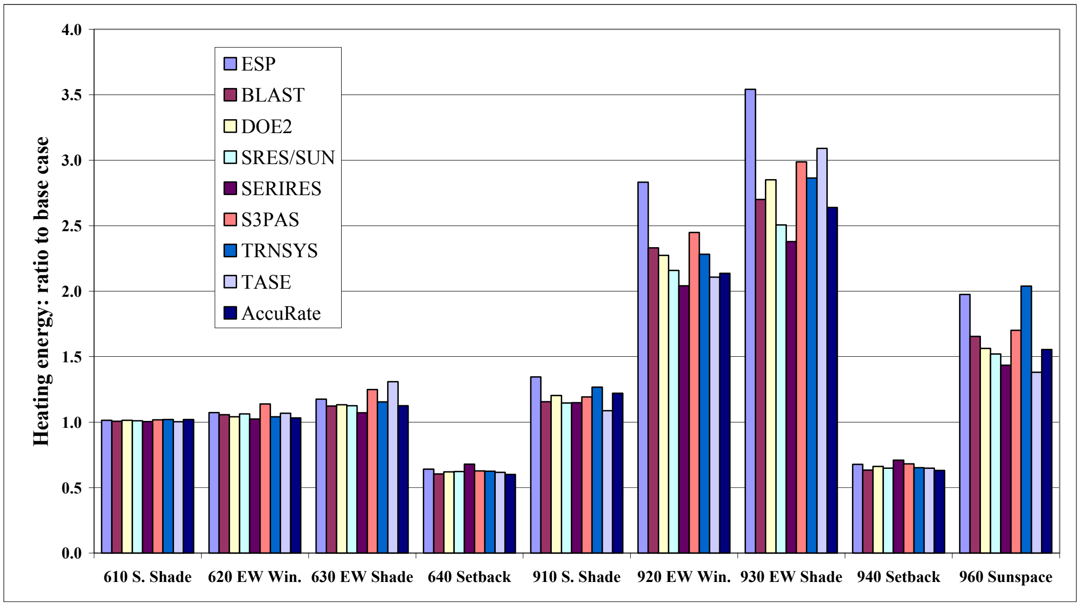

Figure 28. Ratio of annual heating energy to base case (600 or 900)

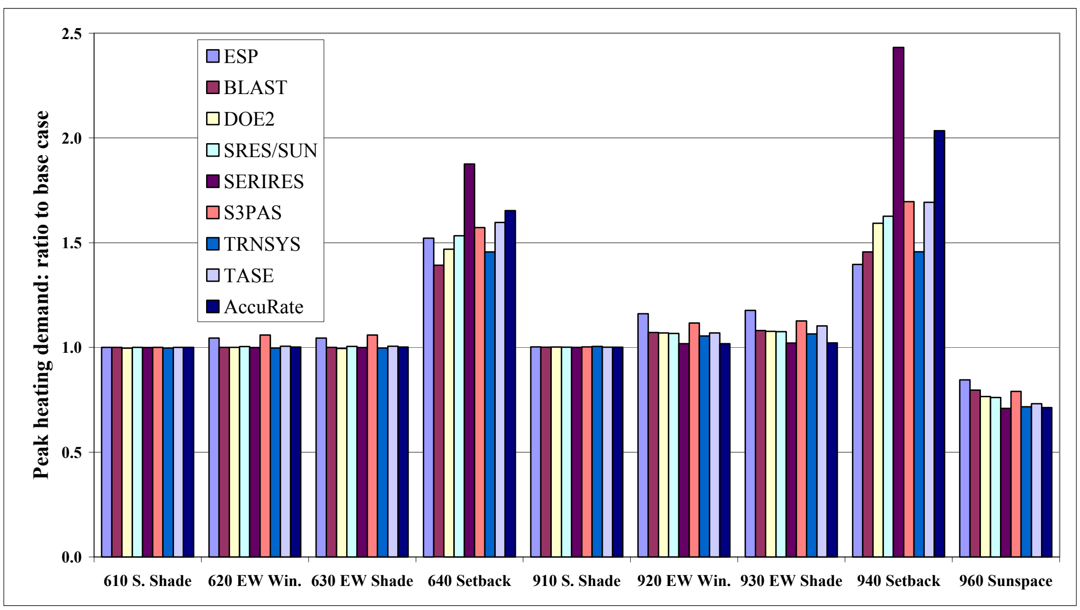

Figure 29. Ratio of peak heating demand to base case (600 or 900)

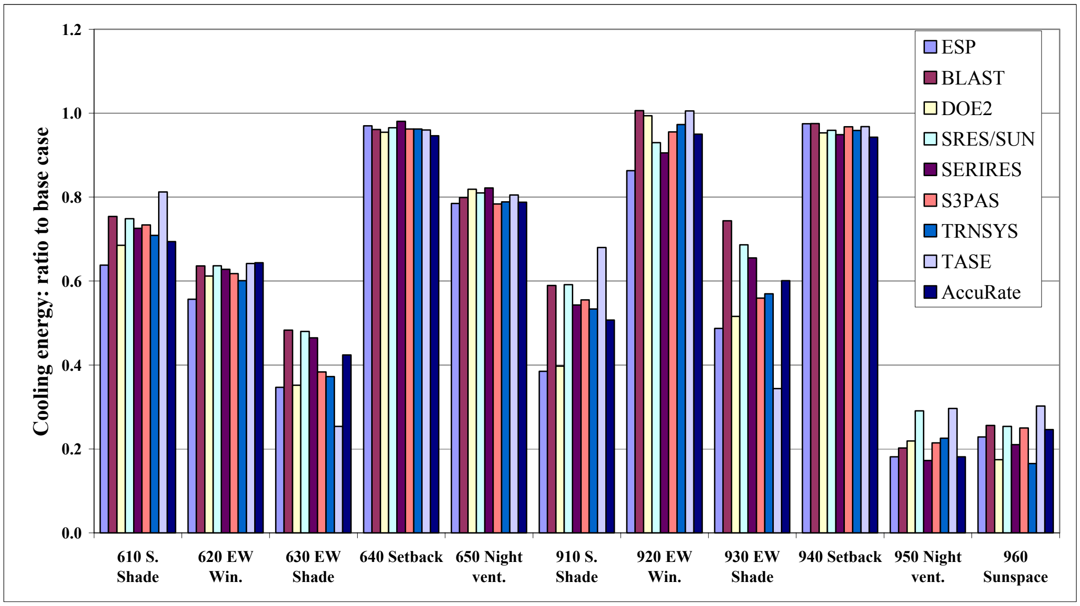

Figure 30. Ratio of annual cooling energy to base case (600 or 900)

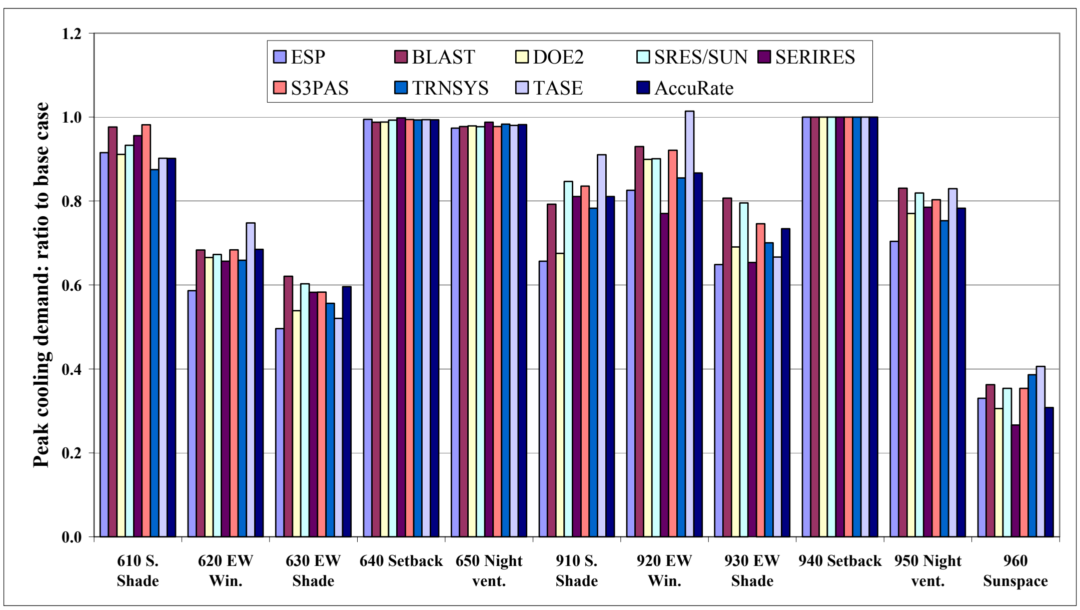

Figure 31. Ratio of peak cooling demand to base case (600 or 900)

5. CONCLUSIONS

1. In general, the AccuRate simulation engine agrees very well with the reference programs, and no major discrepancies were found. The results reported here are consistent with the BESTEST results previously obtained for CHENATH, the NatHERS simulation engine [4].

2. The engine's solar radiation model (incorporating the Perez model for anisotropic diffuse radiation) agrees very well with the reference programs in terms of annual total incident and transmitted solar radiation, and hourly incident solar radiation, on vertical surfaces.

3. Because the engine calculates and controls environmental temperature and not air temperature, it tends to predict somewhat high cooling energies and peak heating and cooling demands when compared with the reference programs. This is especially so for high-mass buildings and for thermostat setback.

6. REFERENCES

1. R. Judkoff and J. Neymark, "International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method". National Renewable Energy Laboratory, Golden, Colorado, USA, Report no. NREL/TP-472-6231.

2. R. Perez, R. Seals, P. Ineichen, R. Stewart and D. Menicucci, "A New Simplified Version of the Perez Diffuse Irradiance Model for Tilted Surfaces". *Solar Energy*, **39 (3)**, 221-231 (1987).

3. A. E. Delsante, "A Comparison of CHENATH, the Nationwide House Energy Rating Scheme Simulation Engine, with Measured Test Cell Data". Proc. ANZES Solar '95 Conference, 441–446. Hobart, 1995.

4. A. E. Delsante, "Using the Building Energy Simulation Test (BESTEST) to Evaluate CHENATH, the Nationwide House Energy Rating Scheme Simulation Engine". Proc. ANZES Solar '95 Conference, 447–455. Hobart, 1995.