




Building Energy Simulation Test for Existing Homes (BESTEST-EX): Instructions for Implementing the Test Procedure, Calibration Test Reference Results, and Example Acceptance-Range Criteria

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Link to Accompanying Zipped Data Files (3.9 MB)

This document is intended for use with the following documents:

Building Energy Simulation Test for Existing Homes (BESTEST-EX), NREL/TP-550-47427

Example Procedures for Developing Acceptance-Range Criteria for BESTEST-EX, NREL/TP-550-47502

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Nomenclature

Italicized terms are defined in Appendix A.

air_seal	air seal retrofit
Approx.	approximate
APR	April
attic_ins.	attic insulation retrofit
Avg.	average
BESTEST	Building Energy Simulation Test
BESTEST-EX	Building Energy Simulation Test for Existing Homes
combined	combined air seal, insulation, low-emissivity window and programmable thermostat retrofit (as used in Figures 1 to 14 and Tables 1 to 14)
Conf.	value determined from confidence interval equations
COP	coefficient of performance
C1C	*targeted high* space cooling consumption scenario
C2C	*targeted low* space cooling consumption scenario
C3C	*fully random*, near-nominal space cooling consumption scenario
C4C	*fully random*, high space cooling consumption scenario
C5C	*fully random*, low space cooling consumption scenario
C6C	*fully random*, mid-high space cooling consumption scenario
C7C	*fully random*, mid-low space cooling consumption scenario
C1H	*targeted high* space heating consumption scenario
C2H	*targeted low* space heating consumption scenario
C3H	*fully random*, near-nominal space heating consumption scenario
C4H	*fully random*, high space heating consumption scenario
C5H	*fully random*, low space heating consumption scenario
C6H	*fully random*, mid-high space heating consumption scenario
C7H	*fully random*, mid-low space heating consumption scenario
DOE	U.S. Department of Energy
DOE-2.1E	DOE-2.1E version JJ Hirsch PC 2.1En136
Econ.	economic
EnergyPlus	EnergyPlus version 3.1
MAR	March
Max	maximum
Min	minimum
Nom	*nominal input*
NOV	November
NREL	National Renewable Energy Laboratory
OCT	October
Ref	reference simulation result
sol_abs	solar absorptance (as used in Figures 1 to 14 and Tables 1 to 14)
SEP	September
setback	thermostat setback (as used in Figures 1 to 14 and Tables 1 to 14)
Sqrt	square root
Stdv	standard deviation ("N−1" [sample] type)
SUNREL	SUNREL version 1.14
wall_ins.	wall insulation retrofit
windows	low-emissivity window retrofit (as used in Figures 1 to 14 and Tables 1 to 14)
"-C"	calibration test cases
"-P"	building physics test cases
$	economic threshold criteria

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Accompanying Files (Electronic Media Contents)

The following files, ***provided within B-EX-Phase-1-Ref-C-Results+Example-acceptance-criteria.zip,*** *apply as they are called out in this document (see README-BESTEST-EX, included with the accompanying electronic files):*

- **B-EX-Calibration-BaseCase-Utility-Data.xls:** Electronic version of utility energy consumption data for use with the calibration test cases, presented in Judkoff et al. (2010a), Section 1.3.1.2.

- **B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls:** Spreadsheet that contains reference simulation results for the utility bill calibration tests; the building physics test case results are also included here for convenience. The example acceptance criteria presented in Judkoff et al. (2010b) are applied to the physics and calibration tests results. Use *BESTEST-EX-Phase-1-Output.xls* (Judkoff et al. 2010a) to enter simulation results for the program being tested.

The following reference simulation input files are provided for informative use:

The subfolder **B-EX-Ref-Simulation-Calibration-Input-Files** contains reference simulation input files developed by NREL for the BESTEST-EX calibration ("-C") test cases. Simulation input files are organized in subfolders by calibration scenario.

Subfolder	Description
\CnC	Cooling tests input files (C1C through C7C)
\CnH	Heating tests input files (C1H through C7H)
\B-EX-Ref-Simulation-Weather-Files	Weather data files

Reference simulation input files are described further within *README-BESTEST-EX-Calibration-Test-Files.doc*, included with the accompanying electronic files. Reference simulation input files for the building physics tests are included with Judkoff et al. (2010b).

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Introduction

BESTEST-EX was initially published (Judkoff et al., 2010a, 2010b) with the intention that the calibration test results needed to be blind, so a certifying agency could use it for certifying calibration methods. After publication, it became apparent that the residential energy retrofit modeling industry wanted to have the ability to self-test their software, and we realized that this ability– consistent with self-testing capability provided for the BESTEST-EX building physics tests – would be beneficial to both software developers and users. Therefore, this document was developed to include previously withheld calibration test results, along with instructions for coordinating the use of this document with the previously published BESTEST-EX documents. Should the need arise in the future for a blind certification test, additional calibration test data would have to be generated for that purpose.

This document provides:

- Instructions for implementing/running the BESTEST-EX physics and calibration tests (Judkoff et al. 2010a); see Section 1 of this document.
- Electronic version of calibration utility data given in the test specification (Judkoff et al. 2010a, Sec 1.3.1.2.); see accompanying files.
- Calibration test reference program results and example acceptance ranges; see Section 2. A certifying or accrediting agency may develop acceptance-range setting criteria to suit particular needs. Neither DOE, NREL, nor the authors of this document may be held responsible for any misfortunes that occur from use of these example acceptance ranges in a certification program.
- Randomly selected explicit inputs for the calibration tests; see Section 3.
- Reference simulation input files for the calibration tests; see accompanying files.
- Clarifications to Judkoff et al. (2010a, 2010b) related to publication of calibration test results for non-blind testing, and other clarifications; see Appendix B of this document. There are no substantive changes to the test specification.

1 Instructions for Implementing Physics Tests and Calibration Tests

The following documents are needed to implement the BESTEST-EX physics and calibration tests:

- *Building Energy Simulation Test for Existing Homes (BESTEST-EX), Phase 1 Test Procedure: Building Thermal Fabric Test Cases,* NREL/TP-550-47427. (Judkoff et al. 2010a)
- *Example Procedures for Developing Acceptance-Range Criteria,* NREL/TP-550-47502. (Judkoff et al. 2010b)
- This document.

Clarifications to Judkoff et al. (2010a, 2010b) related to publication of calibration test results for non-blind testing, and other clarifications are included in Appendix B of this document; there are no substantive changes to the test specification. For definitions of terms used here see Appendix A of this document.

Physics Tests

The physics test cases are to be implemented as described in the test specification (Judkoff et al. 2010a) and compared with results and example acceptance criteria included in Judkoff et al. (2010b). For convenience an electronic version of the physics test results is included in *B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls* accompanying this document.

Calibration Tests

The calibration test cases are to be implemented as described in the test specification (Judkoff et al. 2010a). For convenience, an electronic version of the utility data specified in Judkoff et al. (2010a), Section 1.3.1.2 is included in *B-EX-Calibration-BaseCase-Utility-Data.xls* accompanying this document.

Base-case and energy savings results for the tested program can be compared with results and example acceptance criteria included in Section 2. Calibrated base-case inputs for the tested program can be compared with the randomly selected base-case *explicit inputs* used to develop the reference results; the reference program base-case *explicit inputs* are tabulated in Section 3. The Section 3 *explicit inputs* are implemented in the reference programs as shown in the simulation input files included with the accompanying electronic media.

Publication of calibration test results allows self-assessment of automated, semi-automated, and manual calibration methods.

Note to certifying entities: *The calibration test results published here are best applied for testing automated calibration methods directly integrated with the tested software. For testing semi-automated and manual calibration methods it is better to apply a separate set of results for blind third party testing. Results for additional calibration scenarios needed for blind third party testing have not been developed.*

2 Calibration Test Reference Results and Example Acceptance Criteria

The concepts applied for establishing example acceptance ranges are described in Sections 1, 3, and 4 of Judkoff et al. (2010b). As described in Judkoff et al. (2010b), Section 2, programs must pass 100% of the physics test cases, and programs must pass a reasonable fraction (example: 80%) of the calibration test cases.

An example of applying this procedure to the BESTEST-EX reference results for the utility bill calibration (“-C”) cases follows. Reference results were developed using:

- DOE-2.1E version JJ Hirsch PC 2.1En136 (*DOE-2 Reference Manual* 1981, *DOE-2 Supplement* 1994)
- EnergyPlus version 3.1 (*EnergyPlus Input Output Reference* 2009)
- SUNREL version 1.14 (Deru et al. 2002)

In Figures 1 through 14, the example acceptance range maxima and minima are indicated by “range” bars. The statistically based acceptance ranges are shown with blue range bars; the economic threshold based ranges are shown with green range bars. A tested tool passes a case if its result for that case falls within the greatest maximum and least minimum defined by the blue and green range bars.

The example acceptance ranges for the BESTEST-EX “-C” cases are developed as shown in Tables 1 through 14. An electronic version of the calculations is provided with *B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls* included with the accompanying electronic files. Cell addresses for finding data in the xls file are given in small font below the tables.

Abbreviations used in the figures and tables are included are with the Nomenclature (see the front matter of this document).

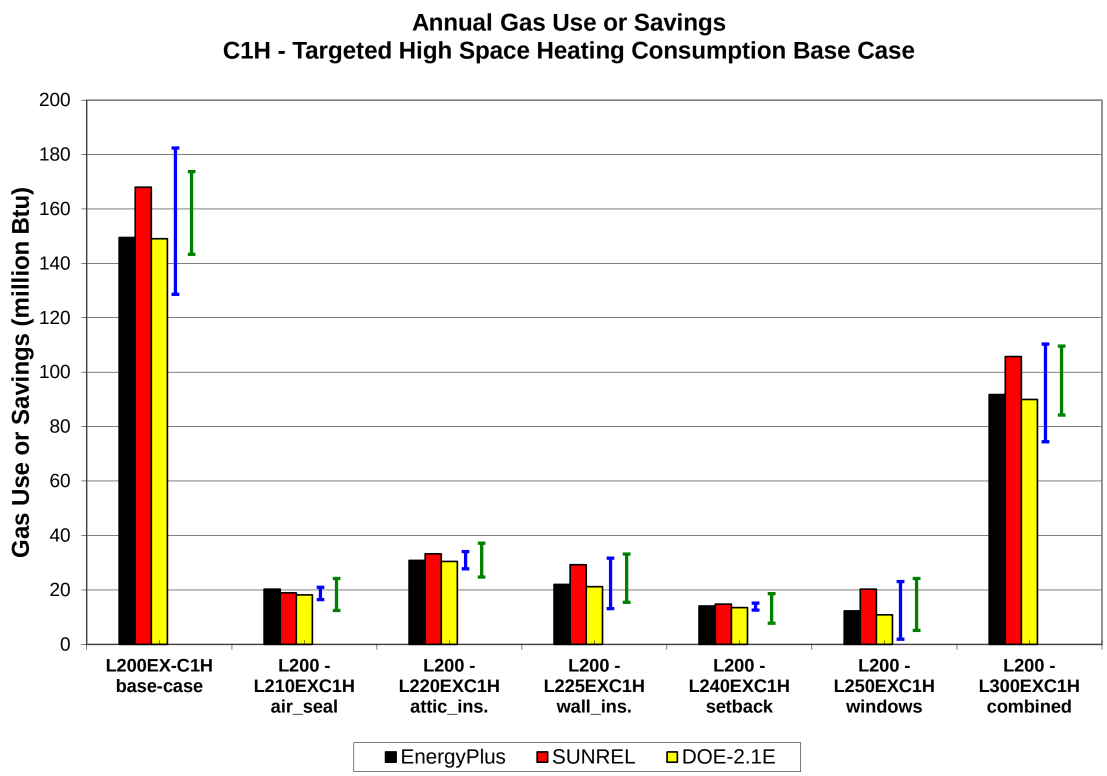

Figure 1. Calibration tests, scenario C1H: reference simulation results and acceptance criteria

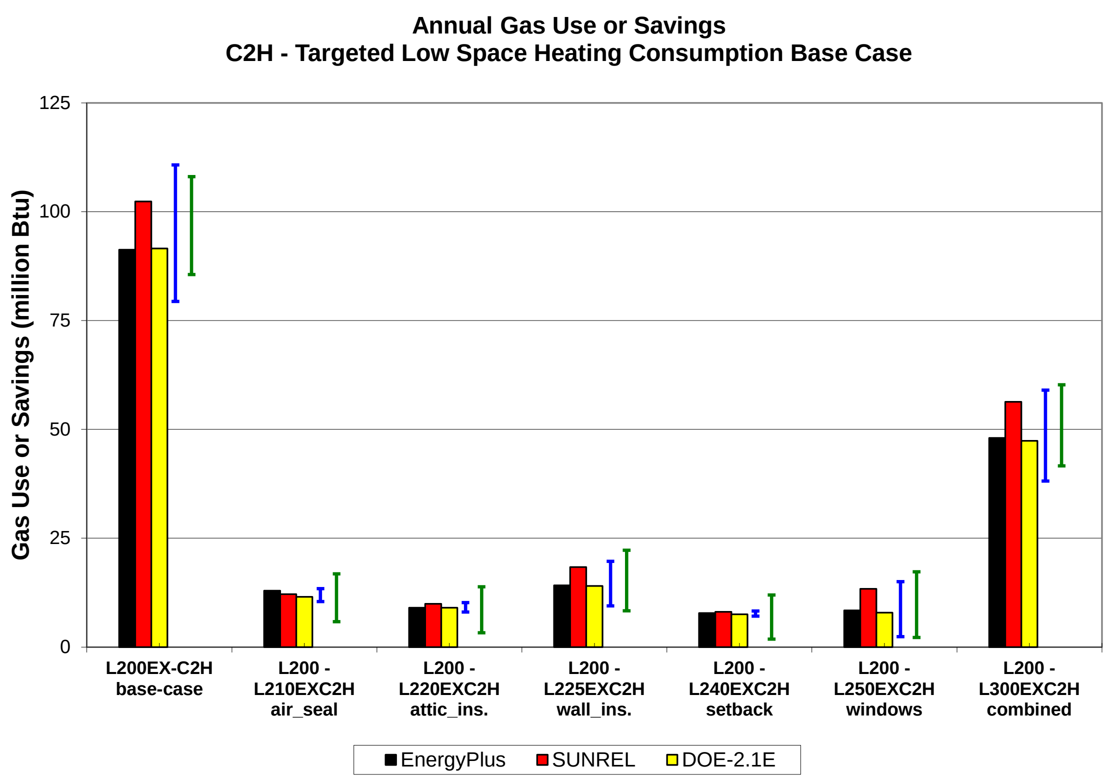

Figure 2. Calibration tests, scenario C2H: reference simulation results and acceptance criteria

Annual Gas Use or Savings
C3H - Fully Random, Near-Nominal Space Heating Consumption Base Case

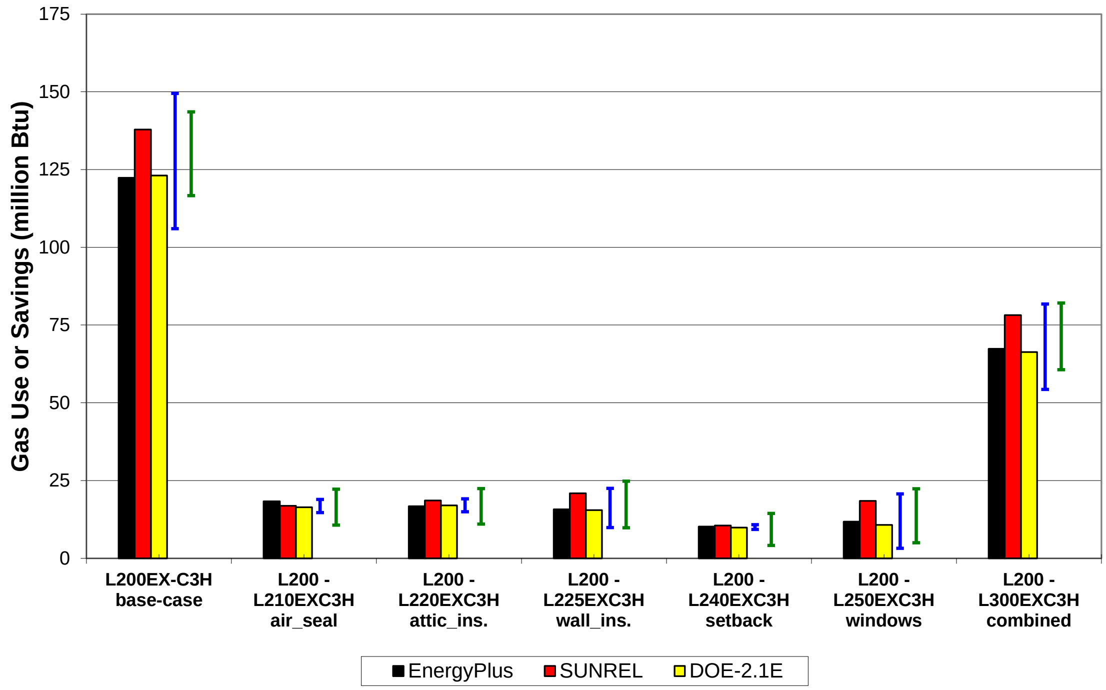

Figure 3. Calibration tests, scenario C3H: reference simulation results and acceptance criteria

Annual Gas Use or Savings
C4H - Fully Random, High Space Heating Consumption Base Case

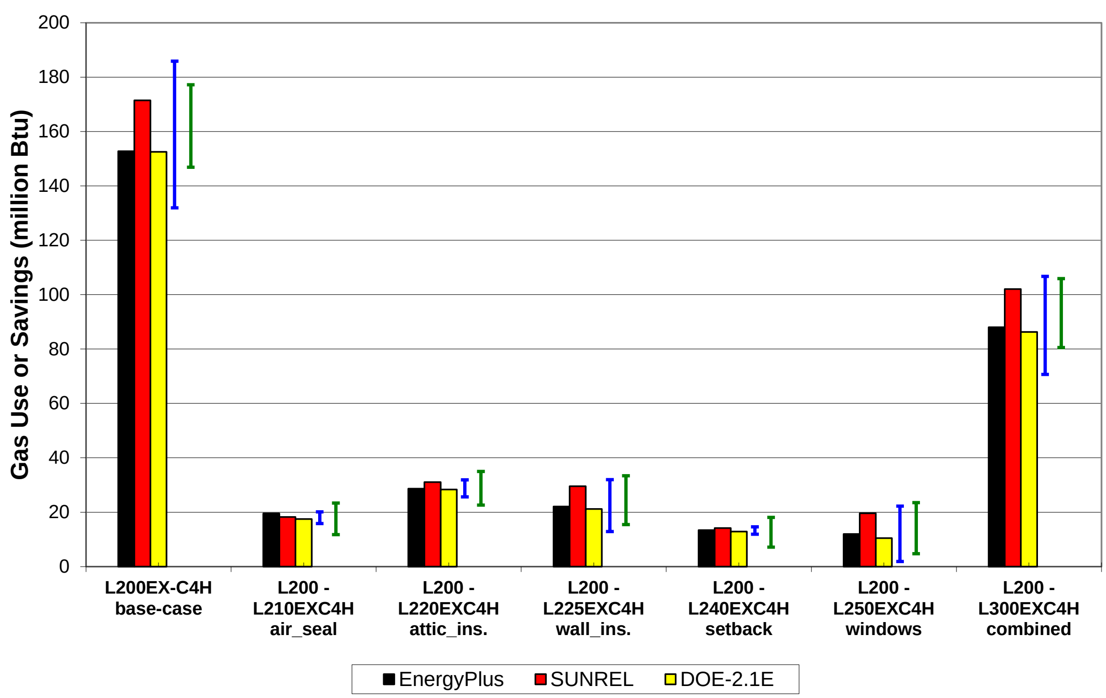

Figure 4. Calibration tests, scenario C4H: reference simulation results and acceptance criteria

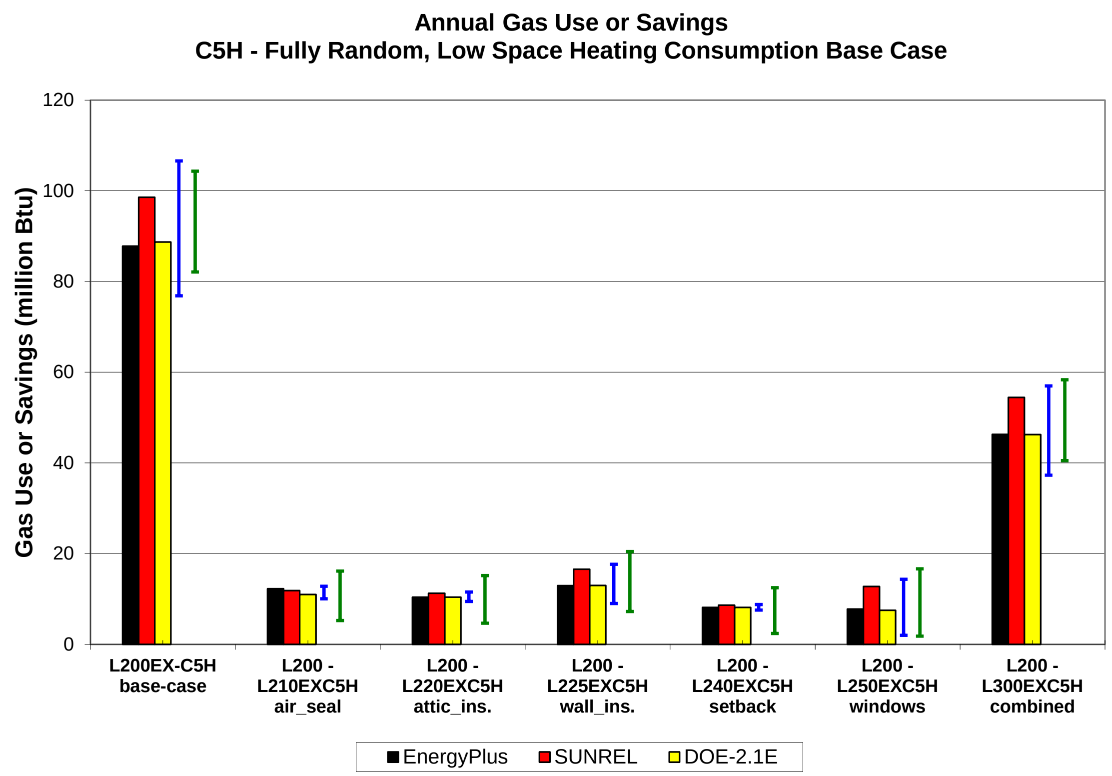

Figure 5. Calibration tests, scenario C5H: reference simulation results and acceptance criteria

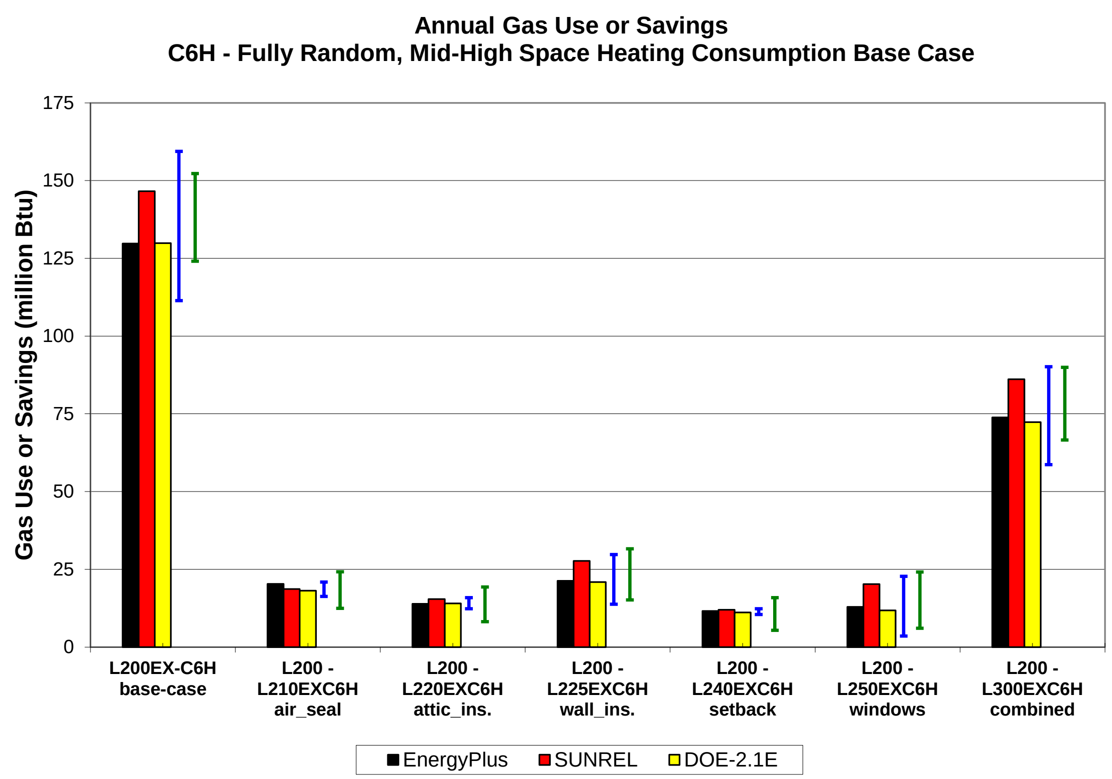

Figure 6. Calibration tests, scenario C6H: reference simulation results and acceptance criteria

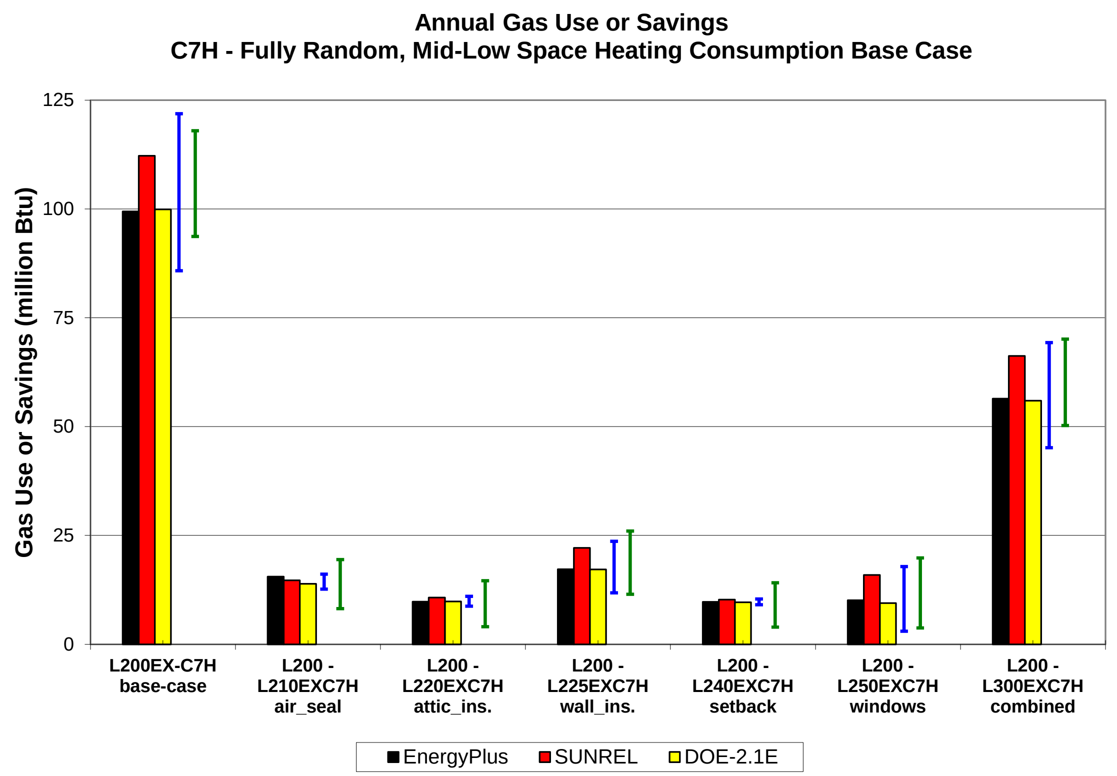

Figure 7. Calibration tests, scenario C7H: reference simulation results and acceptance criteria

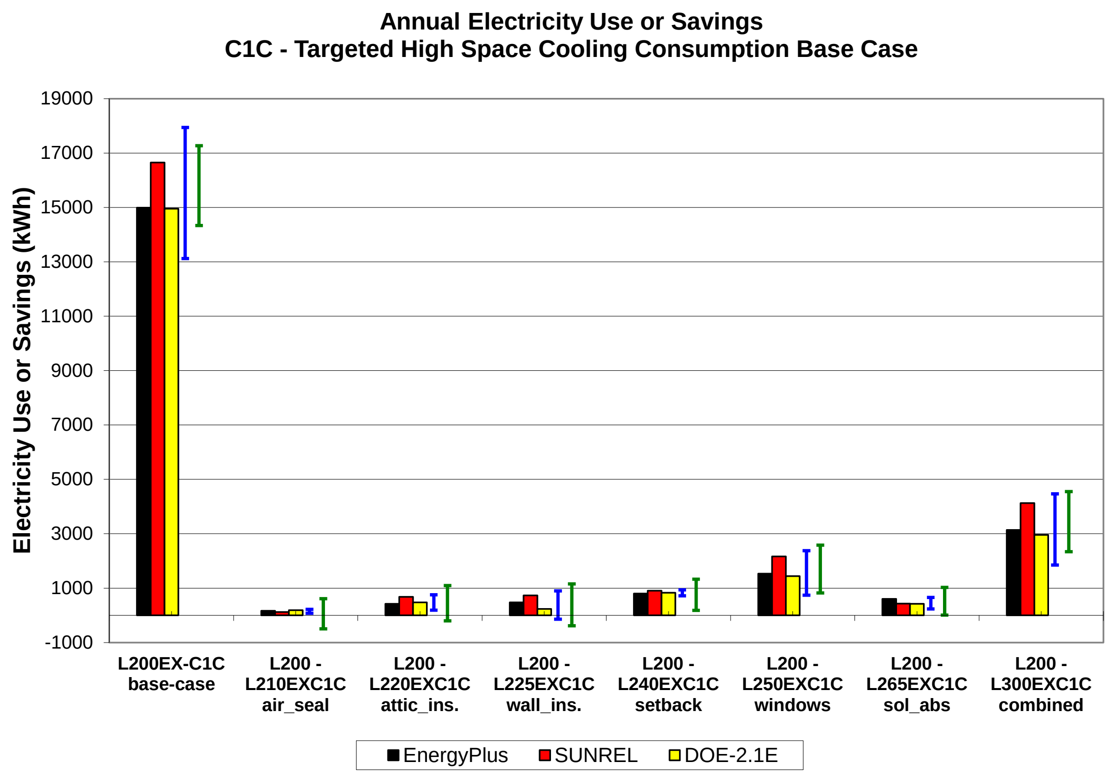

Figure 8. Calibration tests, scenario C1C: reference simulation results and acceptance criteria

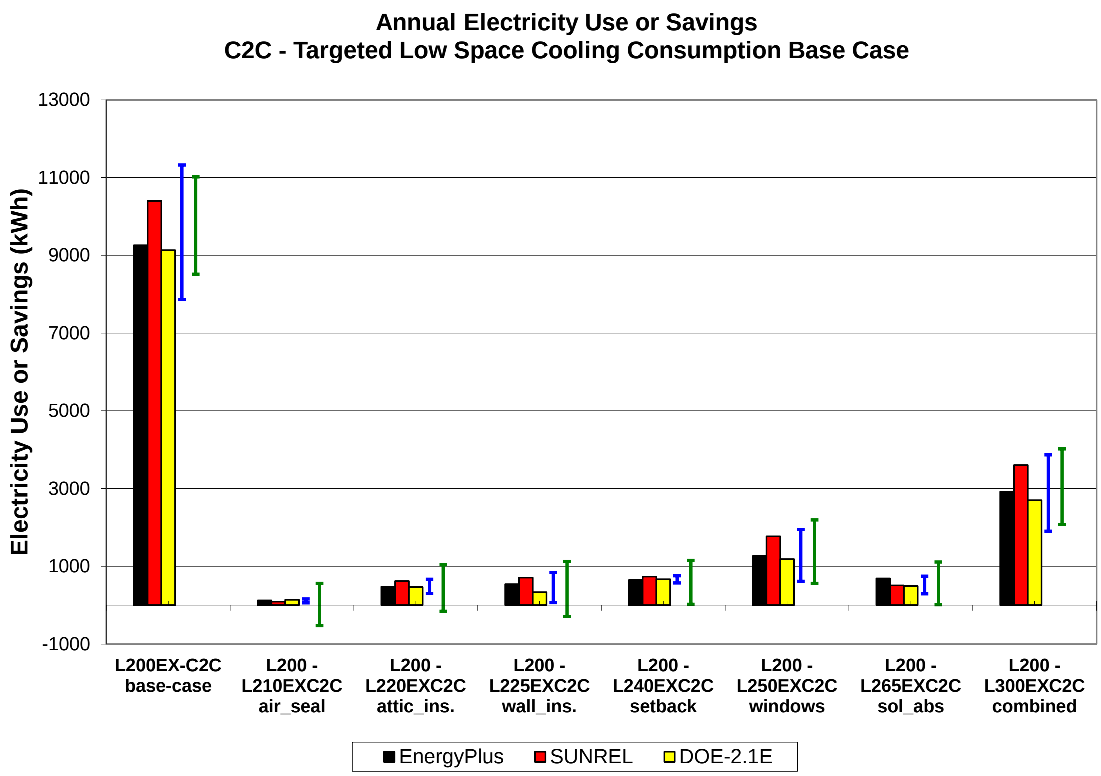

Figure 9. Calibration tests, scenario C2C: reference simulation results and acceptance criteria

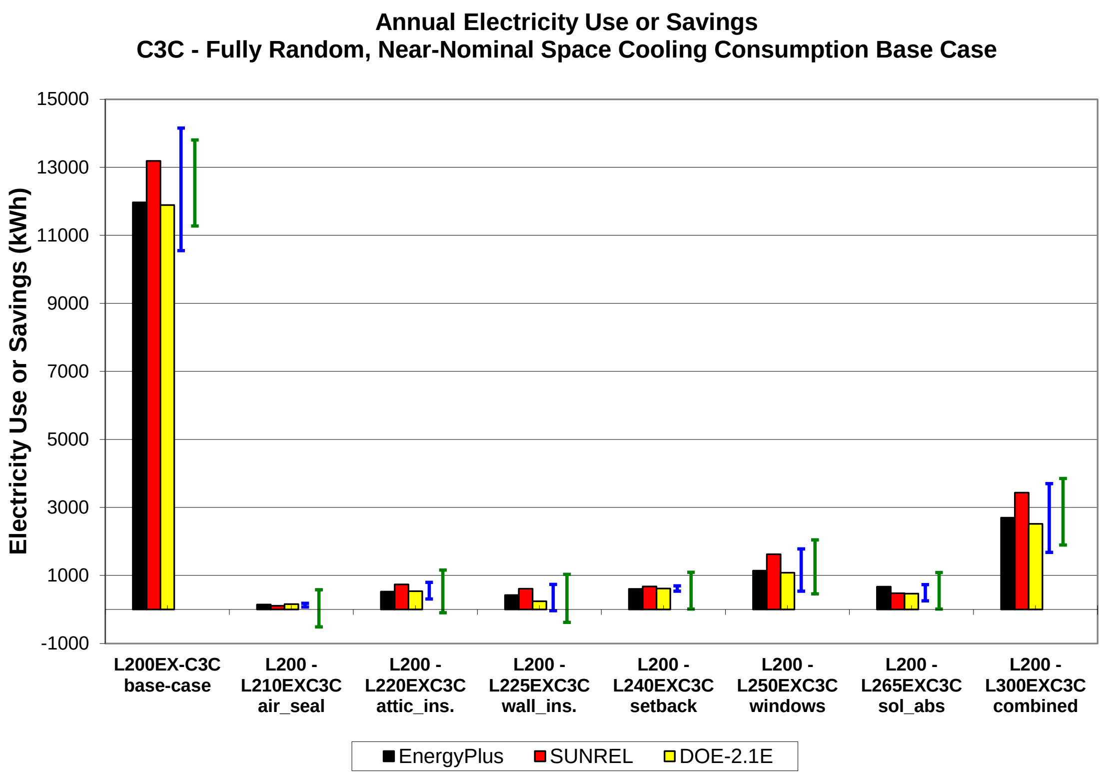

Figure 10. Calibration tests, scenario C3C: reference simulation results and acceptance criteria

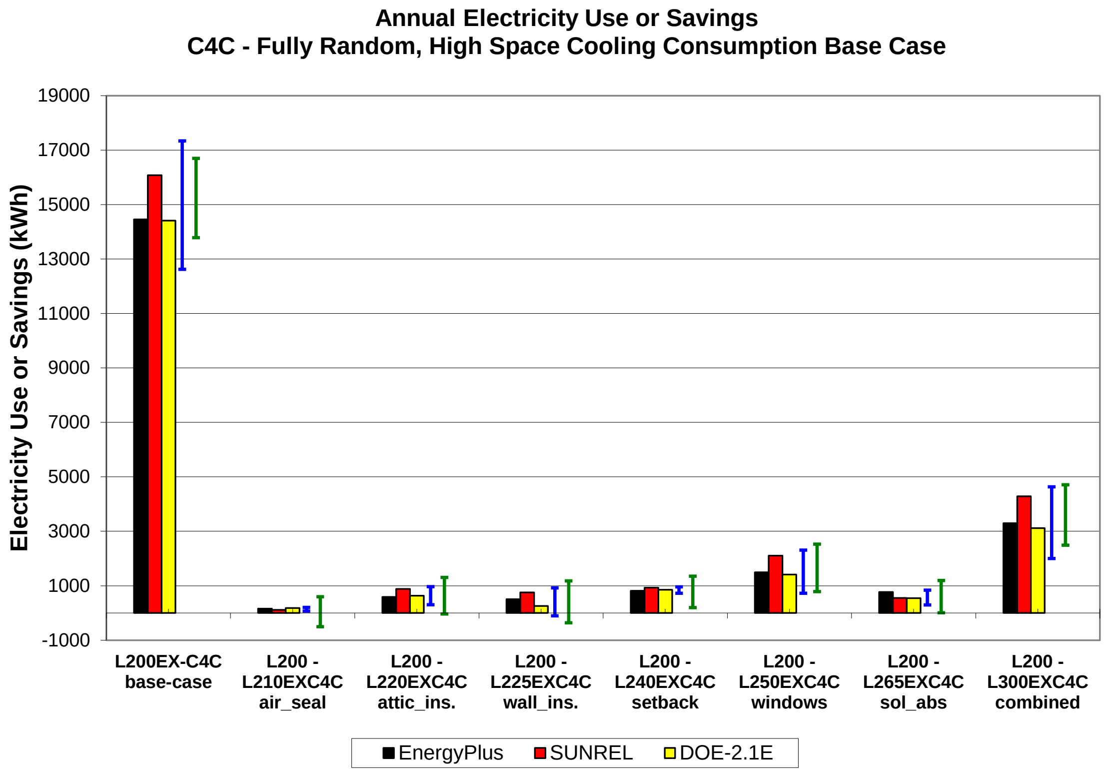

Figure 11. Calibration tests, scenario C4C: reference simulation results and acceptance criteria

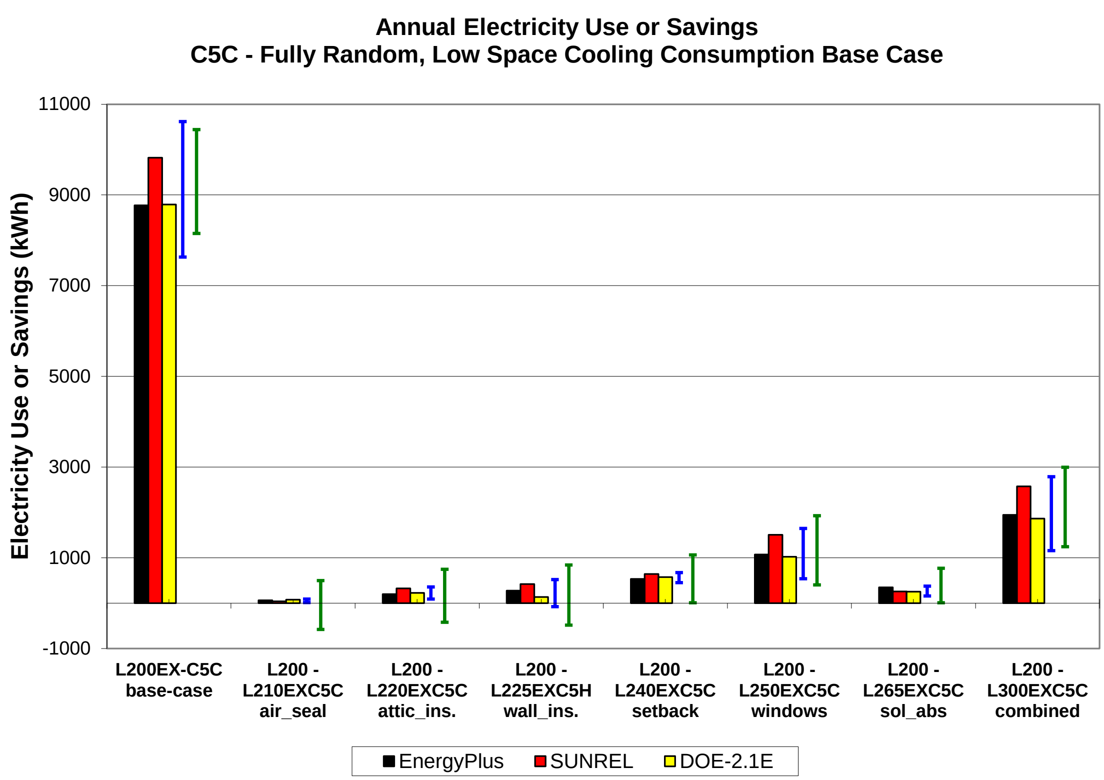

Figure 12. Calibration tests, scenario C5C: reference simulation results and acceptance criteria

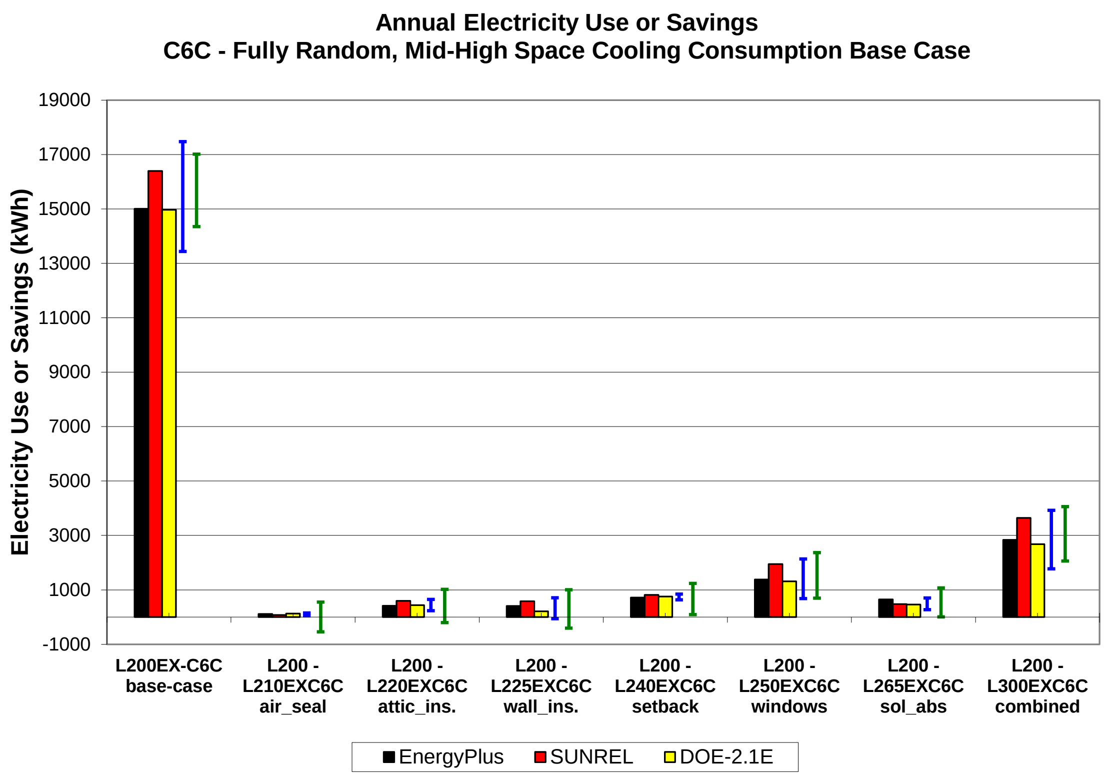

Figure 13. Calibration tests, scenario C6C: reference simulation results and acceptance criteria

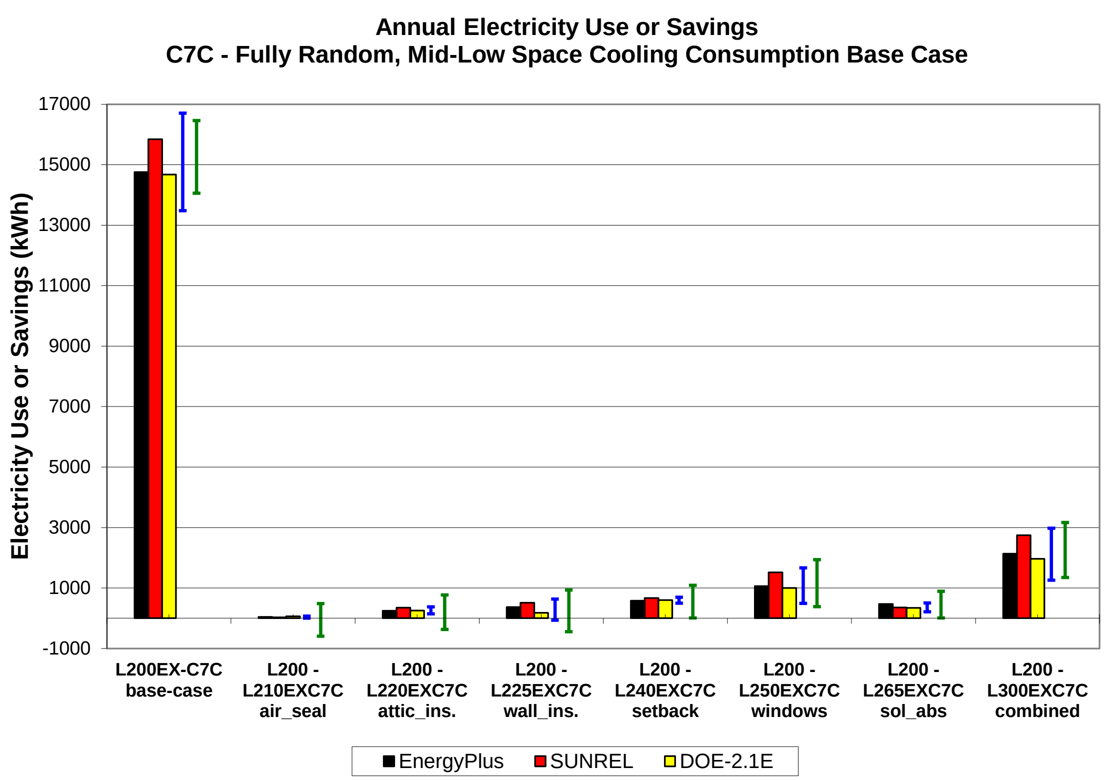

Figure 14. Calibration tests, scenario C7C: reference simulation results and acceptance criteria

Table 1. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C1H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C1H base-case	149.47	168.00	149.01	155.49	182.40	128.58	173.72	143.29	**182.40**	**128.58**
L200 - L210EXC1H air_seal	20.28	18.93	18.15	19.12	20.94	16.45	24.16	12.43	**24.16**	**12.43**
L200 - L220EXC1H attic_ins.	30.82	33.27	30.47	31.52	34.09	27.74	37.15	24.75	**37.15**	**24.75**
L200 - L225EXC1H wall_ins.	21.99	29.27	21.18	24.14	31.65	13.08	33.15	15.45	**33.15**	**13.08**
L200 - L240EXC1H setback	14.07	14.74	13.51	14.11	15.15	12.57	18.63	7.78	**18.63**	**7.78**
L200 - L250EXC1H windows	12.29	20.28	10.83	14.47	23.04	1.83	24.16	5.11	**24.16**	**1.83**
L200 - L300EXC1H combined	91.77	105.72	89.98	95.82	110.35	74.42	109.60	84.26	**110.35**	**74.42**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! AB266:AL277 7/13/2011

Table 2. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C2H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C2H base-case	91.28	102.34	91.54	95.06	110.74	79.38	108.07	85.56	**110.74**	**79.38**
L200 - L210EXC2H air_seal	12.96	12.16	11.54	12.22	13.41	10.46	16.84	5.82	**16.84**	**5.82**
L200 - L220EXC2H attic_ins.	9.03	9.94	9.03	9.33	10.22	8.03	13.83	3.31	**13.83**	**3.31**
L200 - L225EXC2H wall_ins.	14.19	18.38	14.06	15.54	19.69	9.44	22.26	8.33	**22.26**	**8.33**
L200 - L240EXC2H setback	7.82	8.10	7.54	7.82	8.29	7.12	11.98	1.81	**11.98**	**1.81**
L200 - L250EXC2H windows	8.44	13.40	7.92	9.92	15.02	2.41	17.28	2.20	**17.28**	**2.20**
L200 - L300EXC2H combined	48.02	56.35	47.35	50.57	59.03	38.11	60.23	41.62	**60.23**	**38.11**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! AS266:BC277 7/13/2011

Table 3. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C3H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C3H base-case	122.34	137.85	123.06	127.75	149.50	106.00	143.57	116.61	**149.50**	**106.00**
L200 - L210EXC3H air_seal	18.36	16.85	16.41	17.21	18.93	14.67	22.24	10.69	**22.24**	**10.69**
L200 - L220EXC3H attic_ins.	16.74	18.57	16.99	17.43	19.10	14.97	22.45	11.02	**22.45**	**11.02**
L200 - L225EXC3H wall_ins.	15.77	20.89	15.51	17.39	22.50	9.86	24.77	9.79	**24.77**	**9.79**
L200 - L240EXC3H setback	10.23	10.57	9.85	10.22	10.83	9.32	14.45	4.13	**14.45**	**4.13**
L200 - L250EXC3H windows	11.79	18.47	10.74	13.66	20.74	3.25	22.35	5.01	**22.35**	**3.25**
L200 - L300EXC3H combined	67.38	78.22	66.34	70.65	81.74	54.30	82.11	60.61	**82.11**	**54.30**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! BJ266:BT277 7/13/2011

Table 4. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C4H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C4H base-case	152.72	171.44	152.55	158.90	185.87	131.93	177.16	146.83	**185.87**	**131.93**
L200 - L210EXC4H air_seal	19.49	18.20	17.46	18.39	20.12	15.83	23.38	11.74	**23.38**	**11.74**
L200 - L220EXC4H attic_ins.	28.62	31.07	28.33	29.34	31.88	25.60	34.95	22.61	**34.95**	**22.61**
L200 - L225EXC4H wall_ins.	22.08	29.53	21.19	24.26	31.98	12.88	33.41	15.46	**33.41**	**12.88**
L200 - L240EXC4H setback	13.44	14.19	12.90	13.51	14.60	11.91	18.07	7.18	**18.07**	**7.18**
L200 - L250EXC4H windows	11.95	19.60	10.47	14.01	22.27	1.83	23.48	4.74	**23.48**	**1.83**
L200 - L300EXC4H combined	87.99	102.05	86.30	92.11	106.69	70.64	105.93	80.57	**106.69**	**70.64**

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Table 5. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C5H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C5H base-case	87.80	98.59	88.69	91.69	106.57	76.82	104.31	82.08	**106.57**	**76.82**
L200 - L210EXC5H air_seal	12.27	11.85	10.97	11.69	12.82	10.04	16.15	5.24	**16.15**	**5.24**
L200 - L220EXC5H attic_ins.	10.38	11.24	10.38	10.67	11.51	9.43	15.13	4.66	**15.13**	**4.66**
L200 - L225EXC5H wall_ins.	12.93	16.54	12.99	14.15	17.64	9.01	20.43	7.21	**20.43**	**7.21**
L200 - L240EXC5H setback	8.11	8.62	8.12	8.28	8.77	7.56	12.50	2.39	**12.50**	**2.39**
L200 - L250EXC5H windows	7.76	12.76	7.50	9.34	14.34	1.97	16.64	1.77	**16.64**	**1.77**
L200 - L300EXC5H combined	46.31	54.45	46.24	49.00	56.95	37.27	58.33	40.51	**58.33**	**37.27**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! CR266:DB277 7/13/2011

Table 6. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C6H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C6H base-case	129.78	146.57	129.86	135.40	159.42	111.38	152.29	124.05	**159.42**	**111.38**
L200 - L210EXC6H air_seal	20.31	18.68	18.16	19.05	20.93	16.27	24.19	12.44	**24.19**	**12.44**
L200 - L220EXC6H attic_ins.	13.89	15.41	14.01	14.44	15.86	12.34	19.30	8.17	**19.30**	**8.17**
L200 - L225EXC6H wall_ins.	21.30	27.71	20.88	23.30	29.76	13.78	31.60	15.16	**31.60**	**13.78**
L200 - L240EXC6H setback	11.57	12.00	11.13	11.56	12.30	10.48	15.88	5.40	**15.88**	**5.40**
L200 - L250EXC6H windows	12.94	20.26	11.76	14.99	22.75	3.55	24.15	6.04	**24.15**	**3.55**
L200 - L300EXC6H combined	73.81	86.09	72.32	77.41	90.15	58.63	89.98	66.60	**90.15**	**58.63**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! DI266:DS277 7/13/2011

Table 7. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C7H

Total Annual Gas Consumption and Savings (million Btu/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C7H base-case	99.42	112.22	99.88	103.84	121.87	85.80	117.94	93.69	**121.87**	**85.80**
L200 - L210EXC7H air_seal	15.56	14.70	13.92	14.72	16.11	12.69	19.44	8.19	**19.44**	**8.19**
L200 - L220EXC7H attic_ins.	9.77	10.74	9.82	10.11	11.03	8.76	14.62	4.05	**14.62**	**4.05**
L200 - L225EXC7H wall_ins.	17.25	22.14	17.20	18.86	23.65	11.80	26.03	11.47	**26.03**	**11.47**
L200 - L240EXC7H setback	9.76	10.24	9.65	9.88	10.42	9.10	14.13	3.93	**14.13**	**3.93**
L200 - L250EXC7H windows	10.10	15.94	9.48	11.84	17.85	2.99	19.82	3.76	**19.82**	**2.99**
L200 - L300EXC7H combined	56.44	66.22	55.95	59.53	69.30	45.14	70.10	50.23	**70.10**	**45.14**

B-EX-Phase-1-Ref-C-Results+Example-Acceptance-Criteria.xls: GasHtgData! DZ266:EJ277 7/13/2011

Table 8. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C1C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C1C base-case	14989	16649	14952	15530	17938	13123	17270	14331	**17938**	**13123**
L200 - L210EXC1C air_seal	168	121	188	159	216	74	609	-499	**609**	**-499**
L200 - L220EXC1C attic_ins.	421	677	476	525	752	190	1098	-200	**1098**	**-200**
L200 - L225EXC1C wall_ins.	474	734	234	480	902	-141	1155	-387	**1155**	**-387**
L200 - L240EXC1C setback	804	907	833	848	938	716	1328	183	**1328**	**183**
L200 - L250EXC1C windows	1536	2163	1442	1714	2375	739	2584	821	**2584**	**739**
L200 - L265EXC1C sol_abs	604	432	426	487	658	236	1025	>0	**1025**	**>0**
L200 - L300EXC1C combined	3140	4128	2962	3410	4469	1849	4550	2341	**4550**	**1849**

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Table 9. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C2C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C2C base-case	9257	10397	9135	9596	11326	7866	11018	8514	**11326**	**7866**
L200 - L210EXC2C air_seal	124	92	141	119	161	57	563	-528	**563**	**-528**
L200 - L220EXC2C attic_ins.	476	621	464	520	667	303	1042	-157	**1042**	**-157**
L200 - L225EXC2C wall_ins.	542	708	334	528	843	63	1129	-287	**1129**	**-287**
L200 - L240EXC2C setback	646	734	669	683	759	570	1155	25	**1155**	**25**
L200 - L250EXC2C windows	1263	1773	1185	1407	1946	613	2194	564	**2194**	**564**
L200 - L265EXC2C sol_abs	687	508	492	562	745	293	1109	>0	**1109**	**>0**
L200 - L300EXC2C combined	2919	3601	2698	3073	3866	1904	4022	2077	**4022**	**1904**

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Table 10. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C3C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C3C base-case	11969	13184	11892	12348	14150	10547	13805	11271	**14150**	**10547**
L200 - L210EXC3C air_seal	145	109	159	138	181	73	580	-512	**580**	**-512**
L200 - L220EXC3C attic_ins.	526	736	538	600	799	307	1157	-94	**1157**	**-94**
L200 - L225EXC3C wall_ins.	422	608	239	423	734	-36	1029	-382	**1029**	**-382**
L200 - L240EXC3C setback	602	673	616	630	694	536	1095	>0	**1095**	**>0**
L200 - L250EXC3C windows	1141	1622	1077	1280	1782	540	2043	457	**2043**	**457**
L200 - L265EXC3C sol_abs	667	476	464	536	727	253	1088	>0	**1088**	**>0**
L200 - L300EXC3C combined	2696	3432	2518	2882	3699	1678	3853	1897	**3853**	**1678**

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Table 11. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C4C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C4C base-case	14455	16075	14407	14979	17338	12620	16696	13786	**17338**	**12620**
L200 - L210EXC4C air_seal	160	116	178	151	206	71	600	-505	**600**	**-505**
L200 - L220EXC4C attic_ins.	588	883	632	701	969	305	1304	-33	**1304**	**-33**
L200 - L225EXC4C wall_ins.	506	754	259	506	923	-108	1175	-362	**1175**	**-362**
L200 - L240EXC4C setback	819	927	851	866	959	728	1348	198	**1348**	**198**
L200 - L250EXC4C windows	1492	2108	1409	1670	2313	722	2529	789	**2529**	**722**
L200 - L265EXC4C sol_abs	773	551	543	622	842	299	1194	>0	**1194**	**>0**
L200 - L300EXC4C combined	3301	4288	3115	3568	4631	2002	4709	2494	**4709**	**2002**

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Table 12. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C5C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C5C base-case	8770	9820	8787	9126	10620	7631	10441	8149	**10620**	**7631**
L200 - L210EXC5C air_seal	61	39	76	59	89	13	497	-581	**497**	**-581**
L200 - L220EXC5C attic_ins.	200	323	225	249	359	88	744	-421	**744**	**-421**
L200 - L225EXC5H wall_ins.	276	420	133	276	518	-80	841	-488	**841**	**-488**
L200 - L240EXC5C setback	534	640	573	582	672	450	1061	>0	**1061**	**>0**
L200 - L250EXC5C windows	1071	1505	1021	1199	1647	539	1926	401	**1926**	**401**
L200 - L265EXC5C sol_abs	346	258	254	286	374	156	768	>0	**768**	**>0**
L200 - L300EXC5C combined	1943	2575	1863	2127	2785	1158	2997	1242	**2997**	**1158**

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Table 13. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C6C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C6C base-case	15004	16395	14971	15457	17476	13438	17016	14351	**17476**	**13438**
L200 - L210EXC6C air_seal	112	80	132	108	152	43	553	-541	**553**	**-541**
L200 - L220EXC6C attic_ins.	415	599	435	483	653	232	1020	-206	**1020**	**-206**
L200 - L225EXC6C wall_ins.	405	584	216	402	712	-57	1006	-405	**1006**	**-405**
L200 - L240EXC6C setback	714	817	752	761	849	632	1238	94	**1238**	**94**
L200 - L250EXC6C windows	1378	1949	1312	1546	2136	677	2370	691	**2370**	**677**
L200 - L265EXC6C sol_abs	649	473	464	529	704	270	1070	>0	**1070**	**>0**
L200 - L300EXC6C combined	2836	3642	2681	3053	3923	1771	4063	2060	**4063**	**1771**

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Table 14. BESTEST-EX Example Range-Setting Procedure: Calibration Tests, Scenario C7C

Total Annual Electricity Consumption and Savings (kWh/y)					Statisical		Econ. Threshold		Acceptance	
				Ref	Conf. Bounds		Bounds		Range Bounds	
Case	EnergyPlus	SUNREL	DOE-2.1E	Mean	Max	Min	Max	Min	Max	Min
L200EX-C7C base-case	14759	15840	14674	15091	16705	13477	16460	14054	**16705**	**13477**
L200 - L210EXC7C air_seal	43	27	61	44	72	2	482	-593	**482**	**-593**
L200 - L220EXC7C attic_ins.	250	349	256	285	379	146	771	-371	**771**	**-371**
L200 - L225EXC7C wall_ins.	370	512	178	353	636	-63	933	-442	**933**	**-442**
L200 - L240EXC7C setback	579	671	603	618	698	499	1092	>0	**1092**	**>0**
L200 - L250EXC7C windows	1063	1517	1001	1194	1669	493	1939	380	**1939**	**380**
L200 - L265EXC7C sol_abs	471	355	343	389	509	214	892	>0	**892**	**>0**
L200 - L300EXC7C combined	2135	2746	1965	2282	2975	1261	3167	1344	**3167**	**1261**

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3 Randomly Selected Explicit Inputs

Explicit inputs used in the reference simulations are provided in Tables 3-1 and 3-2 for the space heating and space cooling cases, respectively. In these tables the *explicit inputs* for each calibration scenario are provided in the column headed by the name of the given calibration scenario (e.g., “C1H”). The *approximate input range* from which the *explicit inputs* were randomly selected is described in the group of columns headed by “Approx. Input Range”. Information about how the *explicit inputs* are applied in the test procedure and about how they are randomly selected from within the *approximate input ranges* is given in Judkoff et al. (2010a), Section 1 and Appendix F, respectively. Abbreviations used in both tables are included with the Nomenclature (see the front matter of this document).

In Tables 3-1 and 3-2 related groups of inputs are separated by solid lines; dashed/lighter lines separate relevant inputs within a group. Italicized values in Tables 3-1 and 3-2 are equivalent or supplemental *approximate input range* minimum, maximum and nominal values and *explicit input* values, which are calculated based on primary *approximate input range* minimum, maximum and nominal values and randomly selected *explicit input* values (shown in the tables with normal font). For example, for each calibration scenario, siding thickness *explicit inputs* are provided that supplement the randomly selected exterior wall R-values, and these values are within the corresponding listed external siding *approximate input range* minimum and maximum values. An example of the relationship between the external siding thickness and the exterior wall R-value is shown in Judkoff et al. (2010a), Table 1-4.

Table 15. Explicit Inputs for Utility Bill Calibration Tests with Space Heating

HEATING	Explicit Inputs for the Calibration Scenarios[a,b]							Approx. Input Range[a,b]		
Approximate Input	C1H	C2H	C3H	C4H	C5H	C6H	C7H	Min	Nom	Max
Exterior Wall R-Value ($h \cdot ft^2 \cdot °F/Btu$)	5.078	5.141	5.848	4.892	5.495	5.209	5.185	4.500	5.091	6.200
Siding Thickness (in.) [c]	*0.4293*	*0.4686*	*0.9132*	*0.3129*	*0.6908*	*0.5111*	*0.4960*	*0.0685*	*0.4400*	*1.1355*
Attic R-Value ($h \cdot ft^2 \cdot °F/Btu$)	8.511	15.489	12.125	8.699	14.056	15.308	16.933	7.100	13.673	19.300
Fiberglass Batt Thickness (in.)	*1.6487*	*4.1563*	*2.9422*	*1.7155*	*3.6381*	*4.0909*	*4.6794*	*1.1490*	*3.5000*	*5.5450*
Joist Thickness (in.) [d]	*1.6487*	*4.1563*	*2.9422*	*1.7155*	*3.6381*	*4.0909*	*4.6794*	*1.1490*	*3.5000*	*5.5000*
Effective Leakage Area at 4 Pa (in^2)	*207.73*	*195.98*	*177.55*	*197.13*	*195.13*	*188.32*	*207.55*	*137.39*	*196.27*	*215.89*
Equivalent CFM at 50 Pa (see Judkoff et al. [2010a], Table 1-8a)										
Heating, Colo. Spr. (CFM)	4234	3994	3619	4018	3977	3838	4230	2800	4000	4400
Equivalent ACH (see Judkoff et al. [2010a], Table 1-8b) [e]										
Heating, Colo. Spr. (ACH)	*0.808*	*0.762*	*0.691*	*0.767*	*0.759*	*0.733*	*0.807*	*0.534*	*0.760*	*0.835*
Occupant Sensible Loads (Btu/day)	7037	11375	5208	10365	8196	10945	12628	4347	8694	13041
Electric Sensible Loads (Btu/day)	40354	66143	34129	29957	60764	44102	61779	18234	36468	80000
Non-HVAC Electricity to Internal Gains (%)	64.36	80.57	81.38	85.36	73.66	66.16	71.93	60.00	75.00	90.00
Resulting Annual Non-HVAC Electricity Use (kWh/y)	*6707*	*8782*	*4486*	*3754*	*8824*	*7131*	*9188*	*2167*	*5201*	*14263*
Gas Sensible Loads (Btu/day)	12650	15358	17194	16810	19721	13702	15584	7464	14928	22392
Non-HVAC Gas Use to Internal Gains (%)	27.51	23.40	27.48	23.06	29.72	24.23	30.72	20.00	27.50	35.00
Resulting Annual Non-HVAC Gas Use (MBtu/y)	*16.78*	*23.96*	*22.84*	*26.61*	*24.22*	*20.64*	*18.52*	*7.78*	*19.81*	*40.87*
Exterior Solar Absorptance	0.576	0.592	0.716	0.598	0.520	0.608	0.560	0.500	0.600	0.800
Heating Set Point (°F)	69.02	65.44	69.79	69.31	62.95	70.06	66.89	60.00	68.00	75.00
Season (% of total annual space conditioning load)	95.54	91.41	93.13	95.97	95.19	94.92	96.60	90.00	95.00	99.00
Space Conditioning Seasons										
Start Month	*SEP*	*OCT*	*OCT*	*SEP*	*OCT*	*OCT*	*OCT*		*OCT*	
Start Day	*24*	*29*	*13*	*22*	*25*	*7*	*9*		*7*	
End Month	*MAY*	*APR*	*MAY*	*MAY*	*MAY*	*MAY*	*MAY*		*MAY*	
End Day	*23*	*23*	*11*	*26*	*7*	*17*	*18*		*16*	
Furnace Efficiency (%)	64.51	77.08	69.92	68.27	75.52	65.40	74.22	60.00	70.00	80.00

[a] Categories of inputs are separated by solid lines; dashed/lighter lines separate relevant inputs within a group. See Judkoff et al (2010a) for details about how the inputs are applied.

[b] Italicized values indicate equivalent range values and *explicit inputs* that were calculated from basis range values and randomly selected values (shown with normal font).

[c] Wall R-value may be adjusted by varying the modeled siding thickness.

[d] Modeled joist thickness is the same as for insulation, but not greater than 5.5 inches.

[e] This input is for programs that do not use more detailed methods.

Table 16. Explicit Inputs for Utility Bill Calibration Tests with Space Cooling

	COOLING									
	Explicit Inputs for the Calibration Scenarios[a,b]							Approx. Input Range[a,b]		
Approximate Input	**C1C**	**C2C**	**C3C**	**C4C**	**C5C**	**C6C**	**C7C**	**Min**	**Nom**	**Max**
Exterior Wall R-Value (h·ft²·°F/Btu)	5.056	5.136	5.224	4.969	5.126	5.611	4.980	4.500	5.091	6.200
Siding Thickness (in.) [c]	*0.4157*	*0.4657*	*0.5209*	*0.3609*	*0.4595*	*0.7640*	*0.3681*	*0.0685*	*0.4400*	*1.1355*
Attic R-Value (h·ft²·°F/Btu)	13.294	14.500	11.076	10.840	16.828	14.346	18.363	7.100	13.673	19.300
Fiberglass Batt Thickness (in.)	*3.3633*	*3.7985*	*2.5649*	*2.4805*	*4.6412*	*3.7430*	*5.1983*	*1.1490*	*3.5000*	*5.5450*
Joist Thickness (in.) [d]	*3.3633*	*3.7985*	*2.5649*	*2.4805*	*4.6412*	*3.7430*	*5.1983*	*1.1490*	*3.5000*	*5.5000*
Effective Leakage Area at 4 Pa (in²)	*202.63*	*177.18*	*188.70*	*202.38*	*156.69*	*200.23*	*175.57*	*137.39*	*196.27*	*215.89*
Equivalent CFM at 50 Pa (see Judkoff et al. [2010a], Table 1-8a)										
Cooling, Las Vegas (CFM)	3834	3353	3571	3830	2965	3789	3322	2600	3714	4085
Equivalent ACH (see Judkoff et al. [2010a], Table 1-8b) [e]										
Cooling, Las Vegas (ACH)	*0.509*	*0.445*	*0.474*	*0.508*	*0.393*	*0.503*	*0.441*	*0.345*	*0.492*	*0.540*
Occupant Sensible Loads (Btu/day)	11557	6183	9803	11737	10158	7965	12353	4347	8694	13041
Electric Sensible Loads (Btu/day)	57952	28400	52158	50419	30702	56850	63840	18234	36468	80000
Non-HVAC Electricity to Internal Gains (%)	76.59	79.95	84.80	69.95	66.48	67.60	68.13	60.00	75.00	90.00
Resulting Annual Non-HVAC Electricity Use (kWh/y)	*8094*	*3800*	*6579*	*7710*	*4940*	*8996*	*10024*	*2167*	*5201*	*14263*
Gas Sensible Loads (Btu/day)	20877	20407	13574	19012	12866	15915	14577	7464	14928	22392
Non-HVAC Gas Use to Internal Gains (%)	32.63	23.72	27.42	27.38	29.73	24.92	26.49	20.00	27.50	35.00
Resulting Annual Non-HVAC Gas Use (MBtu/y)	*23.35*	*31.40*	*18.07*	*25.34*	*15.80*	*23.31*	*20.09*	*7.78*	*19.81*	*40.87*
Exterior Solar Absorptance	0.554	0.745	0.639	0.577	0.549	0.639	0.703	0.500	0.600	0.800
Cooling Set Point (°F)	77.11	78.44	77.20	77.07	81.88	79.84	82.63	71.00	78.00	86.00
Season (% of total annual space conditioning load)	95.35	94.13	91.60	95.97	97.52	94.20	93.43	90.00	95.00	99.00
Space Conditioning Seasons										
Start Month	*MAR*	*MAR*	*APR*	*MAR*	*MAR*	*APR*	*APR*		*MAR*	
Start Day	*20*	*26*	*3*	*15*	*29*	*2*	*6*		*28*	
End Month	*OCT*	*OCT*	*OCT*	*NOV*	*OCT*	*OCT*	*OCT*		*OCT*	
End Day	*30*	*28*	*22*	*6*	*30*	*26*	*23*		*28*	
COP	2.662	3.093	3.348	2.786	3.259	2.622	3.019	2.500	3.000	3.500

[a] Categories of inputs are separated by solid lines; dashed/lighter lines separate relevant inputs within a group. See Judkoff et al (2010a) for details about how the inputs are applied.

[b] Italicized values indicate equivalent range values and *explicit inputs* that were calculated from basis range values and randomly selected values (shown with normal font).

[c] Wall R-value may be adjusted by varying the modeled siding thickness.

[d] Modeled joist thickness is the same as for insulation, but not greater than 5.5 inches.

[e] This input is for programs that do not use more detailed methods.

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Judkoff, R.; Neymark, J.; Polly, B.; Bianchi, M. (2010b). *Example Procedures for Developing Acceptance-Range Criteria for BESTEST-EX*. NREL/TP-550-47502. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy10osti/47502.pdf.

Appendix A. Definitions

approximate input: an input for which *an approximate input range* has been defined; see listing in Judkoff et al. [2010a], Section 1.3.1.2. Also see *approximate input range.*

approximate input range: the specified range of possible values for an *approximate input* that forms the basis uncertainty range for selecting *calibrated approximate inputs* for the tested programs (see Judkoff et al. [2010a], Section 1.3.1.2), and from which *explicit inputs* are randomly selected in accordance with the process described in Judkoff et al. (2010a), Appendix F. Also see *calibrated input* and *explicit input.*

calibrated input* or *calibrated approximate input: inputs for tested programs that are determined based on specified *approximate input ranges* and *nominal input* values using calibration to obtain agreement with base-case reference utility billing data. Also see *approximate input range* and *nominal input.*

explicit input: inputs for simulations used to develop reference utility billing data that are randomly selected from within specified *approximate input ranges* according to the process described in Judkoff et al. (2010a), Appendix F. Also see *approximate input range.*

fully random**:** Calibration scenario where *explicit inputs* are selected randomly from the entire *approximate input range* (see Judkoff et al. [2010a], Appendix F). Also see *approximate input range* and *explicit input.*

nominal input: an input value as specified for the building physics base case (Case L200EX-P, see Judkoff et al. [2010a], Section 1.2.1).

targeted high**:** Calibration scenario where *explicit inputs* are selected randomly from the portion of the *approximate input range* (upper or lower) that leads to increased space conditioning consumption versus *nominal input* values (see Judkoff et al. [2010a], Appendix F). Also see *approximate input range, explicit input* and *nominal input.*

targeted low**:** Calibration scenario where *explicit inputs* are selected randomly from the portion of the *approximate input range* (upper or lower) that leads to decreased space conditioning consumption versus *nominal input* values (see Judkoff et al. [2010a], Appendix F). Also see *approximate input range, explicit input*, and *nominal input.*

Appendix B. Clarifications to Existing Documents

Clarifications to specific portions of text are indicated with underline/strikethrough. These clarifications are related to publication of calibration test results for non-blind testing and other clarifications. There are no substantive changes to the test specification. The original documents (Judkoff et al. 2010a, 2010b) have not been updated.

Test Specification (NREL/TP-550-47427) – related to going from blind to non-blind testing

Introduction, p. xiii, subparagraph: “Calibrated energy savings test cases ….”

> **Calibrated energy savings test cases with specified base-case monthly utility bill data and uncertainty ranges for selected inputs:** A given audit model (and associated calibration method) is tested by comparing utility-bill-calibrated energy savings predictions to results from the reference programs listed above. ~~Reference results for the calibrated energy-savings tests are not published with the test procedure so that both automated and manual calibration methods are tested blind, without access to the reference results (answers). Practical application of this procedure requires that tested-program results are compared to reference results by a third-party.~~ The calibrated energy savings tests represent a new methodological development, further described under “Methodology” below.

1.1.9.2, p. 2, delete 2nd paragraph

~~Reference results for the calibrated energy-savings tests are not published with the test procedure, so that both automated and manual calibration methods may be tested blind, without access to the reference results. Practical application of this procedure requires that tested-program results are compared to reference results by a third-party.~~

1.3.1.2, p. 48, last paragraph

Reference energy use data provided in Tables 1-24a through 1-24g and Tables 1-25a through 1-25g are the average of the results for the reference simulation models using EnergyPlus, SUNREL, and DOE-2.1E. The reference simulations apply *explicit inputs* randomly selected from within the given *approximate input ranges* (see Appendix F). All reference simulation *explicit inputs* are selected independently for each space-heating and space-cooling base-case scenario, except heating thermostat settings/schedule and furnace efficiency are only selected for space heating cases, and cooling thermostat settings/schedule and cooling COP are only selected for space cooling cases. For the purpose of running the calibration tests, ~~T~~the reference simulation *explicit inputs* are ~~intended to be unknown for the software being tested and are~~ not given in the test specification. The reference simulation *explicit inputs* are included with the calibration test results in a separate document [editor’s note: see Section 3 of this document]. To properly implement the test procedure, do not compare tested program *calibrated inputs* with reference simulation *explicit inputs* until after modeling the calibration tests, i.e., run the test cases as if the reference simulation *explicit inputs* are unknown. Thirteen months of base-case energy use data are provided as recommended by the BESTEST-EX Working Group (2009). In Tables 1-24a through 1-24g and Tables 1-25a through 1-25g, gas use is for the furnace and DHW only; electricity use is for space cooling equipment and all other appliances (except DHW); and HVAC fan electricity is zero, as specified in Section 1.2.1.15.

References, p. 64.

Judkoff, R.; Neymark, J.; Polly, B.; Bianchi, M. (2010). *Example Procedures for Developing Acceptance Range Criteria for BESTEST-EX*. NREL/TP-550-47502~~47542~~. Golden, CO: National Renewable Energy Laboratory.

Appendix F, p. 101, 3rd paragraph, delete last sentence.

~~*All explicit inputs and the calculated values for dependent inputs are not known by the participants testing software.*~~

Appendix G, Section G.1, p. 104, last paragraph

Only the results for the "-P" test cases are shown in the figures and the tables. ~~For the calibrated energy savings ("-C") test cases, reference simulation results and randomly selected explicit inputs used in the reference simulations are intentionally not given for blind testing.~~

I.3.2, p. 123, delete 1st bullet

- ~~Consider developing a version of the procedure for testing programs with automated calibration; such a version would have calibrated savings results available so that results would not have to be reviewed by a third party.~~

Physics Results and Example Acceptance Criteria (NREL/TP-550-47502) – related to going from blind to non-blind testing

Section 2, pp. 1-2

Within BESTEST-EX the building physics ("-P") cases are specified differently than the calibrated energy savings ("-C") cases. The "-P" cases provide explicit inputs for all cases. The "-C" cases provide approximate input ranges for key inputs to account for uncertainty associated with audit information and measurements, occupant behavior, etc. For the "-C" cases, explicit inputs are randomly selected within the approximate input ranges to generate utility bills using the reference simulation programs; tested software tools are allowed to apply calibration given the reference utility billing data and approximate input ranges ~~(selected explicit inputs used for the reference simulations remain hidden to allow for blind testing)~~. Because the "-C" cases apply approximate input ranges (known uncertainty) for selected inputs, and because some base-case scenarios (see Judkoff et al. 2010, Section 1.3.1.2) can have randomly selected reference explicit inputs that are more difficult to estimate from calibration than others, the acceptance criteria for the "-C" cases should be less strict than that for the "-P" cases. Therefore, the following example acceptance criteria are provided:

- "-P" case acceptance
  - Programs must **pass all** designated cases
    - "-P" reference results are provided with the test procedure
  - Compare all energy savings case results
  - Compare annual usage only for the base case (L200EX-P)
- "-C" case acceptance
  - Programs must **pass a reasonable fraction (example: 80%)** of the designated cases
  - "-C" energy savings reference results are ~~not~~ provided. ~~with the test procedure.~~ [Editor's note: See Section 2 of this document.]

- Compare all energy savings case results only
    - Base-case annual usage results are calibrated to reference bills.

Section 5, p. 6, last paragraph

~~Only t~~The results and acceptance ranges for the building physics ("-P") test cases are shown in the figures and the tables. For the calibrati on~~ed energy savings~~ ("-C") test cases, reference simulation results and randomly selected explicit inputs used in the reference simulations are~~ intentionally not given for blind testing~~ provided. [Editor's note: See Sections 2 and 3 of this document.]

Test Specification (NREL/TP-550-47427) – related to BESTEST-EX Methodology

Introduction, pp. xiv, xv:

The building physics test cases described in the preceding section are a direct application of software-to-software comparative test methods. The calibrated energy savings tests required NREL to make a methodological advancement to existing comparative test methods, as follows.

1. **Introduce input uncertainty into the test specification (this represents uncertainty associated with developing inputs from audit survey data):**
    a. Perform sensitivity tests on inputs with potentially high uncertainty to determine their relative effect on outputs; select the inputs that have the greatest effect on outputs as *approximate inputs*.
    b. Specify uncertainty ranges (*approximate input ranges*) for ~~the~~ each *approximate input*~~s~~.
2. **Develop reference simulation results (this is done by the test developers):**
    a. Generate base-case synthetic utility bill data using the same state-of-the-art reference simulation programs ~~as~~ used in the building physics test cases.
        i. For the reference simulations, inputs that are randomly selected from within the specified *approximate input ranges* are designated as *explicit inputs*.~~; the reference simulation explicit inputs are not included in the test specification (kept secret)~~
        ii. All reference simulations use the same or equivalent *explicit inputs* for a given calibration scenario.
        iii. The synthetic utility bill data are taken as the average of the reference simulation results.
    b. Generate reference energy savings results by adjusting appropriate base-case inputs (including *explicit inputs*) as specified for each retrofit case.
3. **Develop tested program results (this is done by the test takers):**
    a. Develop the preliminary non-calibrated base-case model for a given calibration scenario.
    b. Predict energy savings~~ by either:~~ via one of the following:
        i. Calibrate~~ing~~ the base-case model inputs using the synthetic utility bills (described in 2a~~ above~~), ~~and~~ then apply~~ing~~ the specified retrofit cases to the calibrated model.~~, or~~

ii. Apply~~ing~~ the specified retrofit to the ~~non-~~uncalibrated base-case model and then calibrate~~ing~~ or correct~~ing~~ energy savings predictions using the synthetic utility bills (without adjustment to base-case model inputs)~~, or~~ e.g., as (calibrated savings) = (predicted savings) × (base-case actual bills)/(base-case predicted bills).

iii. Other calibration methods. The test cases make no recommendation about how to perform calibrations.

4. **Compare results of tested programs (and their calibration techniques) versus reference simulation base-case usage and retrofit energy savings projections:**

   a. Example acceptance criteria (Judkoff et al. 2010b) may be used to facilitate the comparison.

The conceptual framework for this method was first proposed by Judkoff (2008) with important refinements contributed by others (Neymark and Norton 2009; Neymark et al. 2009). Development of the method was facilitated by convening a technical committee of software producers (the "BESTEST-EX Working Group") to ~~provide~~ help ~~with quantifying~~ estimate approximate input ranges and develop~~ing~~ tested program results (see Step 1b and Step 3~~, respectively, above~~). The test procedure and example acceptance range criteria ~~was~~ were developed in an iterative process that allowed improvement of the test specification during the simulation trials and helped simulation trial participants to improve their software.

5. **Performing Calibration Tests Without Using Reference Programs**

In its purest form, the calibration test would be implemented without using the reference simulation programs. Instead, synthetic utility billing data would be generated with the tested program itself. Such a pure calibration test requires a) automated calibration or b) that the modeler running the calibration test does not know the explicit inputs used to develop the synthetic utility bills~~, implying that an additional modeler is needed, and there is a "firewall" between the two modelers~~. Either method is acceptable, but the latter is impractical for certifying entities.

One process for self-testing a calibration method applied for a given program is described below (this can be done in a number of ways, as long as the modeler does not know the explicit inputs used to generate synthetic utility bills for any given case):

- ***Develop uncalibrated results***
  - Develop an uncalibrated base-case model using *nominal input* values listed in Judkoff et al. (2010a), Appendix F, Table F-1.
    - Equivalent and supplemental *nominal inputs* related to these values are provided in the tables of Judkoff et al. (2010a), Section 1.2.1. [Editor's note: Also see Section 3 of this document.]
  - Apply specified inputs for retrofit measures to the uncalibrated base-case model to obtain uncalibrated energy savings results.
- ***Develop reference base-case utility billing data***
  - Randomly select *explicit inputs* from within the given *approximate input ranges*, as described in Judkoff et al. (2010a), Appendix F. Replace the nominal inputs in the uncalibrated base-case model with the randomly selected *explicit inputs* to create a reference base-case model for the calibration scenario.
    - In the original work, the randomly selected space conditioning season (% of total annual space conditioning load) was converted to equivalent start and end dates

by A) running an initial full-year annual simulation using the randomly selected *explicit inputs* for a given scenario and then B) analyzing the annual output to determine the start and end dates that would evenly crop the season to the randomly selected percentage. For example, if a 95% heating season was chosen, the date at which 2.5% of the annual heating load was reached was used as the start date, while the date at which 97.5% of the annual heating load was reached was used as the end date. This process can be implemented in self-testing, or as a simplification, annual simulations can be conducted and the annual space conditioning results can be multiplied by the season percentage expressed as a fraction (e.g., 0.95 corresponds to 95% season).

  - Repeat the above step to create multiple calibration scenarios (each having its own reference base-case model) such that randomly selected *explicit inputs* are difficult to recall without looking at the input files. That is, adhere to the principle that the person implementing the calibration tests does not know, or cannot recall, the explicit inputs associated with each test case (i.e., be self-blinded).
    - For programs with purely automated calibration methods, self-blinding is not necessary and the process of Appendix F may be followed as described.
  - Run each reference base-case model and extract reference utility billing data from the output files for each scenario.
    - Do not review input data that are included with the output.

- ***Develop reference energy savings results***
  - For each selected calibration scenario, develop reference energy savings results by applying specified inputs for the retrofit measures to the reference base-case models containing randomly selected *explicit inputs.*

- ***Develop calibrated base-case and energy savings results***
  - For each selected calibration scenario, develop calibrated base-case models beginning with *nominal inputs* (i.e., using the uncalibrated base-case input file), and calibrate that model (i.e., develop *calibrated inputs*) to the reference base-case utility billing data for the selected scenario.
  - Apply specified inputs for retrofit measures to the calibrated base-case model to obtain calibrated energy savings results.
  - The above two bullets demonstrate one of multiple ways that utility data may be used for calibration. Another possible use of utility data is to calibrate energy savings directly. For example, this may be accomplished by applying the specified retrofit to the uncalibrated base-case model and then revising energy savings predictions using the synthetic utility bills (without adjustment to the base-case model inputs). For example, as (calibrated savings) = (predicted savings) × (base-case actual bills)/(base-case predicted bills).

- ***For each calibration scenario compare calibrated model energy savings results and calibrated base-case inputs to reference energy savings results and reference base-case explicit inputs.***
  - The benefit of calibration for the self-tested program may be estimated by comparing energy savings predictions of the calibrated models versus the uncalibrated models versus the reference results. This is analogous to comparing "WG-CAL", "WG-UNCAL", and "REF" in Judkoff et al. (2010a), Appendix G, Section G.2.

- A software developer cannot apply the example acceptance criteria of Judkoff et al. (2010b) for their new calibration scenarios for only one set of reference program results.