Technical Report LBNL-54658

BuildOpt 1.0.1 Validation

Michael Wetter*, Elijah Polak†, Van P. Carey‡

March 25, 2004

Abstract

We validated the BuildOpt building energy simulation program (Wetter, 2004). We used the ANSI/ASHRAE Standard 140-2001 (ASHRAE, 2001) to validate the thermal models, and we used test series that were produced in the Task 21 of the International Energy Agency (IEA) Solar Heating & Cooling Program (Fontoynont et al., 1999; Laforgue, 1997) to validate the daylighting model. There are no significant differences between BuildOpt's results and the results reported in the validation suites.

*Simulation Research Group, Building Technologies Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA (MWetter@lbl.gov).

†Department of Electrical Engineering, University of California at Berkeley, Berkeley, CA 94720, USA (polak@eecs.berkeley.edu).

‡Department of Mechanical Engineering, University of California at Berkeley, Berkeley, CA 94720, USA (vcarey@me.berkeley.edu).

Contents

List of Tables

List of Figures

Disclaimer

1 Thermal Model

1.1 Introduction

To validate BuildOpt's thermal models, we used the ANSI/ASHRAE Standard 140-2001 (ASHRAE, 2001). This standard has been developed to identify and to diagnose differences in predictions for whole building energy simulation software that may possibly be caused by software errors. The test consists of a series of specified test cases that progress systematically from the simple to the relatively realistic case. Output values, such as annual energy consumptions, peak loads, annual minimum, average and maximum room air temperatures, and some hourly data are compared to the results of other building energy simulation programs, namely to ESP, BLAST, DOE2.1D, SUNCODE, SERIRES, S3PAS, TRNSYS and TASE.

We used the so-called "basic test cases" to validate BuildOpt. The basic test cases test the ability to model such combined effects as thermal mass, solar gains, window-shading devices, internally generated heat, outside air infiltration, sunspaces and thermostat control.

1.2 Specification of the Test Cases

We will now present a brief overview of the basic test cases. We refer the reader to ASHRAE (2001) for a more detailed description.

There are three series of basic cases:

- The low mass basic tests (Cases 600 through 650), which use a light weight building envelope.
- The high mass basic tests (Cases 900 through 960), which use heavy weight walls, a heavy weight floor and include an additional building configuration with a sunspace.
- The free-float basic tests (Cases with ending "FF"), which have no heating or cooling system.

Tab. 1.2 lists all the base cases. For BuildOpt, only the cases in non-italic font were simulated. Case 630 and Case 930 were not simulated because BuildOpt has no model for vertical shading devices. Case 650 and Case 950 were not simulated because BuildOpt has no model for night ventilation.

Fig. 1 shows the building configuration used for the Cases 600, 610, 640, 650, 900, 930, 940 and 950, Fig. 2 shows the building configuration used for the Cases 620, 630, 920 and 930, and Fig. 3 shows the building configuration with sunspace used for the Case 960. The roof and the external shading devices are not shown.

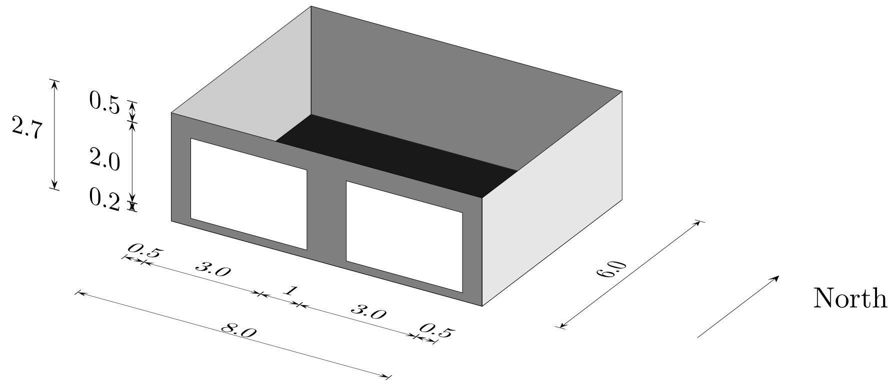


Figure 1: Isometric view of building with south windows. The roof is not shown.

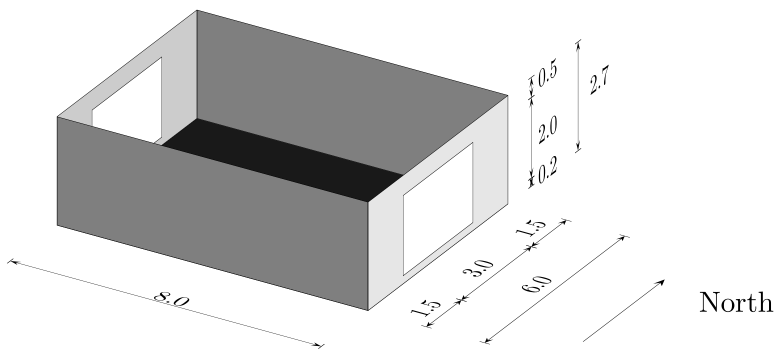


Figure 2: Isometric view of building with west and east windows. The roof is not shown.

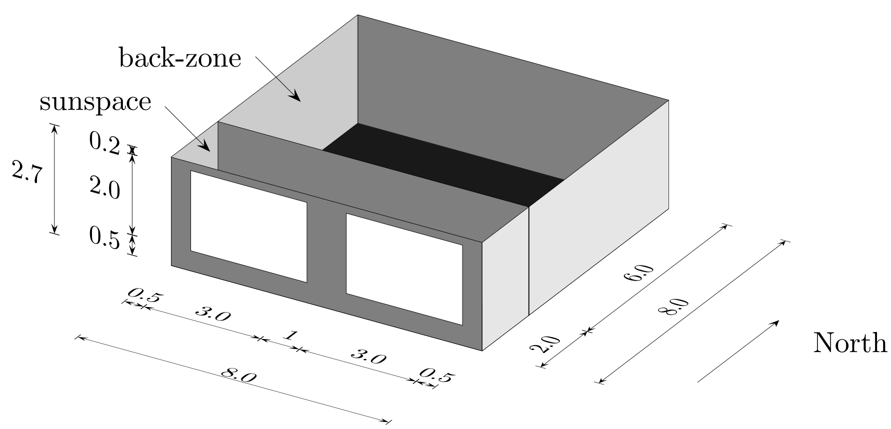


Figure 3: Isometric view of building with sunspace. The roof is not shown.

Case	H, C, V °C	Mass	INTGEN W	INFILTR 1/h	INT IR EMIT	EXT IR EMIT	INT SW ABSORPT	EXT SW ABSORPT	Glass m^2	ORIENT	SHADE	COMMENTS
600	20, 27	L	200	0.5	0.9	0.9	0.6	0.6	12	S	no	Case 600 tests south solar transmission.
610	20, 27	L	200	0.5	0.9	0.9	0.6	0.6	12	S	1.0 mH	Cases 610, 600 test south overhang.
620	20, 27	L	200	0.5	0.9	0.9	0.6	0.6	6, 6	E, W	no	Cases 620, 600 test east and west solar transmittance/incidence.
630	*20, 27*	*L*	*200*	*0.5*	*0.9*	*0.9*	*0.6*	*0.6*	*6, 6*	*E, W*	*1.0 mHV*	*Cases 630, 620 test east and west overhangs and fins.*
640	SETBACK	L	200	0.5	0.9	0.9	0.6	0.6	12	S	no	Cases 640, 600 test night setback.
650	*27, V*	*L*	*200*	*0.5*	*0.9*	*0.9*	*0.6*	*0.6*	*12*	*S*	*no*	*Case 650, 600 test venting.*
900	20, 27	H	200	0.5	0.9	0.9	0.6	0.6	12	S	no	Cases 900, 600 test thermal mass and solar interaction.
910	20, 27	H	200	0.5	0.9	0.9	0.6	0.6	12	S	1.0 mH	Cases 910, 900 test south overhang/mass interaction.
920	20, 27	H	200	0.5	0.9	0.9	0.6	0.6	6, 6	E, W	no	Cases 920, 900 test east and west transmittance/mass interaction.
930	*20, 27*	*H*	*200*	*0.5*	*0.9*	*0.9*	*0.6*	*0.6*	*6, 6*	*E, W*	*1.0 mHV*	*Cases 930, 920 test east and west shading/mass interaction.*
940	SETBACK	H	200	0.5	0.9	0.9	0.6	0.6	12	S	no	Cases 940, 900 test setback/mass interaction.
950	*27, V*	*H*	*200*	*0.5*	*0.9*	*0.9*	*0.6*	*0.6*	*12*	*S*	*no*	*Cases 950, 900 test venting/mass interaction.*
960	2ZONE, SS	See specification in Test Procedures										Case 960 tests passive solar/interzonal heat transfer.
600FF 900FF *650FF* *950FF*	NONE NONE *NONE, V* *NONE, V*	These cases, labeled FF (interior temperatures free-float), are exactly the same as the corresponding non-FF cases except there are no mechanical heating or cooling systems.										

Table 1: Description of base cases, reproduced from ASHRAE (2001). (For BuildOpt, only the cases in non-italic font were simulated.)

1.3 Modeling Notes

We will now present the modeling notes in the format defined in ASHRAE (2001).

STANDARD 140 OUTPUT FORM - MODELING NOTES INSTRUCTIONS: See Annex A2. SOFTWARE: BuildOpt VERSION: 1.0.1 DOCUMENT BELOW THE MODELING METHODS USED IF ALTERNATIVE MODELING METHODS OR ALGORITHMS ARE AVAILABLE IN THE SOFTWARE BEING TESTED.
Simulated Effect: *Complexity of the physical models.* Optional Settings or Modeling Capabilities: `MODELCOMPLEXITY`, *any integer between 0 and 4 (inclusive). If 0 is selected, then the coarsest models will be used, and if 4 is selected, the most detailed models will be used.* Setting or Capability Used: `MODELCOMPLEXITY, 4;` Physical Meaning of Option Used: *Perez's model is used to compute the diffuse solar irradiation. The convective heat transfer coefficients at room-side surfaces are computed as a function of the temperature difference.*

Simulated Effect:
Heat conduction in opaque materials.
Optional Settings or Modeling Capabilities:
`ELEMENTS`, *any non-zero natural number.*
Setting or Capability Used:
`ELEMENTS,`
`  10;`
Physical Meaning of Option Used:
The number of elements used in the Galerkin method is equal to 10 *for a reference material of* 20 cm *concrete. For other materials, the number of elements is adjusted based on a Fourier number similarity.*

Simulated Effect:

Settings of differential algebraic equation solver.

Optional Settings or Modeling Capabilities:

See BuildOpt documentation.

Setting or Capability Used:

```
DASPK,
 1E-4,     ! Relative tolerance.
 1E-4,     ! Absolute tolerance.
  600,     ! HMAX, maximum step size for time integration.
 10,       ! H0, initial step size for time integration.
 -1,       ! Maximum order of integration scheme
           ! (-1: use default).
 Y_d,      ! Method to compute consistent initial conditions.
           ! If Y_d, then Y_d is given, Y_a and Y'_d
           ! are computed.
           ! If Y', then Y is computed.
 INCLUDE,  ! Flag to include algebraic variables in
           ! the error test.
 10,       ! MXNIT, maximum number of Newton iterations
           ! for IV computation.
 100,      ! MXNJ,  maximum number of Jacobian
           ! evaluations for IV computation.
 -1,       ! MXNH, maximum number of values of the
           ! artificial step size parameter H in
           ! the IV computation (-1: use default).
           ! Only used if Y_d is selected above.
 OFF,      ! Line search flag (ON, OFF).
 -1,       ! EPINIT, swing factor in the Newton
           ! iteration convergence test.
 0,        ! Extra printing in IV computation (0: off).
 3600;     ! Report interval in seconds.
```

1.4 Results

a) Annual Loads and Peak Loads

For the high mass test cases, the annual cooling load and the annual peak cooling are on the lower side compared to the results of the other tested programs, in particular for Case 900 and Case 940. For these cases, the annual cooling load and the annual peak cooling are about 15% lower than the ones of the other tested programs (see Fig. 9, Fig. 11, Fig. 17 and Fig. 19). For the other test cases, BuildOpt's results agree well with the results of the other tested programs.

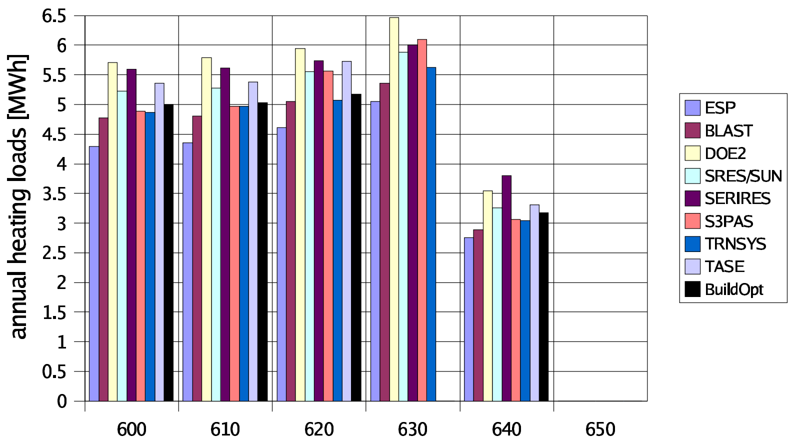


Figure 4: Annual heating loads for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. In Case 650, the heating system is switched off.

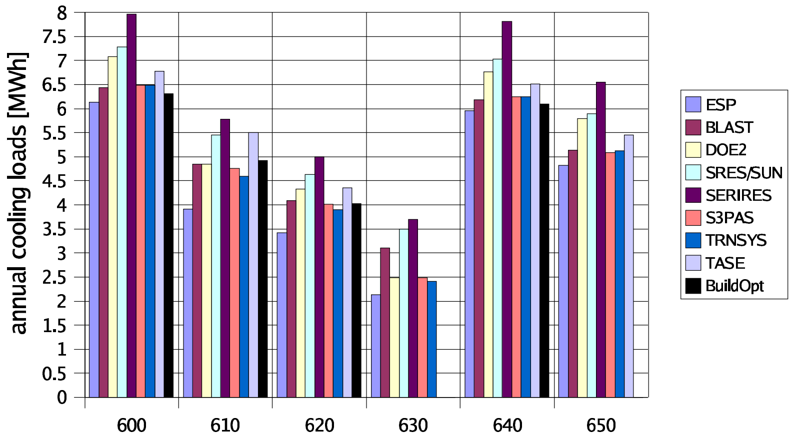


Figure 5: Annual sensible cooling loads for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 650 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

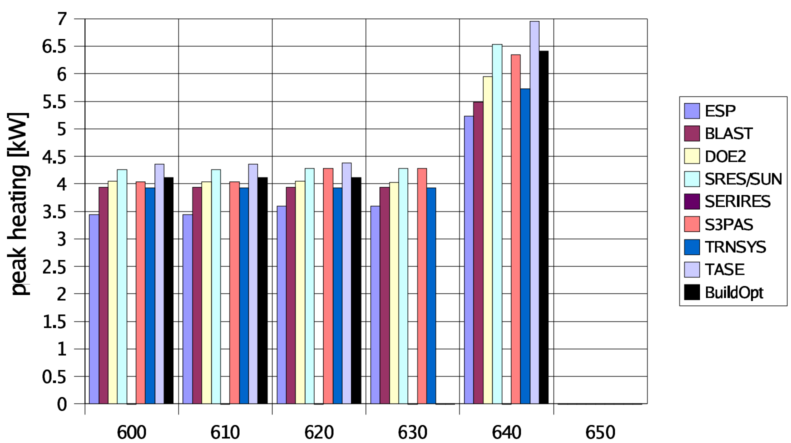


Figure 6: Peak heating loads for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. In Case 650, the heating system is switched off.

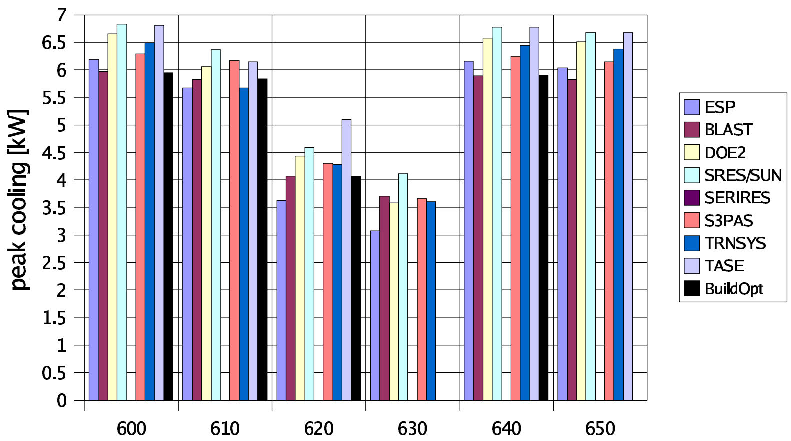


Figure 7: Annual peak sensible cooling loads for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 650 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

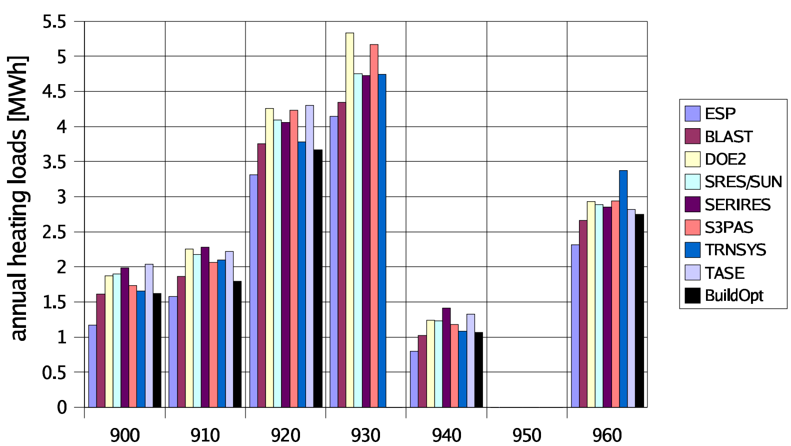


Figure 8: Annual heating loads for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. In Case 950, the heating system is switched off.

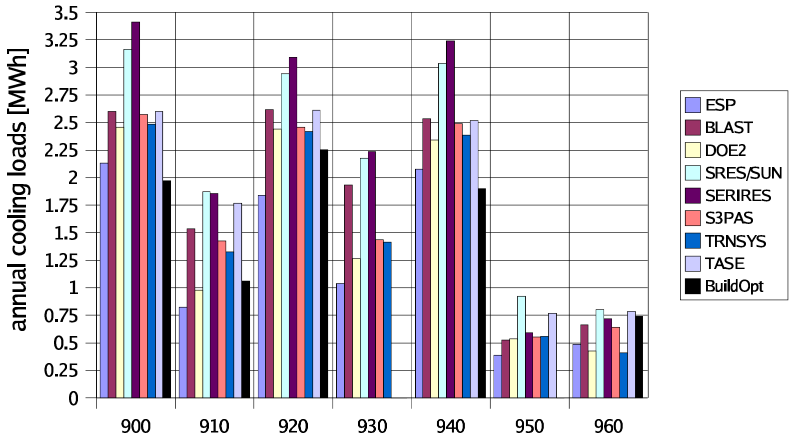


Figure 9: Annual sensible cooling loads for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 950 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

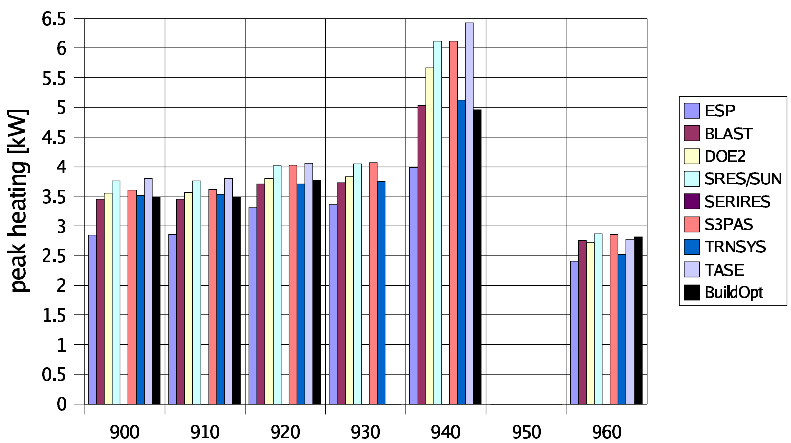


Figure 10: Peak heating loads for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. In Case 950, the heating system is switched off.

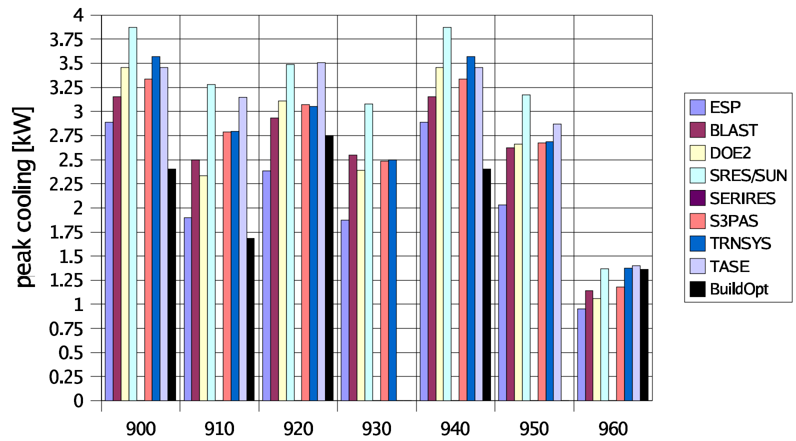


Figure 11: Annual peak sensible cooling loads for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 950 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

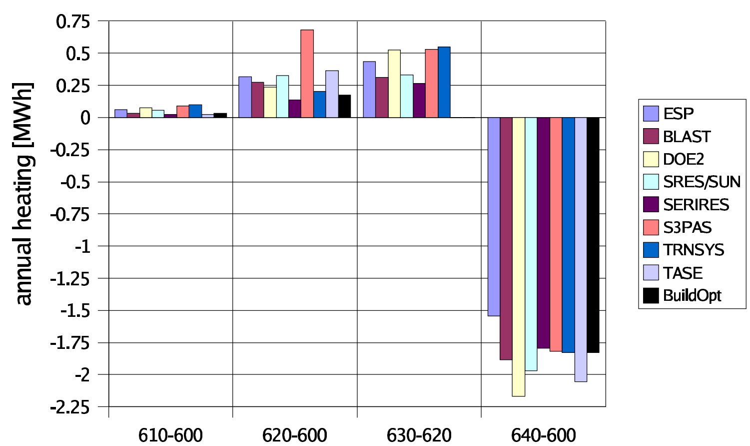


Figure 12: Sensitivity of annual heating load for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices.

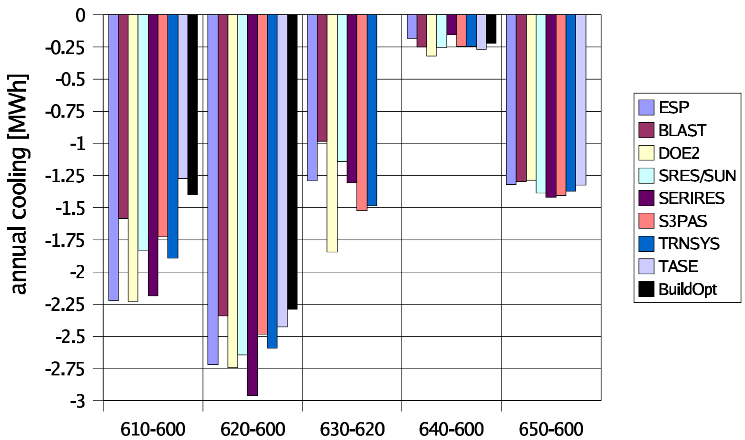


Figure 13: Sensitivity of annual sensible cooling load for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 650 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

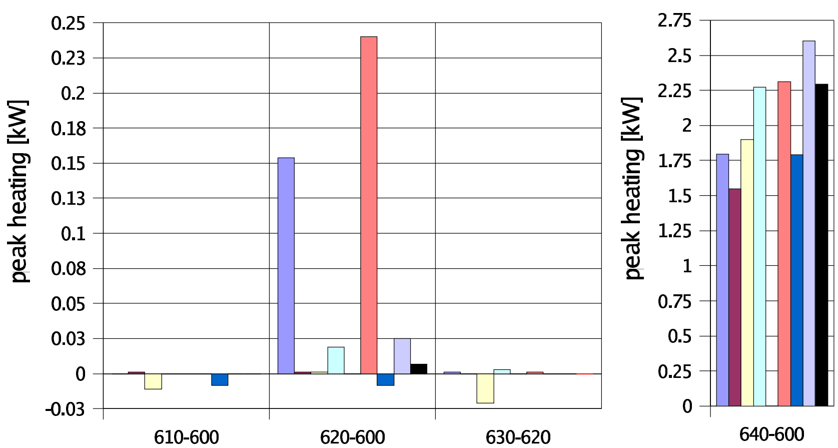


Figure 14: Sensitivity of peak heating load for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices.

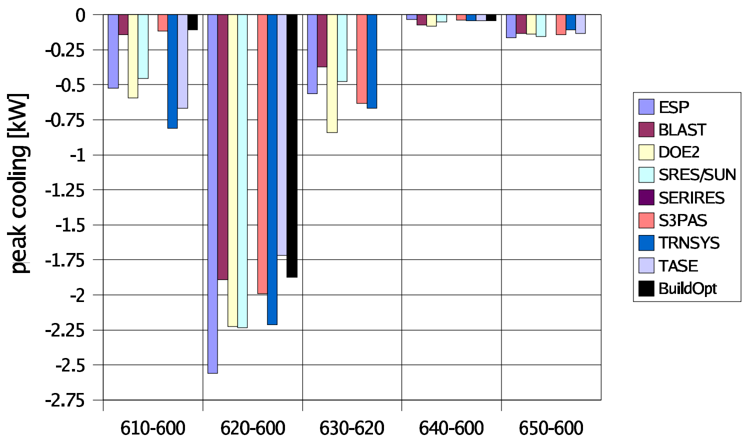


Figure 15: Sensitivity of peak sensible cooling load for low mass buildings. Case 630 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 650 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

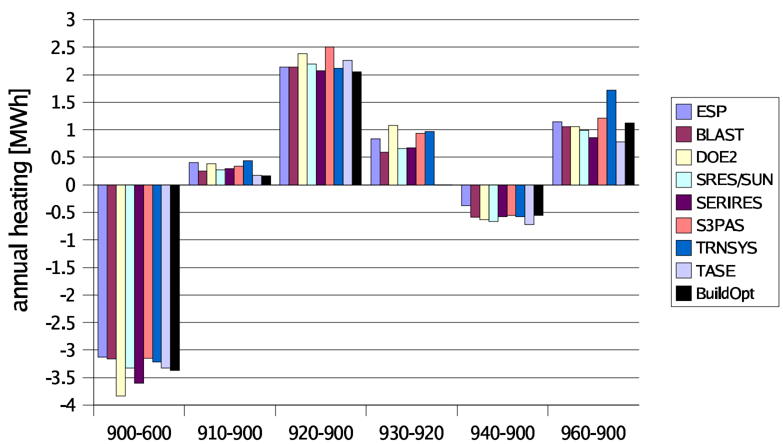


Figure 16: Sensitivity of annual heating load for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices.

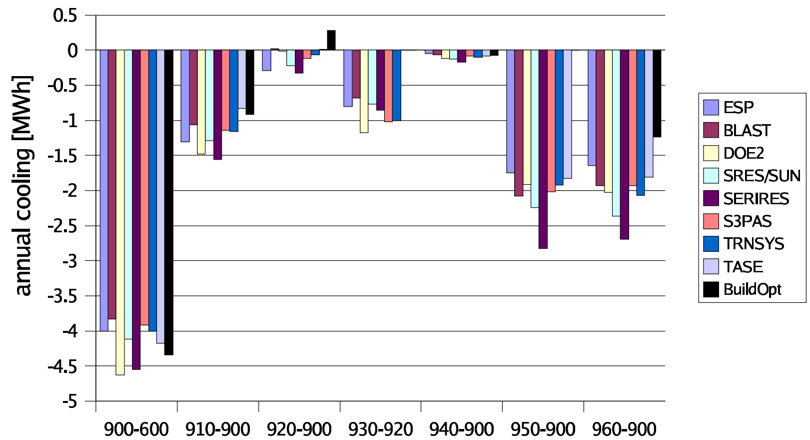


Figure 17: Sensitivity of annual sensible cooling load for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 950 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

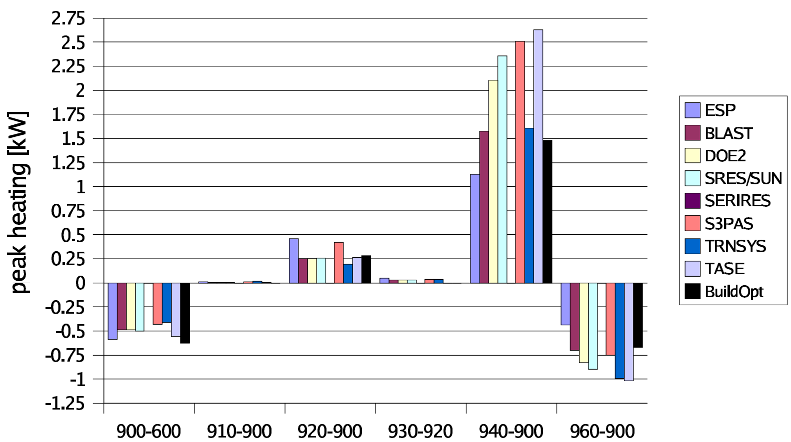


Figure 18: Sensitivity of peak heating load for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices.

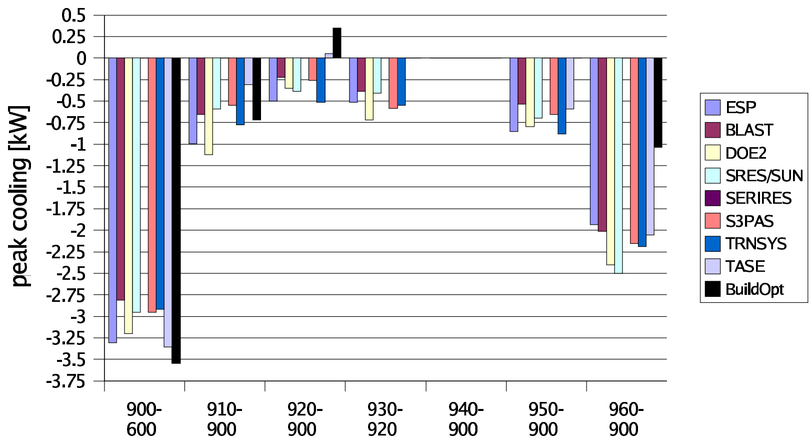


Figure 19: Sensitivity of peak sensible cooling load for high mass buildings. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices. Case 950 was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

b) Indoor Air Temperatures

The minimum indoor air temperature computed by BuildOpt is for the low mass test cases in the range of the results of the other tested programs, but it is for the high mass test cases 1 K lower. The average indoor air temperature computed by BuildOpt is within the range of the results of the other tested programs. The maximum indoor air temperature computed by BuildOpt is for the high mass test cases 3 K lower and for the low mass test cases 4 K lower than the results of the other tested programs. Consequently, for Case 900FF, there are fewer hours with a high indoor air temperature compared to the other tested programs, but the number of hours with low indoor air temperature coincides well with the results of the other tested programs (see Fig. 23). On January 4, the hourly free float temperature is in the range of results of the other tested programs for both, the low mass test case (see Fig. 24) and the high mass test case (see Fig. 25).

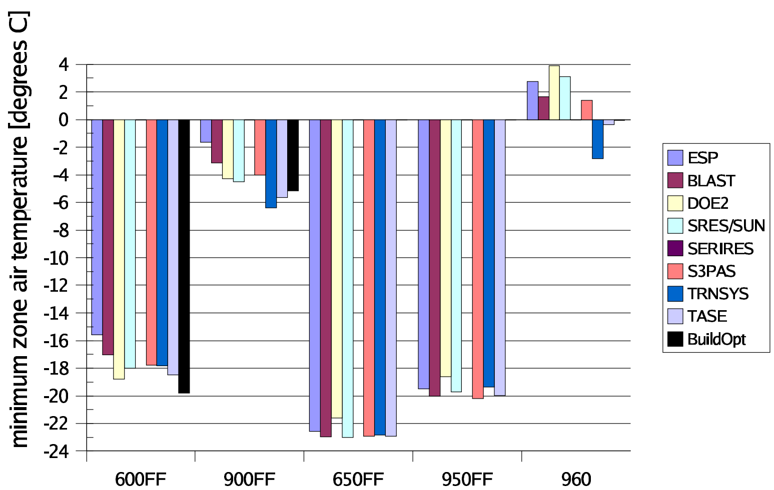


Figure 20: Minimum hourly annual temperature for free-float test cases. Case 650FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation. Case 950FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

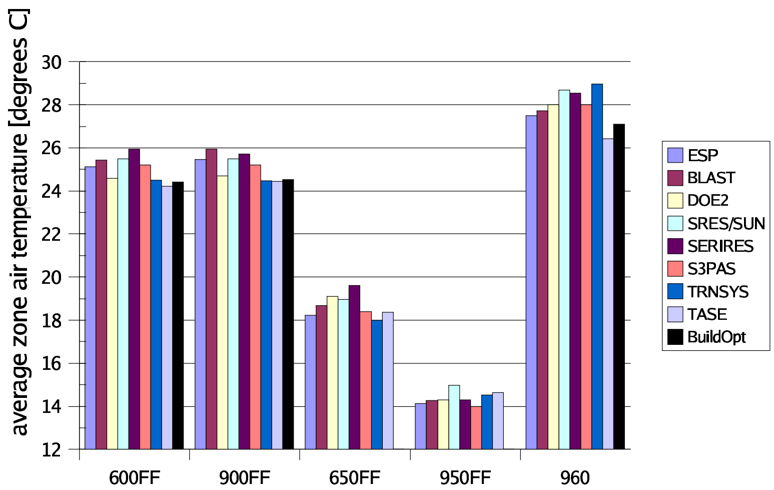


Figure 21: Average hourly annual temperature for free-float test cases. Case 650FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation. Case 950FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

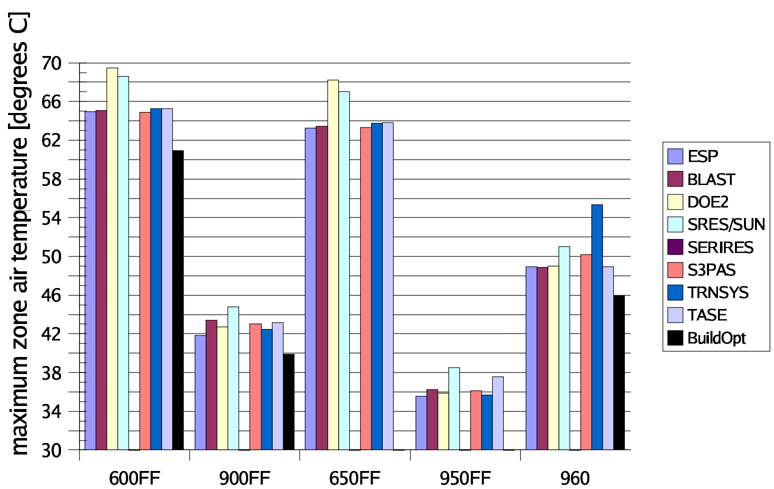


Figure 22: Maximum hourly annual temperature for free-float test cases. Case 650FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation. Case 950FF was not simulated with BuildOpt because it has no model for time-scheduled ventilation.

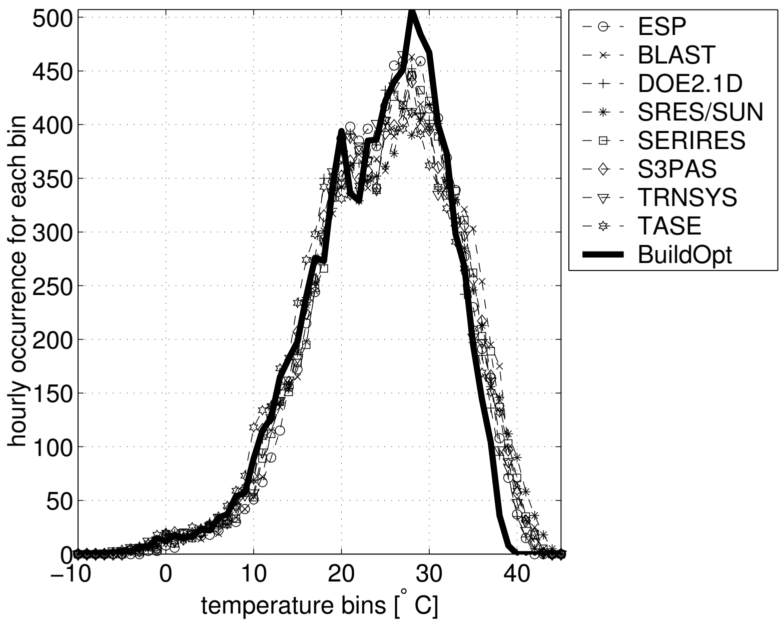


Figure 23: Annual hourly temperature frequency for each 1°C bin for Case 900FF.

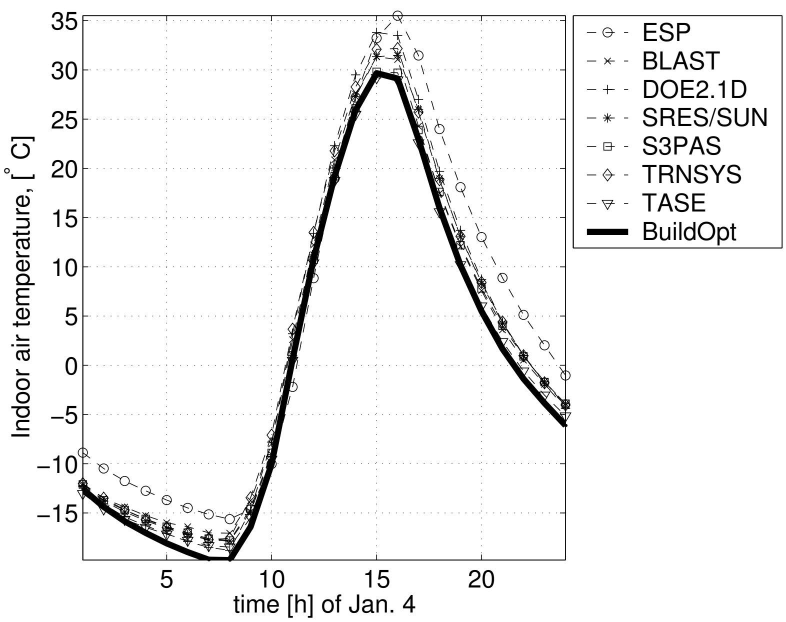


Figure 24: Hourly free float temperatures on January 4 for low mass building (Case 600FF).

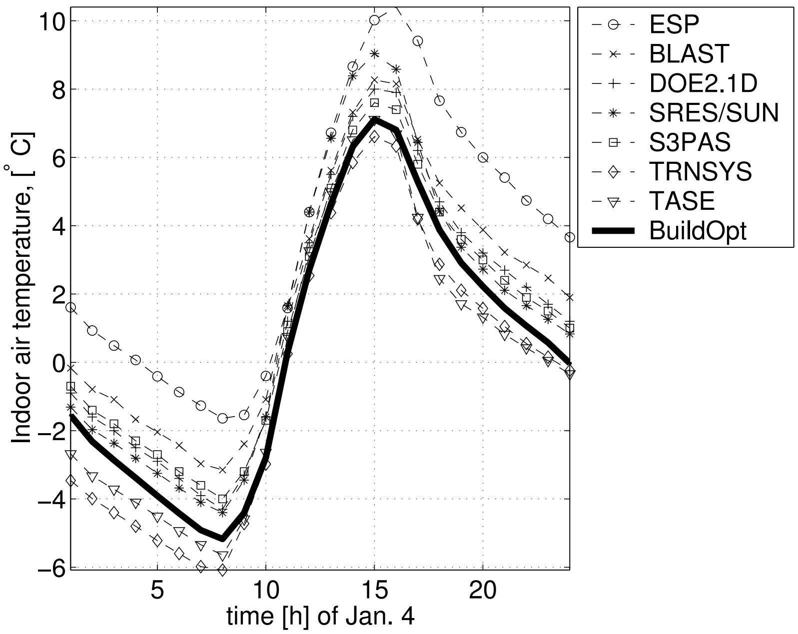


Figure 25: Hourly free float temperatures on January 4 for heavy mass building (Case 900FF).

c) Incident and Transmitted Solar Radiation

The annual incident and transmitted solar radiation computed by BuildOpt coincides with the results of the other tested programs. However, on March 5 and July 27, which are cloudy days, BuildOpt's hourly incident solar radiation on a south surface is shifted by 1 hour compared to the results of the other tested programs (see Fig. 29 and Fig. 30). The values of BuildOpt are nearly symmetric to 12: 00, whereas the values of the other tested programs are nearly symmetric to 13: 00. For this building site, on March 5, 1990, the sun is highest at 12: 11, and on July 27, 1990, it is highest at 12: 06 (neglecting daylight savings time).[1] Thus, the solar radiation should nearly be symmetric to 12: 00, as computed by BuildOpt, rather than to 13: 00, as computed by the other tested programs.

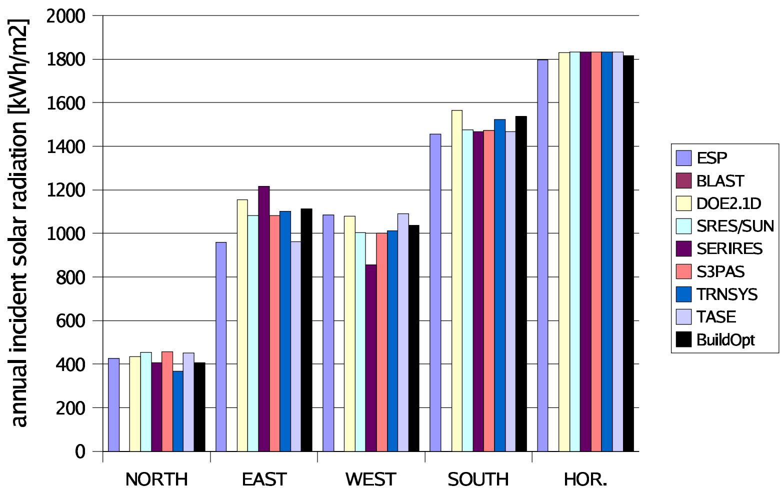


Figure 26: Annual incident solar radiation.

[1] See, for example, http://aa.usno.navy.mil/data/docs/RS_OneDay.html.

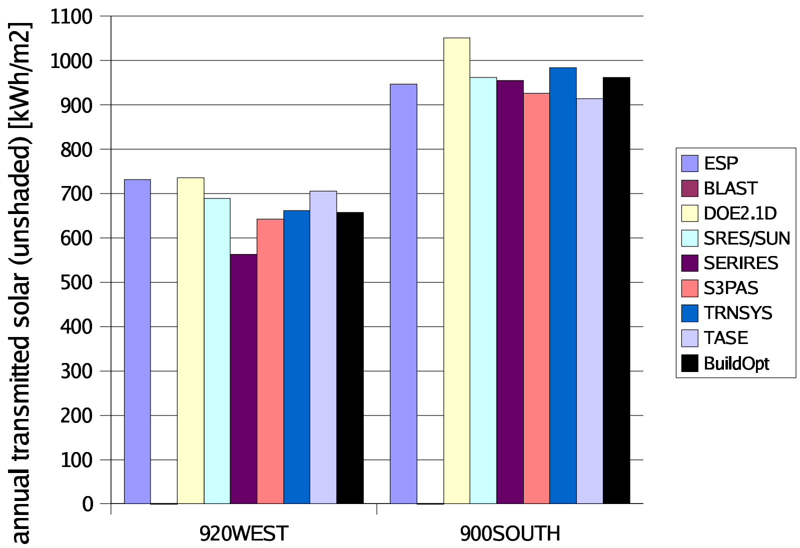


Figure 27: Annual transmitted solar radiation with unshaded windows.

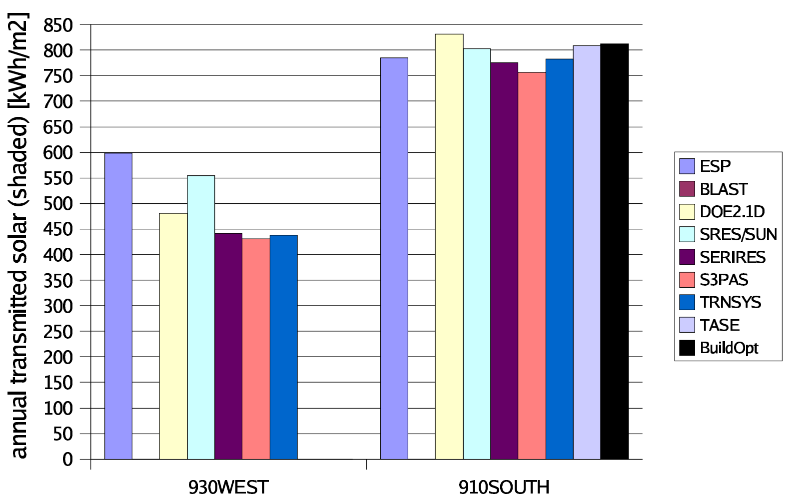


Figure 28: Annual transmitted solar radiation with shaded windows. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices.

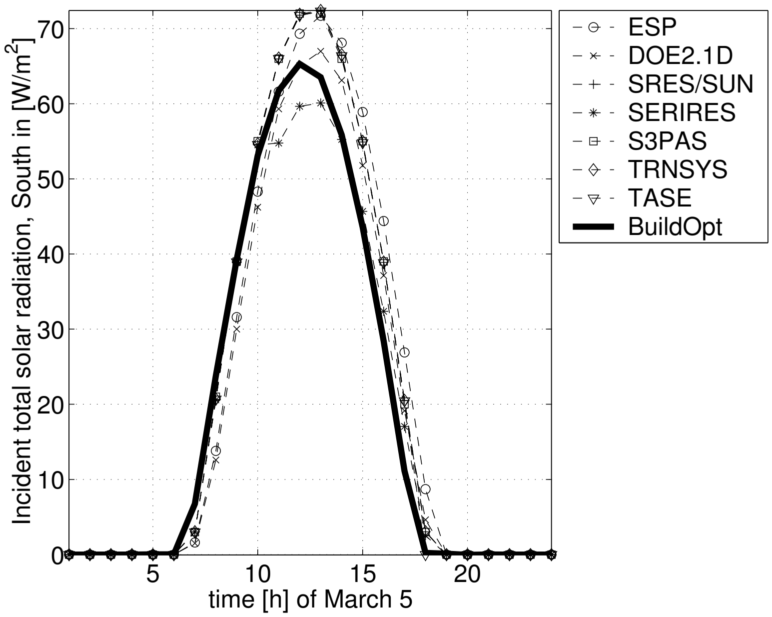


Figure 29: Hourly incident solar radiation on a cloudy day (March 5) on the south facing surface.

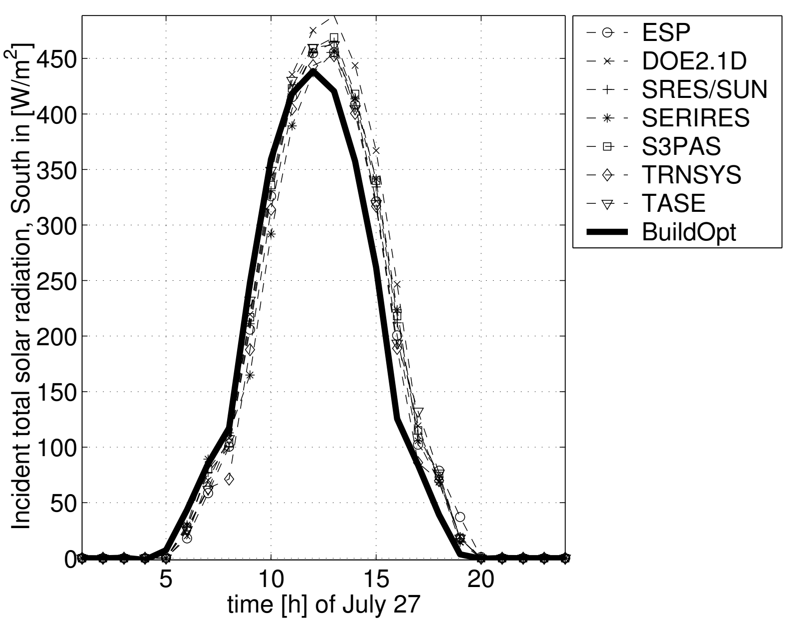


Figure 30: Hourly incident solar radiation on a clear day (July 27) on the south facing surface.

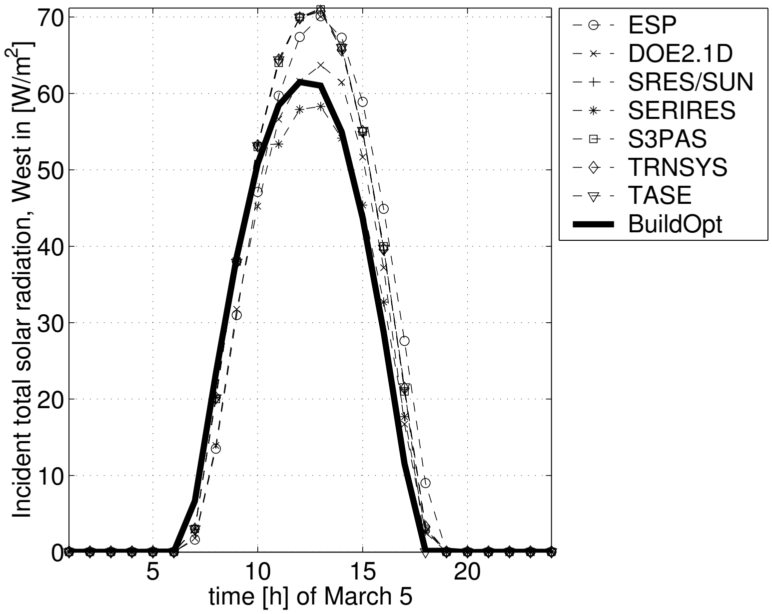


Figure 31: Hourly incident solar radiation on a cloudy day (March 5) on the west facing surface.

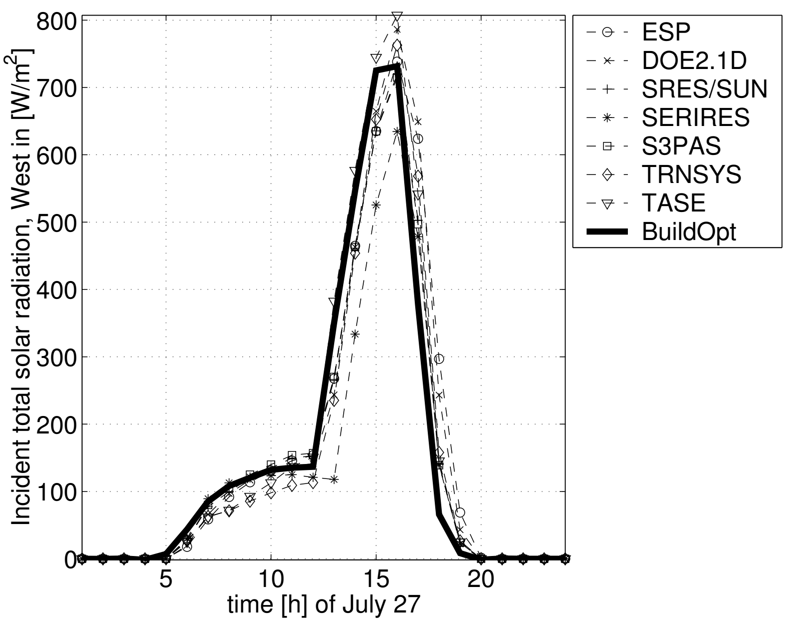


Figure 32: Hourly incident solar radiation on a clear day (July 27) on the west facing surface.

d) Solar Transmissivity and Shading Coefficients

The solar transmissivity and the shading coefficients computed by BuildOpt coincide with the results of the other tested programs.

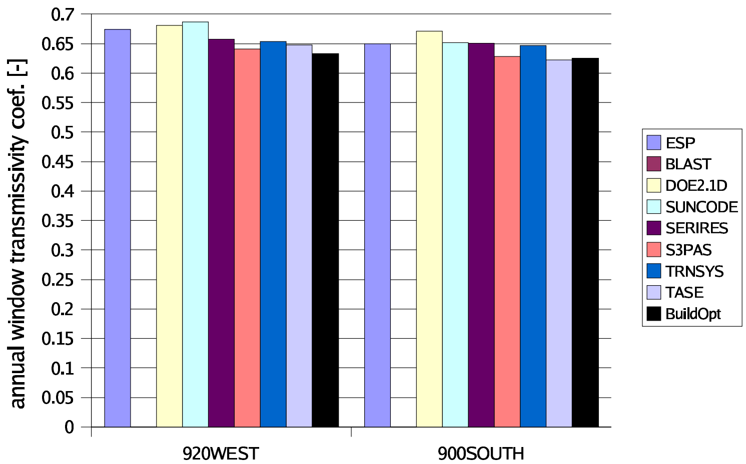


Figure 33: Annual transmissivity coefficient of windows. This is the ratio between the unshaded transmitted solar radiation and the incident solar radiation.

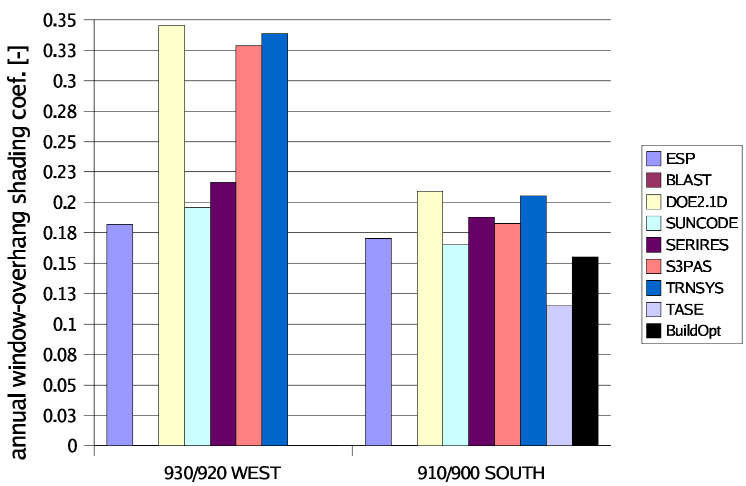


Figure 34: Annual overhang and fin shading coefficients. The shading coefficient is defined as one minus the ratio between the shaded transmitted solar radiation and the unshaded transmitted solar radiation. Case 930 was not simulated with BuildOpt because it has no model for vertical shading devices.

e) Hourly Heating and Cooling Power

The hourly heating and cooling power coincide with the results of the other tested programs.

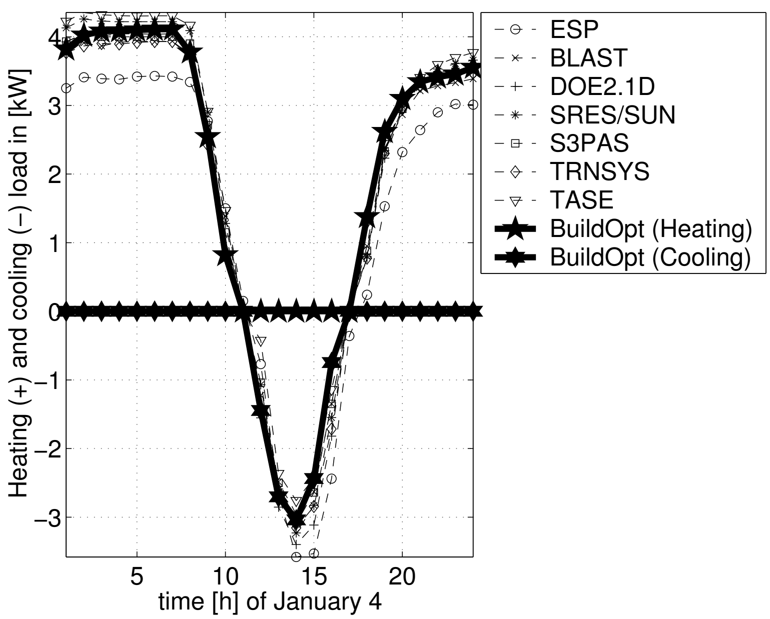


Figure 35: Hourly heating and cooling power on January 4 for low mass building (Case 600).

1.5 Conclusions

BuildOpt's results coincide for most tests with the results of the other tested programs. The largest differences are for the high mass test cases. For these tests, the annual cooling load and the annual peak cooling computed by BuildOpt is low compared to the values of the other tested programs. Also, for the free floating cases, the maximum and the minimum indoor air temperature computed by BuildOpt are low. However, the differences are relatively small, and we do not think that they are caused by a modeling error or a programming error.

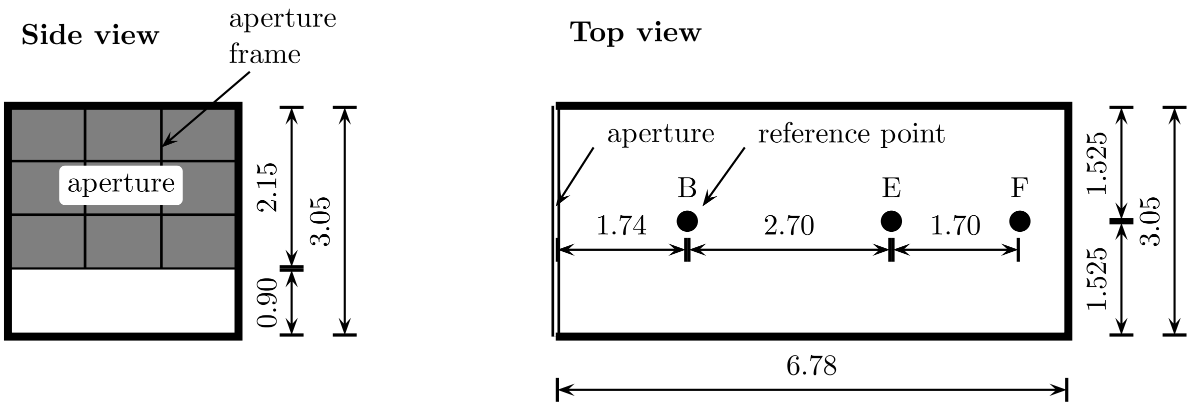


Figure 36: LESO scale model. The gray area in the left-hand figure shows the location of the aperture, and the black dots in the right-hand figure show the location of the daylight reference points.

2 Daylighting Model

2.1 Introduction

For the validation of the daylighting model, we used the benchmark tests from Laforgue (1997) and Fontoynont et al. (1999) that have been produced in the Task 21 of the International Energy Agency (IEA) Solar Heating & Cooling Program. These benchmark tests compare the values of the daylight factors for rectangular room configurations with increasing complexity. (The daylight factors are defined as the ratio of the illuminance on indoor surfaces at specific locations to the simultaneous horizontal illuminance on the roof.) The here presented daylight factors were obtained either by measurement, by using analytical computations, or by using different commercially available detailed daylighting simulation programs.

All test cases have a room aperture with no glass. Hence, for the daylight validation, we set the light transmittance of the window to one for all incidence angles. However, we remind that if a room has a window, then BuildOpt uses the same window model for the daylight transmittance and for the solar transmittance, with possibly different input data. This window model was validated in Section 1.

Due to the model simplifications in BuildOpt's daylighting model, we used only the results for side-lit rooms with an isotropic sky, and we compared only daylight factors on horizontal surfaces.

2.2 Specification of the Test Cases

a) LESO Scale Model

For the first set of test cases, we used data from the scale model of the Laboratoire d'Energy Solaire (LESO) of the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. Fig. 36 shows the scale model with the location of the daylight reference points that we used in our validation. All daylight reference points are 0.75 m above the floor. Fontoynont et al. (1999) report that the frame of the aperture was not simulated with any of the software. For the room and ground reflectance, we used the reflectance values shown in Tab. 2.[2]

	case (a)	case (b)	case (c)	case (d)
Ceiling	0	0	0.83	0.83
Walls	0	0	0.60	0.60
Floor	0	0	0.28	0.28
Ground	0	0.29	0	0.29

Table 2: Reflectance values for the LESO scale model.

b) CSTB/ECAD Scale Model

For the second set of test cases, we used data from the scale model of the Centre Scientifique du Bâtiment (CSTB), France. Fig. 37 shows the scale model and the location of the reference points that we used in our validation. We used the reflectance values shown in Tab. 3.[3]

	case (a) and (b)	case (c) and (d)
Ceiling	0	0.70
Walls	0	0.50
Floor	0	0.30
Ground	0	0.30

Table 3: Reflectance values for the CSTB scale model.

For case (a), the daylight reference points were located on the floor and for case (b), they were located 0.8 m above the floor. For case (c), the daylight reference points were

[2] Laforgue (1997) lists in the test specification for cases (a) and (b) reflectance for all room surfaces and for the ground of 0.02, in contradiction to the values listed in the result tables, which are zero for all room surfaces and for the ground. The difference between the results is small.

[3] The ground reflectance is not specified in Laforgue (1997). However, from the daylight factors that are tabulated in Laforgue (1997), one can conclude that for cases (a) and (b), the ground reflectance must be zero. For cases (c) and (d), the results in Laforgue (1997) were obtained by using a ground reflectance of 0.30 (Carroll, 2003). This value accounted for the fact that the 1:10 scale model was placed on a 1 m high table, and hence, the view factor to the sky was as in a room on the 4-th floor. Consequently, an observer that looks downward from the ceiling may see part of the illuminated sky.

for Genelux and BuildOpt on the floor, for SUPERLITE 0.08 m above the floor, and at an unspecified height for the CSTB sim results. For case (d), the daylight reference points were 0.8 m above the floor for all tabulated values.

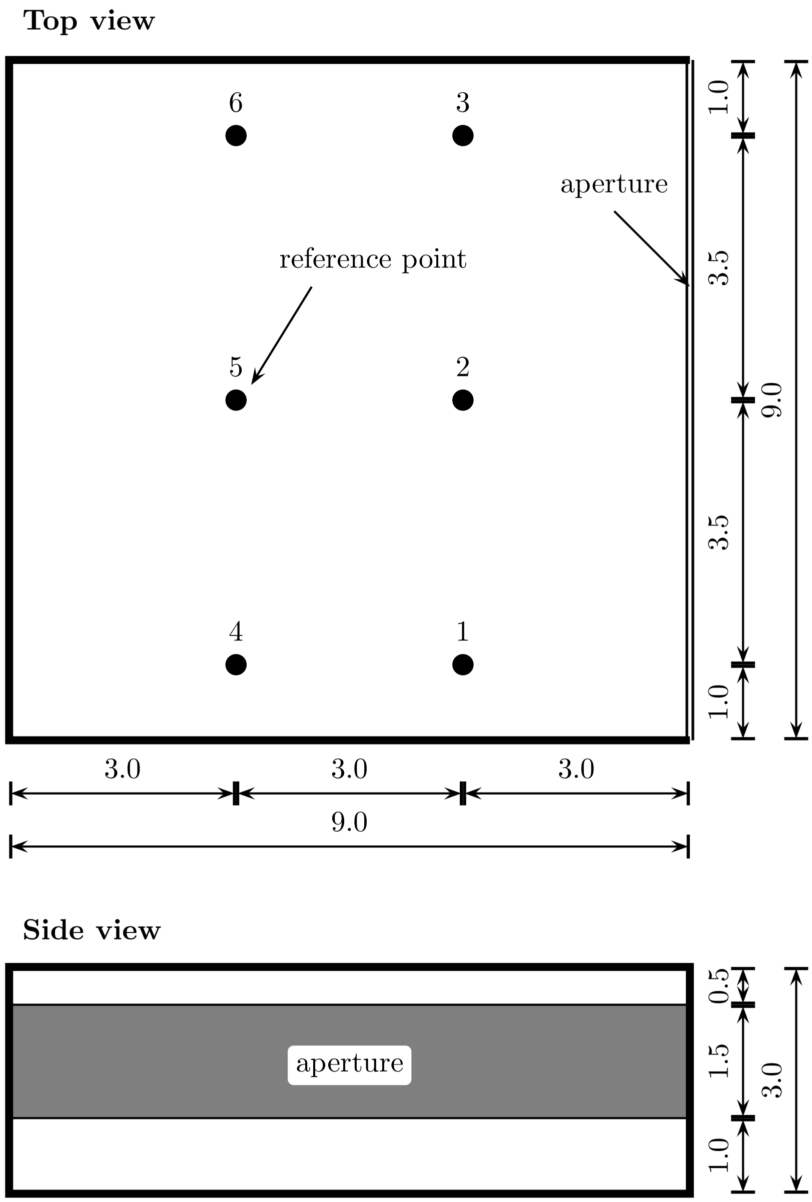


Figure 37: CSTB scale model. The black dots in the top figure show the location of the daylight reference points, and the gray area in the bottom figure shows the location of the aperture.

2.3 Results

a) LESO Scale Model

Tab. 4 and Fig. 38 show the daylight factors for all benchmark tests for the LESO scale model that we used in the BuildOpt validation. For the cases (a) and (b) in which all room surfaces are non-reflecting, BuildOpt's daylight factors are within the range of the other results at the reference points E and F which are at a distant of 4.44 m and 6.14 m from the aperture. For the reference point B, which is at a distant of 1.74 m from the aperture, the daylight factor computed by BuildOpt is about 3.5% higher in absolute value than the values listed in Laforgue (1997). For the cases (c) and (d), which used a room with reflecting surfaces, the daylight factors at all reference points are within the range of the other tabulated results. For the daylight reference points E and F, which are far away from the aperture, the daylight factors computed by BuildOpt are on the lower side compared to the other tabulated results. This is because with increasing distance between daylight reference point and aperture, more of the daylight that arrives at the reference point underwent multiple reflections. However, BuildOpt computes only the first reflection, and consequently, it underestimates the daylight illuminance for locations far away from the aperture.

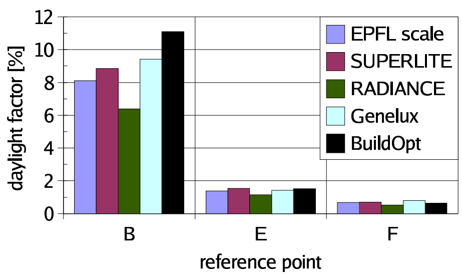
Case (a)					
Point	EPFL scale	SUPERLITE	RADIANCE	Genelux	BuildOpt
B	8.11	8.86	6.39	9.42	11.09
E	1.39	1.53	1.14	1.43	1.51
F	0.68	0.69	0.53	0.80	0.65

Case (b)					
Point	EPFL scale	SUPERLITE	RADIANCE	Genelux	BuildOpt
B	8.27	9.17	6.57	9.42	11.13
E	1.34	1.57	1.26	1.43	1.53
F	0.69	0.70	0.48	0.80	0.66

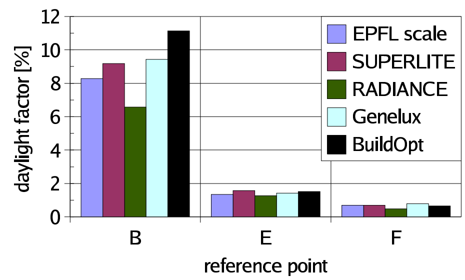
Case (c)					
Point	EPFL scale	SUPERLITE	RADIANCE	Genelux	BuildOpt
B	12.13	11.5	8.44	10.54	11.96
E	4.09	3.17	2.40	2.29	1.90
F	3.12	2.21	1.46	1.48	1.18

Case (d)					
Point	EPFL scale	SUPERLITE	RADIANCE	Genelux	BuildOpt
B	12.74	13.27	8.55	13.4	13.37
E	4.24	3.90	2.38	3.56	2.50
F	3.18	2.69	1.49	2.34	1.55

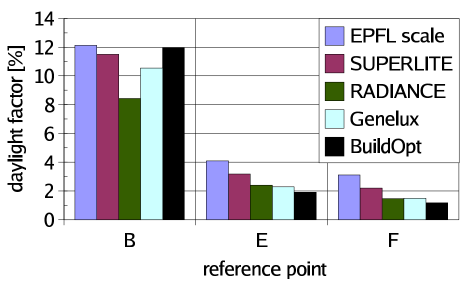
Table 4: Daylight factors in [%] for the LESO scale model with an isotropic sky.



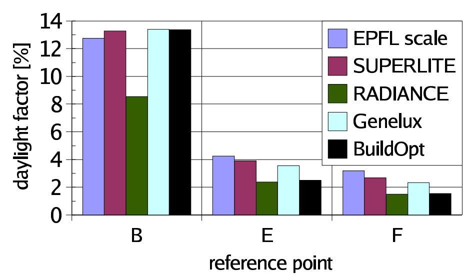
(a) Reflectance inside 0%, ground 0%.



(b) Reflectance inside 0%, ground 29%.



(c) Reflectance inside non-zero, ground 0%.

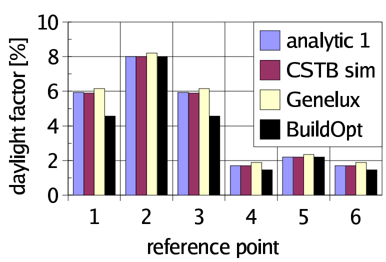


(d) Reflectance inside non-zero, ground 29%.

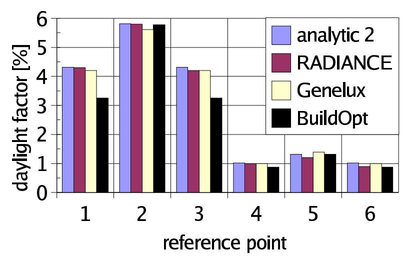
Figure 38: Daylight factors for the LESO scale model with an isotropic sky.

b) CSTB/ECAD Scale Model

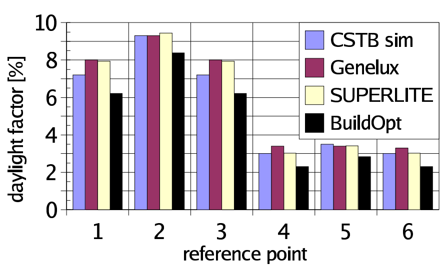
Tab. 5 and Fig. 39 show the daylight factors for all benchmark tests for the LESO scale model. For the cases (a) and (b) which used a room with black surfaces, BuildOpt's results are in the range of all other results except at the reference points 1 and 3, at which the daylight factor computed by BuildOpt is 1% to 2% lower in absolute value. For cases (c) and (d) that used a room with gray surfaces, BuildOpt underestimates the daylight factor by 2% in absolute value for the reference points that are close to the aperture. The accuracy is higher for reference points that are farther away from the aperture. In general, BuildOpt tends to underestimate the daylight factors because it does not account for multiple reflectances.



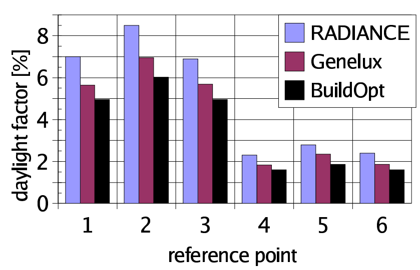
(a) Reflectance inside 0%, ground 0%, reference points on floor.



(b) Reflectance inside 0%, ground 0%, reference points 0.8 m above floor.



(c) Reflectance inside non-zero, ground 30%, reference points on floor.



(d) Reflectance inside non-zero, ground 30%, reference points 0.8 m above floor.

Figure 39: Daylight factors for the CSTB/ECAD scale model with an isotropic sky.

Case (a)				
Point	analytic 1	CSTB sim	Genelux	BuildOpt
1	5.94	5.90	6.16	4.57
2	8.01	8.00	8.21	8.00
3	5.94	5.90	6.16	4.57
4	1.71	1.70	1.89	1.47
5	2.21	2.20	2.35	2.20
6	1.71	1.70	1.89	1.47

Case (b)				
Point	analytic 2	RADIANCE	Genelux	BuildOpt
1	4.32	4.30	4.20	3.26
2	5.81	5.80	5.62	5.79
3	4.32	4.20	4.20	3.26
4	1.02	1.00	1.00	0.87
5	1.32	1.20	1.39	1.32
6	1.02	0.90	1.00	0.87

Case (c)				
Point	CSTB sim	Genelux	SUPERLITE	BuildOpt
1	7.20	8.00	7.93	6.22
2	9.30	9.30	9.44	8.38
3	7.20	8.00	7.93	6.22
4	3.00	3.40	3.03	2.30
5	3.50	3.40	3.42	2.83
6	3.00	3.30	3.03	2.30

Case (d)			
Point	RADIANCE	Genelux	BuildOpt
1	7.00	5.64	4.96
2	8.50	6.95	6.03
3	6.90	5.69	4.96
4	2.30	1.84	1.61
5	2.80	2.35	1.87
6	2.40	1.87	1.61

Table 5: Daylight factors in [%] for the CSTB/ECAD scale model with an isotropic sky.

2.4 Conclusions

The daylight factors computed by BuildOpt coincide for most test cases with the daylight factors that were obtained with other, substantially more detailed, commercial daylighting programs or by using analytical formulas.

The largest differences between BuildOpt's results and the values tabulated in the IEA reports from Laforgue (1997) and Fontoynont et al. (1999) are for rooms with black surfaces at reference points that are close to a wall. For these cases, BuildOpt underestimates the daylight factor by 2% in absolute value.

For the more realistic cases in which the room has reflecting surfaces, the daylight factors computed by BuildOpt are either within the range of the tabulated values, or within an absolute difference of 1%.

For rooms with reflecting surfaces, BuildOpt tends to underestimate the daylight factors at locations far away from the aperture because it does not take into account multiple reflections.

3 Acknowledgments

This research was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of the Building Technologies Program of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098, by Hewlett Packard Research Laboratories and by CITRIS.

References

ASHRAE (2001). ANSI/ASHRAE Standard 140-2001, Standard method of test for the evaluation of building energy analysis computer programs.

Carroll, W. L. (2003). Personal communication.

Fontoynont, M., Laforgue, P., Mitanchey, R., Aizlewood, M., Butt, J., Carroll, W., Hitchcock, R., Erhorn, H., Boer, J. D., Dirksmöller, M., Michel, L., Paule, B., Scartezzini, J. L., Bodart, M., and Roy, G. (1999). IEA SHC Task 21/ECBCS Annex 29, Daylight in buildings, Subtask C1: Validation of daylighting simulation programmes. Technical Report T21/C1-/FRA/99-11, International Energy Agency.

Laforgue, P. (1997). IEA SHC Task 21/ECBCS Annex 29, Daylight in buildings, Subtask C1: Draft report of Genelux simulations and other software results. Technical Report T21/C1/97-10, International Energy Agency.

Wetter, M. (2004). BuildOpt – a new building energy simulation program that is built on smooth models. Technical Report LBNL-54657, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.