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Example Procedures for Developing Acceptance-Range Criteria for BESTEST-EX

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National Renewable Energy Laboratory

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Technical Report
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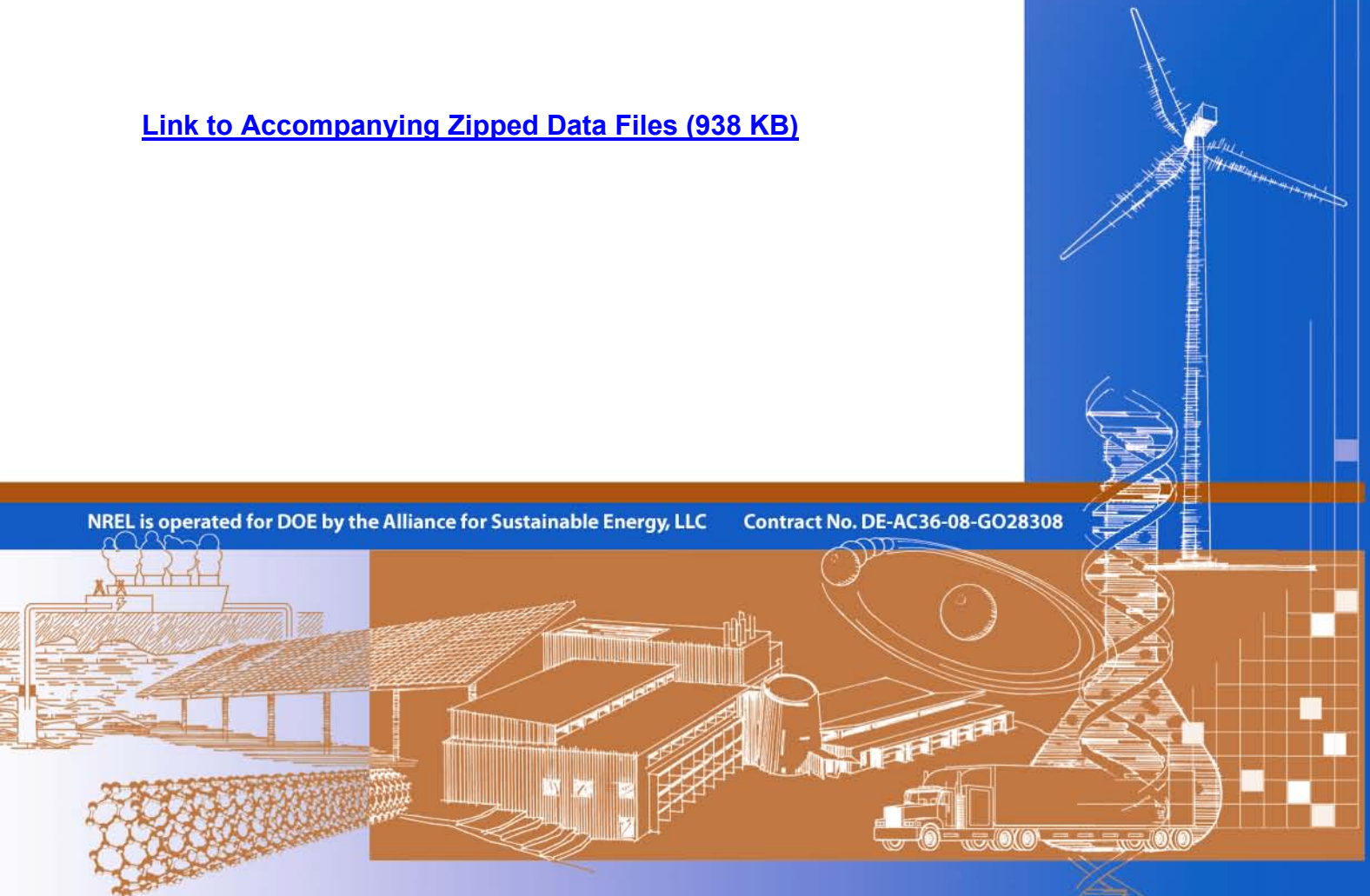

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Prepared under Task No. ARRB.1000

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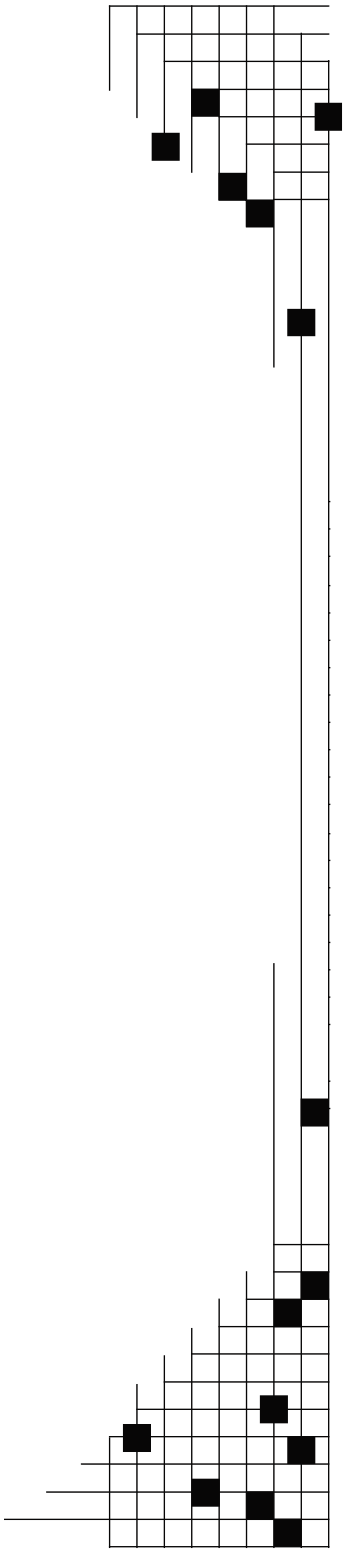

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Nomenclature

Avg.	average
BESTEST	Building Energy Simulation Test
Conf	confidence interval
DOE	U.S. Department of Energy
DOE-2.1E	DOE-2.1E version JJ Hirsch PC 2.1En136
E+	EnergyPlus version 3.1
EIA	Energy Information Administration
HERS	Home Energy Rating System
Ins.	insulation
Max	maximum
Min	minimum
NREL	National Renewable Energy Laboratory
Ref	reference simulation result
sol_abs	solar absorptance
Sqrt	square root
Stdv	standard deviation (“N−1” [sample] type)
SUNREL	SUNREL version 1.14
“-C”	calibrated energy savings test cases
“-P”	building physics test cases

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Accompanying Files (Electronic Media Contents)

*The following file **provided within B-EX-Phase-1-Ref-P-Results+Example-acceptance-criteria.zip** applies as it is called out in this document:*

B-EX-Phase-1-Ref-P-Results+Example-Acceptance-Criteria.xls: Spreadsheet that contains reference simulation results presented in Judkoff et al. 2010, Appendix G. The example acceptance criteria presented in this document are applied to the physics results in the accompanying spreadsheet.

Introduction

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 criteria in a certification program.

This document provides an example procedure for establishing acceptance-range criteria to assess results from software undergoing BESTEST-EX (Judkoff et al. 2010). This example method for BESTEST-EX is a modified version of the method described in HERS BESTEST (Judkoff and Neymark 1995).

1 Establishing Acceptance Ranges

In choosing algorithms for determining acceptance ranges, it is important to consider the following:

1. Establishing a buffer range around reference results is desirable for the following reasons:
    - Minor differences have minor energy cost impacts; therefore, a result just outside the range of reference results should be acceptable.
    - Where confidence interval ranges are very narrow, it is advisable to have alternative "economic threshold" buffer zone range expansion criteria so software is not eliminated because of relatively insignificant differences in energy consumption or energy costs.
    - Allow some bias for cautious (conservative) energy savings predictions, but limit the allowed overprediction of energy savings.
2. The use of statistical confidence intervals (Spiegel 1961) provides a theoretical basis for developing acceptance ranges. The 95% confidence level was chosen for the example presented here because a 97.5% confidence interval would widen the acceptance range to a point where the test cases lack meaning (are too easy to pass). In HERS BESTEST it was determined empirically that for most cases, confidence coefficients corresponding to confidence intervals in the range of 80%–95% yield reasonable acceptance ranges.
3. Where reference results are very close together, such that the confidence interval maximum or minimum values could fall very close to the reference results maximum or minimum values, a value of $6/month (about 5% of annual heating consumption and 10% of annual cooling consumption for the building physics base case [L200EX-P]) is applied to the range. This results in range expansion values of ± 5.72 million Btu/yr and ± 621 kWh/yr assuming $12.58/million Btu and $0.116/kWh average 2006–2008 residential retail (delivered) heating season gas and cooling season electricity prices, respectively (EIA 2009a, 2009b). These values are taken as a reasonable threshold of economic uncertainty. That is, any software disagreements within ± 5.72 million Btu or ± 621 kWh of the reference results extremes for a given case, including difference (or "delta") cases, would result in relatively insignificant utility cost disagreements and therefore should not be cause for eliminating a given software tool, even if it falls outside confidence limits based on the chosen confidence interval. Depending on fuel prices, climate, mortgage lending policies, and other circumstances in specific regions, it may make sense to adjust these criteria.
4. To limit allowed overprediction of energy savings, the confidence interval and economic threshold criteria for extending the maximum range are reduced to 90%, and 3.88 million Btu/yr or 421 kWh/yr, respectively. This is discussed further in the development of the acceptance range setting equations (see Section 3).
5. Some cases may deserve stricter acceptance criteria than would be generated using the range setting procedure described above. A possible example would be cases with higher absolute loads or higher load differences. In these cases, where the percentage variation among reference results can be roughly consistent with those for lower load cases, the higher values may produce an unreasonably large extension of the acceptance range in terms of estimated fuel costs. Acceptance ranges may be narrowed by altering the confidence interval or the economic threshold buffer. However, the acceptance range must always include the maximum and minimum values of the reference results.

2 BESTEST-EX Acceptance Criteria Overview

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

3 Example of Procedure for Developing Acceptance Ranges

Table 1 presents example fictitious results and acceptance range limits that result from the example procedure described here. A step-by-step description of the procedures used to arrive at each element is also included. Values indicated by bold font in Table 1 are the resulting acceptance range limit values for the fictitious results set, as determined using the example range setting criteria described below. This is a modified version of the example originally presented in HERS BESTEST Volume 1, Appendix H. A notable difference between the HERS BESTEST example and that in BESTEST-EX is that the example in BESTEST-EX focuses on energy savings sensitivity (or "delta") cases; only one building physics case (L200EX-P) is examined in an annual usage ("absolute") context for developing BESTEST-EX acceptance criteria.

1. Using Reference Results 1, 2, and 3 from Table 1, determine the maximum reference result, the minimum reference result, the sample mean (average) of the reference results, and the sample standard deviation (using N−1 method) of the reference results. These quantities are shown in Table 1 as "Ref Max," "Ref Min," "Ref Mean," and "Ref Stdv," respectively.

Table 1. Example Range Criteria Using Fictitious Reference Results

Description	Case 1 (10^6 Btu)	Case 2 (10^6 Btu)	Delta Case 1 − Case 2 (10^6 Btu)
Reference Result 1	73.00	46.00	27.00
Reference Result 2	70.00	45.00	25.00
Reference Result 3	82.00	49.00	33.00
Ref Max	82.00	49.00	33.00
Ref Min	70.00	45.00	25.00
Ref Mean	75.00	46.67	28.33
Ref Stdv ("N−1" [sample] type)	6.24	2.08	4.16
Ref 95% Conf Max	**90.51**	51.84	
Ref 90% Conf Max			35.35
Ref 95% Conf Min	**59.49**	41.50	**17.99**
Ref Max + 5.72 million Btu (6.035 GJ)*	87.72	**54.72**	
Ref Max + 3.88 million Btu (4.094 GJ)			**36.88**
Ref Min − 5.72 million Btu (6.035 GJ)	64.28	**39.28**	19.28
Example Range Max	**90.51**	**54.72**	**36.88**
Example Range Min	**59.49**	**39.28**	**17.99**

* 1 million Btu = 1.055056 GJ = 0.2930711 MWh.

2. Calculate the confidence interval for the population sample mean assuming a Student's t distribution (Spiegel 1961) based on the reference results. The extremes (confidence limits) of the confidence interval for the population mean are determined from:

$$L_a = X + \frac{n(t_c)s}{\sqrt{N}} \qquad \text{(Eq. 1)}$$

$$L_b = X - \frac{(t_c)s}{\sqrt{N}} \qquad \text{(Eq. 2)}$$

Where:

L_a = maximum confidence limit for the confidence interval
L_b = minimum confidence limit for the confidence interval
X = sample mean
t_c = confidence coefficient, see below
s = sample standard deviation = SQRT{SUM[$(x_j - \text{AVG}(x_j))^2$]/($N$−1)}, for j = 1 to N
N = number of samples
n = upper limit reduction factor to limit overprediction of energy savings; n = 1 for annual usage ("absolute") results.

The confidence coefficient (t_c) is determined by the sample size and the desired confidence interval. For this example, with a sample size of three (N = 3) and a desired confidence interval of 95%:

$$t_c = 4.303 \text{ (see Table 2 for other confidence coefficients)} \quad \text{(Eq. 3)}$$

To limit allowed overprediction of energy savings, for energy savings sensitivity ("delta") results "*n*" was selected such that the upper acceptance range limit results from a 90% confidence interval. This results in an asymmetric acceptance range that implicitly allows bias for cautious (conservative) energy savings predictions. Equation 3a solves for "*n*", applying values of Table 2, as:

$$n = 2.920 / 4.303 = 0.6786 \quad \text{(Eq. 3a)}$$

Plugging values from above into Equations 1 and 2 gives:

$$L_{a95} = X + \frac{(4.303)s}{\sqrt{3}} \text{ (for "absolute" maxima)} \quad \text{(Eq. 4)}$$

$$L_{a90} = X + \frac{(0.6786)(4.303)s}{\sqrt{3}} \text{ (for "delta" maxima)} \quad \text{(Eq. 5)}$$

$$L_b = X - \frac{(4.303)s}{\sqrt{3}} \text{ (for "absolute" and "delta" minima)} \quad \text{(Eq. 6)}$$

The resulting confidence limits are shown in Table 1 as "Ref 95% Conf Max," "Ref 90% Conf Max," and "Ref 95% Conf Min."

Table 2 provides a limited set of Student's t confidence coefficients that may be used for other sample sizes and confidence intervals. Additional tables for other confidence limits and sample sizes are available in many statistics text books.

Table 2. Sample Student's t Confidence Coefficients (t_c)

Sample Size (N)	Desired Confidence Interval		
	80%	90%	95%
2	3.078	6.314	12.706
3	1.886	2.920	4.303
4	1.638	2.353	3.182
5	1.533	2.132	2.776
6	1.476	2.015	2.571
7	1.440	1.943	2.447
8	1.415	1.895	2.363

3. Similarly, calculate:

$$L_c = \text{(Ref Max)} + n \times 5.72 \text{ million Btu (6.035 GJ)} \quad \text{(Eq. 7)}$$

$$L_d = \text{(Ref Min)} - 5.72 \text{ million Btu (6.035 GJ)} \quad \text{(Eq. 8)}$$

The results of these calculations are shown in Table 1 as "Ref Max + 5.72 million Btu (6.035 GJ)" (applying $n = 1$ in Equation 7), "Ref Max + 3.88 million Btu (4.094 GJ)" (applying $n = 0.6786$ in Equation 7), and "Ref Min − 5.72 million Btu (6.035 GJ)" (applying Equation 8).

4. The example acceptance range ("Range Max," "Range Min") is then determined for the delta results by taking the maximum of "Ref 90% Conf Max" and "Ref Max + 3.88 million Btu (4.094

GJ)" as "Range Max" and the minimum of "Ref 95% Conf Min" and "Ref Min − 5.72 million Btu (6.035 GJ)" as "Range Min." Similarly, the "Range Max" for absolute results is determined by taking the maximum of "Ref 95% Conf Max" and "Ref Max + 5.72 million Btu (6.035 GJ)"; "Range Min" for the absolute results is the same as that for the delta results. Using Table 1, a software tool passes a case if its test result falls within the "Example Range Max" and "Example Range Min" for that case. In Table 1, fictitious sets of results are used, such that the confidence interval ranges and the economic threshold ranges set the range extremes for Case 1 and Case 2, respectively. It is also possible to have results where one range-setting method sets one extreme and the other range-setting method sets the other extreme, as shown in the "Delta Case 1 − Case 2" result of Table 1.

For this example, a software tool would "pass" a particular test case if its result for that test case falls within the acceptance range represented by "Example Range Max" and "Example Range Min" in the bottom portion of Table 1. Similarly, a software tool would pass a test suite if its results for all "-P" test cases and a satisfactory fraction of "-C" test cases in the given test suite fall within all acceptance ranges.

4 Additional Criteria

For the building physics test cases the above criteria allow zero and opposite sensitivities to pass some of the cases. This occurs where the sensitivity of the retrofit is relatively small. As a result of preliminary simulation trials, additional criteria were added so that zero and opposite sensitivities are not allowed to pass for the following cases:

- L260−L265EXPC (electricity consumption decrease by cool roof for the building physics tests with space cooling)
- L200−L265EXCnC (electricity consumption decrease by cool roof for the calibrated energy savings tests with space cooling)
- L200−L240EXCnC (electricity consumption decrease by thermostat "setup" for the calibrated energy savings test with space cooling).

This rule was applied for these cases only. Of the building physics cooling test case results that would allow zero and opposite sensitivities to pass before applying the additional criteria, the cool roof (Case L265EX-P) has the largest mean sensitivity among reference results. Without the additional criteria, the minimum range boundary for the "-P" thermostat setup sensitivity (versus the base case) is just above zero; however, many "-C" results for thermostat setup sensitivity would be allowed to have zero and opposite sensitivities. Other cases either had enough sensitivity so that applying the additional criteria was not necessary, or had too little sensitivity in the reference simulation results for the building physics cases to justify applying the additional criteria.

5 Acceptance Criteria as Applied to "-P" Test Cases

An example of applying this procedure to the BESTEST-EX reference results for the "-P" 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 and 2 the 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 "-P" cases are developed as shown in Tables 3 and 4. An electronic version of the calculations is provided with *B-EX-Phase-1-Ref-P-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.

Only the results and acceptance ranges for the building physics ("-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.

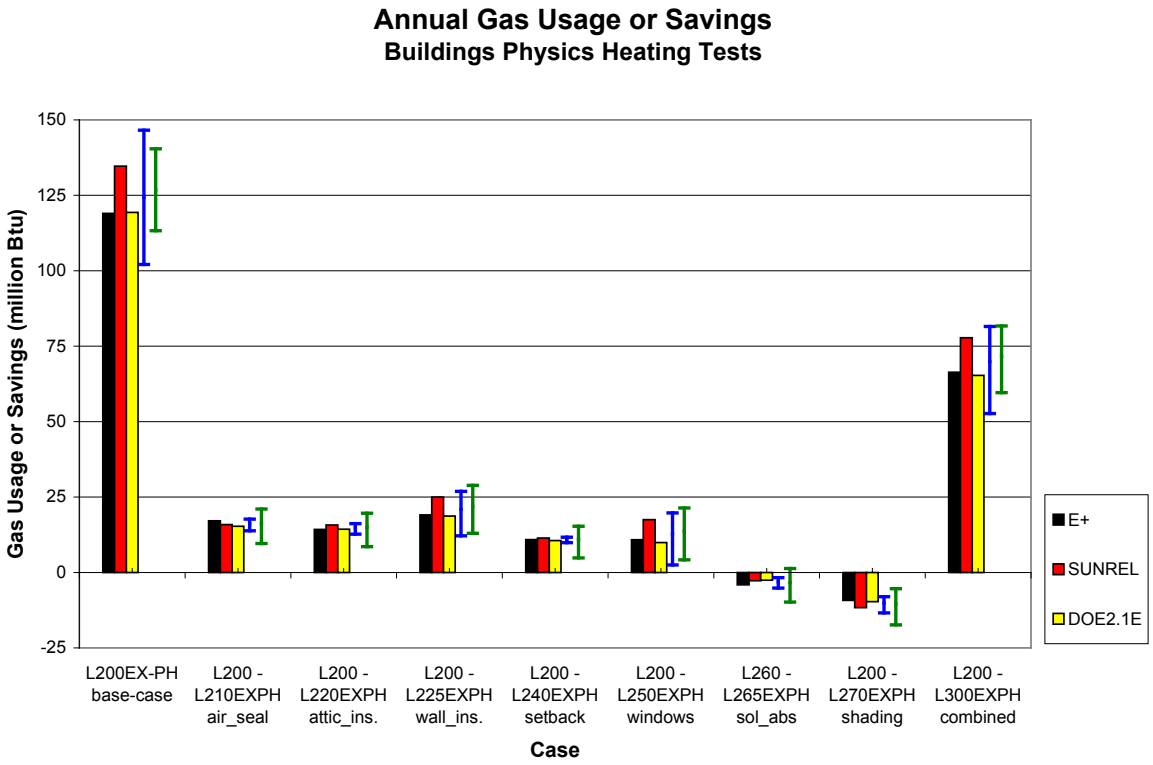

Figure 1. Building physics heating tests: Reference simulation results and acceptance criteria

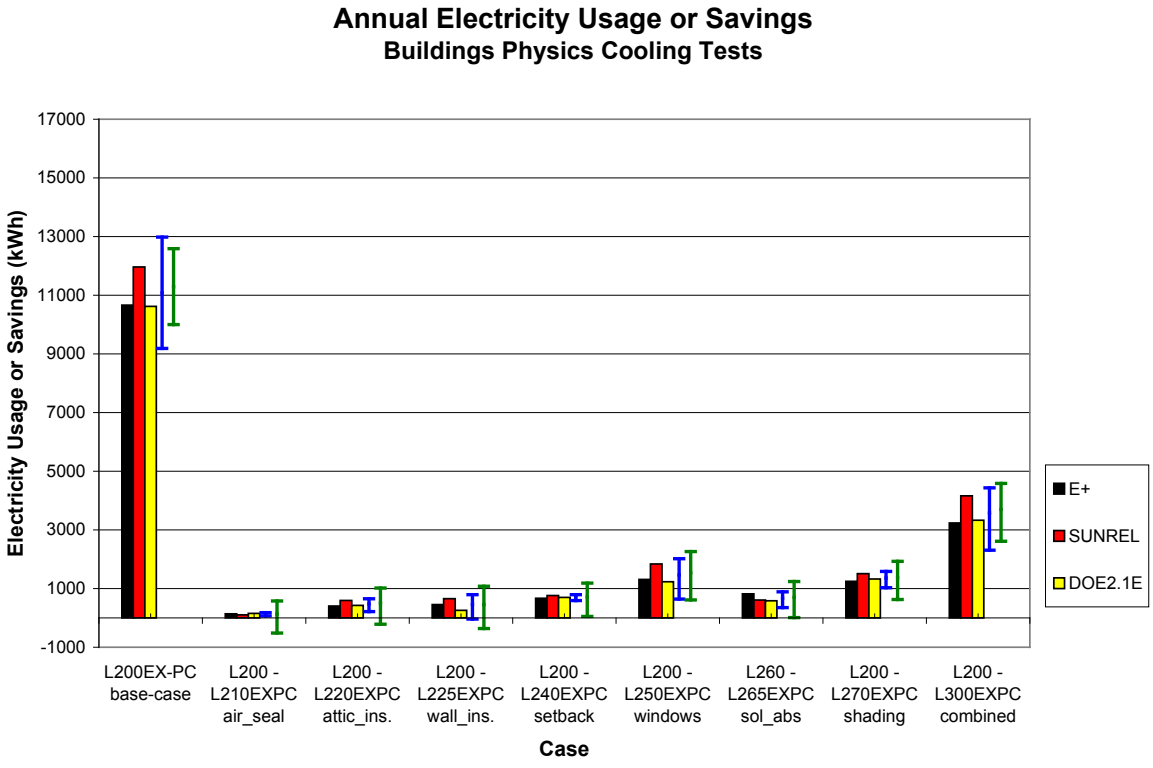

Figure 2. Building physics cooling tests: Reference simulation results and acceptance criteria

Table 3. BESTEST-EX Example Range-Setting Procedure: Building Physics Heating Tests

Total Annual Gas Consumption and Savings (million Btu/y)										
Case	EnergyPlus	SUNREL	DOE2.1E	Ref MEAN	Conf Max	Conf Min	$ Max	$ Min	Range Max	Range Min
L200EX-PH base-case	119.01	134.68	119.32	124.34	146.59	102.08	140.40	113.29	**146.59**	**102.08**
L200 - L210EXPH air_seal	17.14	15.88	15.33	16.12	17.68	13.81	21.02	9.61	**21.02**	**9.61**
L200 - L220EXPH attic_ins.	14.27	15.74	14.34	14.78	16.19	12.72	19.63	8.55	**19.63**	**8.55**
L200 - L225EXPH wall_ins.	19.10	25.00	18.69	20.93	26.88	12.16	28.88	12.97	**28.88**	**12.16**
L200 - L240EXPH setback	10.91	11.42	10.56	10.96	11.69	9.89	15.30	4.84	**15.30**	**4.84**
L200 - L250EXPH windows	10.86	17.50	9.92	12.76	19.73	2.49	21.38	4.20	**21.38**	**2.49**
L260 - L265EXPH sol_abs	-4.08	-2.74	-2.58	-3.13	-1.74	-5.19	1.31	-9.81	**1.31**	**-9.81**
L200 - L270EXPH shading	-9.27	-11.66	-9.65	-10.19	-8.03	-13.38	-5.38	-17.38	**-5.38**	**-17.38**
L200 - L300EXPH combined	66.38	77.81	65.34	69.85	81.51	52.66	81.70	59.62	**81.70**	**52.66**

B-EX-Phase-1-Ref-P-Results+Example-Accpetance-Criteria.xls: GasHtgData! A264:L277 7-May-2010

Table 4. BESTEST-EX Example Range-Setting Procedure: Building Physics Cooling Tests

Total Annual Electricity Consumption and Savings (kWh/y)										
Case	EnergyPlus	SUNREL	DOE2.1E	Ref MEAN	Conf Max	Conf Min	$ Max	$ Min	Range Max	Range Min
L200EX-PC base-case	10664	11966	10622	11084	12982	9186	12587	10001	**12982**	**9186**
L200 - L210EXPC air_seal	140	103	156	133	178	67	577	-517	**577**	**-517**
L200 - L220EXPC attic_ins.	405	596	428	476	653	216	1018	-216	**1018**	**-216**
L200 - L225EXPC wall_ins.	454	656	259	456	792	-38	1078	-362	**1078**	**-362**
L200 - L240EXPC setback	671	765	700	712	793	593	1186	50	**1186**	**50**
L200 - L250EXPC windows	1310	1840	1234	1461	2017	642	2261	613	**2261**	**613**
L260 - L265EXPC sol_abs	821	609	586	672	890	350	1242	>0	**1242**	**>0**
L200 - L270EXPC shading	1247	1508	1325	1360	1585	1028	1929	626	**1929**	**626**
L200 - L300EXPC combined	3235	4161	3330	3575	4435	2309	4583	2614	**4583**	**2309**

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Abbreviations used in tables:

Conf	=	value determined from confidence interval equations (see Equations 1 through 6)
Max	=	maximum
Min	=	minimum
Ref	=	reference simulations
$	=	economic threshold criteria (see Equations 7 and 8)

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14. ABSTRACT *(Maximum 200 Words)*
This document provides an example procedure for establishing acceptance-range criteria to assess results from software undergoing BESTEST-EX. This example method for BESTEST-EX is a modified version of the method described in HERS BESTEST.

15. SUBJECT TERMS
bestest; retrofit energy savings; building energy simulation; acceptance criteria

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