A COMPARATIVE VALIDATION BASED CERTIFICATION TEST FOR HOME ENERGY RATING SYSTEM SOFTWARE

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ABSTRACT

This paper summarizes a two volume National Renewable Energy Laboratory (NREL) report entitled "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)" (Judkoff and Neymark, 1995a). HERS BESTEST is a comparative validation method for evaluating the credibility of building energy software used by Home Energy Rating Systems. As NREL has now produced two comparative validation methods for testing building energy simulation software, the other method being International Energy Agency Building Energy Simulation Test and Diagnostic Method (IEA BESTEST) (Judkoff and Neymark, 1995b), a comparison detailing the capabilities and appropriate use of the two methods is also included.

INTRODUCTION

This paper summarizes a two volume National Renewable Energy Laboratory (NREL) report entitled "Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)" (Judkoff and Neymark, 1995a). HERS BESTEST is a method for evaluating the credibility of building energy software used by Home Energy Rating Systems. The method provides the technical foundation for "certification of the technical accuracy of building energy analysis tools used to determine energy efficiency ratings" as called for in the U.S. Energy Policy Act of 1992 (Title I, Subtitle A, Section 102, Title II, Part 6, Section 271). Certification is accomplished with a uniform and carefully documented set of test cases that facilitate the comparison of a software tool with several of the best public-domain, state-of-the-art building energy simulation programs available in the United States. This set of test cases represents the Tier 1 and Tier 2 Tests for Certification of Rating Tools as described in DOE 10 CFR Part 437, and the HERS Council *Guidelines for Uniformity* (HERS Council, 1995).

BACKGROUND

The theoretical basis for building energy software comparative validation testing had already been developed in "International Energy Agency Building Energy Simulation Test and Diagnostic Method" (IEA BESTEST) (Judkoff and Neymark, 1995b). For that work, NREL led a group consisting of experts from the International Energy Agency (IEA) Solar Heating and Cooling Program Task 12b and the IEA Buildings and Community Systems Program Task 21c. The 5-year international research effort resulted in a software testing methodology that is being adopted by Canada, Britain, Finland, Belgium, France, Italy, Spain, Sweden, the United States, New Zealand, Australia, and the California Energy Commission. Additionally, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) is currently adapting IEA BESTEST into an ASHRAE standard method of test for building energy simulation software. Important conclusions of the IEA BESTEST effort were:

- The BESTEST method trapped bugs and faulty algorithms in every program tested.
- The IEA 12b/21c experts unanimously recommend that no program be used until it is "BESTESTed".
- BESTEST is an economic means of testing, in several days, software that has taken many years to develop.
- Even the most advanced whole building energy models show a significant range of disagreement in the calculation of basic building physics.
- Improved modeling of building physics is as important as improved user interfaces.

Software testing based on intermodel comparisons forms one portion of an overall validation methodology that was first developed at NREL in 1983 and that has been further refined since then by NREL and a number of European researchers (Bloomfield, 1988; Bowman and Lomas, 1985; Irving, 1988; Judkoff, 1988; Judkoff and Neymark, 1995b; Judkoff et al., 1983; Lomas, 1991; Lomas et al., 1994). The overall validation methodology consists of three parts:

- Analytical Verification - in which the output from a program, subroutine, or algorithm is compared to the result from a known analytical solution for isolated heat transfer mechanisms under very simple boundary conditions
- Empirical Validation - in which calculated results from a program, subroutine, or algorithm are compared to monitored data from a real structure, test cell, or laboratory experiment

- Comparative testing - in which a program is compared to itself or to other programs. The comparative approach includes "sensitivity testing" and "intermodel comparisons."

SUMMARY OF THE HERS BESTEST COMPARATIVE VALIDATION CASE DESCRIPTIONS

The Tier 1 tests consist of a basic house with typical glazing and insulation. Specific cases are designed to test a building energy computer program with respect to the following components of heat and mass transfer:

- Infiltration
- Wall and ceiling R-Value
- Glazing physical properties, area, and orientation
- South overhang
- Internal loads
- Exterior surface color
- Energy inefficient building
- Crawl space
- Uninsulated and insulated slab
- Uninsulated and insulated basement.

The Tier 2 tests consist of the following additional elements related to passive solar design:

- Direct gain passive solar home
- Variation in mass
- Glazing orientation
- East and west shading
- Glazing area
- South overhang.

To help avoid user input errors, the input requirements for the test cases were kept as simple as possible, while remaining as close as possible to "typical" constructions and thermal and physical properties. For this reason, HERS BESTEST follows as closely as possible typical building descriptions and physical properties published by U.S. sources such as the:

- American Society of Heating Refrigerating and Air Conditioning Engineers (*ASHRAE Handbook Fundamentals, 1993*),
- Lawrence Berkeley National Laboratory (LBNL),
- National Association of Home Builders (NAHB),
- National Fenestration Rating Council (NFRC),
- U.S. Department of Energy (*Housing Characteristics, 1990*).

BASE BUILDING SUMMARY

The HERS BESTEST base building is a 1539 ft^2 (143.0 m^2) single-story house with one conditioned zone (the main floor), an unconditioned attic, and a vented crawl space. **Figure 1** shows the basic building geometry. The geometry remains similar for all cases with minimal changes to allow the investigation of sensitivity to certain features noted above.

Key thermal and physical properties of the base building are listed below in English units with metric units in parentheses:

- Exterior surface thermal resistances:
  – Walls: R-12 (2.1 m^{2}K/W)
  –Ceiling: R-20 (3.5 m^{2}K/W)
  –Floor: R-14 (2.5 m^{2}K/W)
- Windows
  –Gross area: 270 ft2 (25.1 m^2)
  –Net glass area: 197 ft2 (18.3 m^2)
  –Single glazed, clear glass
  –Aluminum frame with thermal break
  –Wall weighted area distribution
  –No shading
- Infiltration: 0.67 ACH
- Internal gains
  –Sensible: 56105 Btu/day (59.2 MJ/day)
  –Latent: 12156 Btu/day (12.8 MJ/day)
- Total thermal capacitance: 6006 Btu/F (11.4 MJ/°C)
- Interior/exterior opaque surface solar absorptance: 0.6
- Interior/exterior opaque surface infrared emittance: 0.9

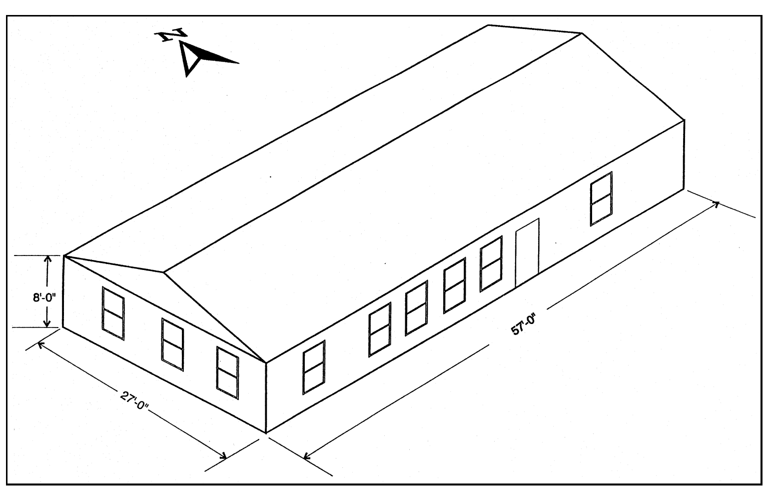

Figure 1 - HERS BESTEST Base Building Axonometric

Table 1 - HERS BESTEST Case Descriptions - Tier 1 and Tier 2 Tests

CASE #/ Test Tier	SUBFLOOR	INFILTR (ACH)	R-VALUE (h ft² F/Btu) WALLS, (Note 2) CEILING	FLOOR	WINDOW DATA TYPE	AREA (ft²) (Note 3)	ORIENT	SHADE	COMMENTS **(Note 1)**
L100A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Base building. Simple construction with typical glazings and insulation. Represents average of US building stock.
L110A/ T1	VC	**1.5**	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests infiltration.
L120A/ T1	VC	0.67	**24,60**	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests wall and ceiling R-value together.
L130A/ T1	VC	0.67	12,21	14	**DLEW**	Gross: 270 Net: 197	AVG DIST	NO	Tests glazing physical properties together.
L140A/ T1	VC	0.67	12,21	14	**None**	**0**	**N/A**	NO	Tests glazing area.
L150A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	**1.0 S**	NO	Tests glazing orientation.
L155A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	**1.0 S**	**H**	Tests South opaque overhang.
L160A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	**0.5E,0.5W**	NO	Tests E/W glazing orientation.
L165A/ T2	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	**0.5E,0.5W**	**HV**	Tests E/W shading.
L170A/ T1	VC	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	**Internal loads = 0.** Tests internal loads.
L200A/ T1	VC	**1.5**	**5,12**	**4**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Lumped sensitivity low efficiency. Tests HERS ability to cover wide range of construction.
L202A/ T1	VC	**1.5**	**5,12**	**4**	SATB	Gross: 270 Net: 197	AVG DIST	NO	**Exterior Solar Absorptance = 0.2.** Tests low exterior solar absorptance.
L302A/ T1	**SLAB**	0.67	12,21	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated slab using ASHRAE perimeter method.
L304A/ T1	**SLAB**	0.67	12,21	**EDGE INS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests perimeter insulated slab using ASHRAE perimeter method.
L322A/ T1	**BASE-MENT**	0.67	12,21 **(Note 4)**	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated full basement using ASHRAE method.
L324A/ T1	**BASE-MENT**	0.67	12,21 **(Note 4)**	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with insulated full basement using ASHRAE method.
P100A/ T2	VC	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	NO	**High mass passive solar construction.** Base building for P-series cases.
P105A/ T2	VC	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	**H**	Tests South opaque overhang.
P110A/ T2	VC	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	NO	**Low mass version of passive base case.** Tests mass effect.
P140A/ T2	VC	0.67	**24,60**	**23**	**None**	**0**	**N/A**	NO	Tests glazing area.
P150A/ T2	VC	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	AVG DIST	NO	Tests glazing orientation.

ABBREVIATIONS
SUBFLOOR = construction below main floor, VC = ventilated crawl space, SLAB = slab on grade, BASEMENT = full basement.
INFILTR (ACH) = Infiltration (Air Changes per Hour)
R-VALUE, FLOOR: UNINS = slab or basement coupled to ground, EDGE INS = 4 ft. deep perimeter slab insulation.
WINDOW DATA: SATB = single pane, clear glass, aluminum frame with thermal break; DLEW = double pane, low-e glass, wood frame, insulated spacer; DW = double pane, clear glass, wood frame, metal spacer.
ORIENT = Orientation; AVG DIST = window area distributed over walls in proportion to total exterior wall area.
N/A = not applicable; 1.0 S = all windows on south wall; 0.5E, 0.5W = 50% of window area on east wall and 50% of window area on west wall.
SHADE = window shading device; H = horizontal shade (overhang); HV = horizontal and vertical shading (overhang and fins).
ASHRAE = American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

NOTES
Note1: Changes to Case L100A are highlighted with bold font.
Note 2: These are composite R-values including all materials, films, and the presence of the attic for ceiling R-value; see Section 2 for more detail.
Note 3: Gross area is the total window area including the frame; net area is the area of just the glass portion of the window.
Note 4: Basement below-grade wall R-values including the ground are: L322A = R-8, L324A = R-19.

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HERS BESTEST includes numerous tables of material properties disaggregated for each envelope component as well as other details necessary for different software with different input requirements to be able to generate equivalent models. These tables are not included here due to space constraints.

Separate weather sites of Colorado Springs, Colorado, U.S., and Las Vegas, Nevada, U.S. are used for heating and cooling loads respectively. Thermostat settings were for either heating-only or cooling-only in the respective climates. Avoiding a deadband thermostat makes the test better for non-hourly simulation tools.

Table 1 lists the characteristics of all the cases in HERS BESTEST. Cases beginning with "L" (e.g. L100A) are generally low mass (wood frame construction) tests. Cases beginning with "P" (e.g. P100A) test passive solar features and thermal mass.

EXAMPLE RESULTS

Comparative testing as applied in the HERS BESTEST method includes a set of results from public domain reference programs that have already been subjected to extensive analytical, empirical, and intermodel testing. The following programs were used to generate reference results:

- BLAST 3.0 Level 215
- DOE2.1E-W54
- SERIRES/SUNCODE 5.7.

BLAST 3.0 is the program used by the U.S. Department of Defense for energy efficiency improvements to their buildings. (*BLAST User Reference, 1991*) DOE2.1E is considered to be the most advanced of the programs sponsored by the U.S. Department of Energy, and is the technical basis for setting national building energy codes and standards in the United States. (*DOE2 Reference Manual, 1981, DOE2 Supplement, 1994*) SUNCODE 5.7 is based on the public domain program SERIRES-1.0 developed by NREL. (Palmiter et al., 1983) These are representative of the current best public-domain, state-of-the-art, hourly building energy simulation programs available in the United States.

The example results generated using the above programs include tables of:

- Annual heating loads
- Annual cooling loads
- Delta annual heating loads
- Delta annual cooling loads
- Monthly heating loads
- Monthly cooling loads.

Including monthly load results was done to make it easier to test non-hourly tools with seasonal cutoff.

Table 2 shows some example results for annual heating and cooling loads. **Table 3** shows some example results for sensitivity of annual heating and cooling loads to changes in the building envelope.

Graphs are also given showing only the maximum and minimum example results for each case for:

- Annual heating loads
- Annual cooling loads
- Delta annual heating loads
- Delta annual cooling loads.

Figure 2 shows an example graph of maximum and minimum results for annual heating loads. **Figure 3** shows an example graph of maximum and minimum results for sensitivity of annual heating loads to changes in the building envelope.

COMPARISON OF HERS BESTEST TO IEA BESTEST

HERS BESTEST differs greatly from IEA BESTEST, although both focus on the building envelope. HERS BESTEST was designed to test simplified tools likely to be used for residential modeling, and specifically Home Energy Rating Systems (HERS). Therefore, the base case building is representative of typical residential construction. IEA BESTEST was designed for analyzing detailed hourly simulation software. As

Table 2 - HERS BESTEST Tier 1 Reference Results Annual Heating Loads

Colorado Springs, CO Annual Heating (MBtu/y)			
Case #	BLAST	DOE2	SERIRES/ SUNCODE
L100AC	61.94	58.00	72.40
L110AC	85.93	81.36	96.52
L120AC	50.27	45.08	57.83
L130AC	46.34	45.82	49.98
L140AC	49.14	47.24	52.48
L150AC	54.92	49.47	64.03
L155AC	57.38	52.28	66.91
L160AC	62.88	58.28	73.50
L170AC	73.06	71.64	85.45

Table 3 - HERS BESTEST Tier 1 Reference Results Delta Annual Heating Loads

Colorado Springs, CO Annual Heating Sensitivity (MBtu/y)			
Case #	BLAST	DOE2	SERIRES/ SUNCODE
L110AC-L100AC	23.99	23.37	24.12
L120AC-L100AC	-11.67	-12.92	-14.57
L130AC-L100AC	-15.60	-12.18	-22.42
L140AC-L100AC	-12.80	-10.76	-19.92
L150AC-L100AC	-7.02	-8.53	-8.37
L155AC-L150AC	2.46	2.81	2.88
L160AC-L100AC	0.94	0.28	1.10
L170AC-L100AC	11.12	13.64	13.05

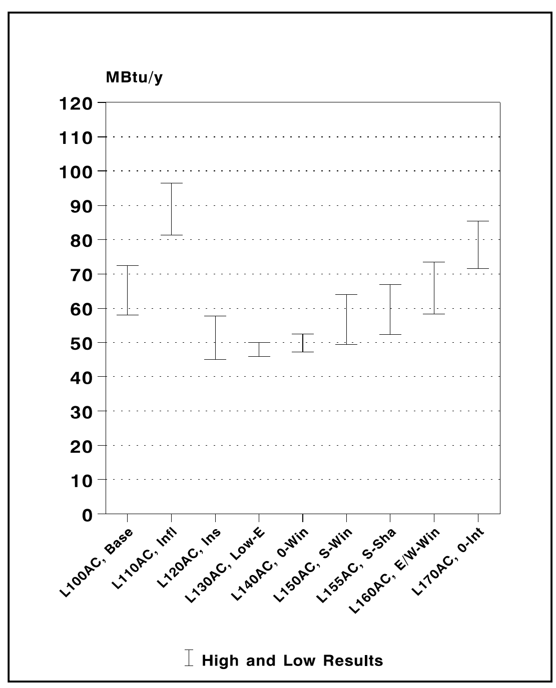

Figure 2 – HERS BESTEST Tier 1 Reference Results Annual Heating Load

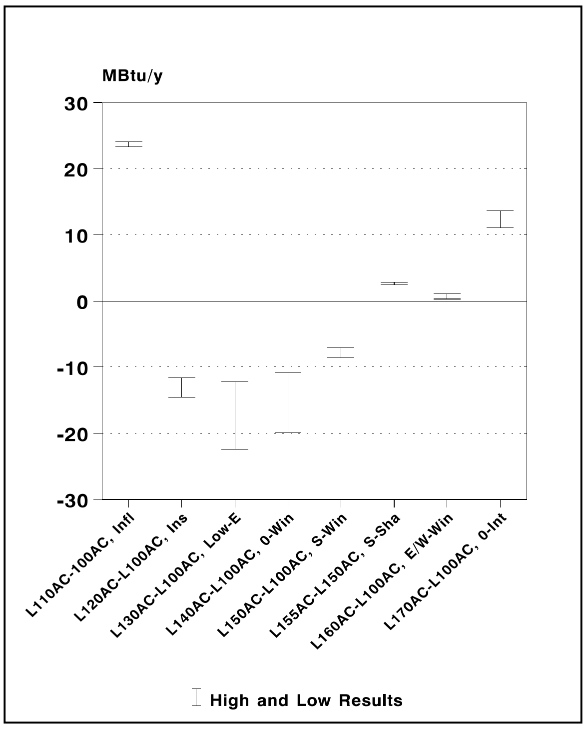

Figure 3 – HERS BESTEST Reference Results Delta Annual Heating Load

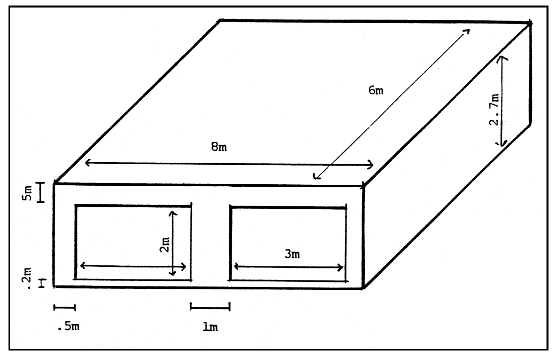

Figure 4 – IEA BESTEST Base Building Isometric

Table 4 - Test Matrix Category Checklist, HERS BESTEST Tier 1 & Tier 2 versus IEA BESTEST

Tests	BESTEST: HERS	BESTEST: IEA
BASIC CAPABILITIES		
Wall and Ceiling R-Value	Yes	No
Infiltration	Yes	Yes
Internal Heat Generation	Yes	Yes
Inefficient Building (lumped param.)	Yes	No
WINDOWS		
Window Area	Yes	Yes
Window Orientation	Yes	Yes
Window South Overhang	Yes	Yes
Window East & West Shading	Yes	Yes
Window Solar Transmittance	No	Yes
Window Combined Thermal/Optic (Lo-E)	Yes	No
Solid Conduction	Yes	Yes
THERMAL MASS/PASSIVE SOLAR		
Low Mass Series	Yes	Yes
High Mass/Passive Solar Series	Yes	Yes
Thermal Mass and Solar Interaction	Yes	Yes
Thermal Mass without Solar Gains	No	Yes
South Shading and Mass Interaction	No	Yes
E/W Transmittance and Mass Interaction	No	Yes
E/W Shading and Mass Interaction	No	Yes
Passive Solar/Interzone Heat Transfer	No	Yes
RADIATIVE HEAT TRANSFER AND SURFACE CONVECTION		
Exterior SW Absorptance	Yes	Yes
Interior SW Absorptance/Cavity Albedo	No	Yes
Exterior IR Emittance	No	Yes
Interior IR Emittance	No	Yes
Interior/Exterior Surface Convection	No	Yes
MECHANICAL EQUIPMENT		
Thermostat Setback	No	Yes
Thermostat Deadband	No	Yes
Mechanical Ventilaiton	No	Yes
GROUND HEAT TRANSFER		
Crawl Space	Yes	No
Ground Coupling	Yes	Yes
Floor Slab Insulation	Yes	No
Basement Wall Insulation	Yes	No

such, it goes into greater detail in testing specific building physics algorithms and has a much simpler base case envelope. For example see **Figure 4** regarding IEA BESTEST and compare it with **Figure 1** regarding HERS BESTEST. Additional features of the HERS BESTEST base building versus the IEA BESTEST base building are:

- Unconditioned attic
- Vented crawl space
- Structural wood framing included in walls
- Windows evenly distributed over all walls with more typical window area to floor area ratio
  –HERS BESTEST: 18% gross window area, 13% net glass area to floor area
  –IEA BESTEST: 25% net glass area to floor area
- Windows include sash
- Interior wall mass included
- Separate doors
- No deadband thermostat (heating only Colorado Springs, cooling only Las Vegas).

HERS BESTEST's sensitivity tests are also more representative of realistic variations to residential construction. Consequently, they do not allow the detailed diagnosis available from the IEA BESTEST cases. However, they cover low-emissivity windows, wall insulation, and foundation configurations which were not covered in IEA BESTEST. A detailed comparison of testing capabilites between HERS BESTEST and IEA BESTEST is presented in **Table 4**.

Table 5 - Types of Published Results,
HERS BESTEST versus IEA BESTEST

Published Example Results	BESTEST: HERS	IEA
Annual Heating Loads	Yes	Yes
Annual Heating Load Sensitivity	Yes	Yes
Annual Cooling Loads	Yes	Yes
Annual Cooling Load Sensitivity	Yes	Yes
Monthly Heating Loads	Yes	No
Monthly Cooling Loads	Yes	No
Annual Hourly Peak Heating Loads	No	Yes
Ann. Hourly Peak Htg. Load Sensitivity	No	Yes
Annual Hourly Peak Cooling Loads	No	Yes
Ann. Hourly Peak Clg. Load Sensitivity	No	Yes
Maximum Annual Hourly Zone Temp.	No	Yes[1]
Minimum Annual Hourly Zone Temp.	No	Yes[1]
Average Annual Hourly Zone Temp.	No	Yes[1]
Annual Incident Solar Radiation	No	Yes[1]
Ann. Transmitted Sol. Rad. (Unshaded)	No	Yes[1]
Annual Transmitted Sol. Rad. (Shaded)	No	Yes[1]
Annual Transmissivity Coef. of Windows	No	Yes[1]
Annual Overhang and Fin Shading Coefs.	No	Yes[1]
Annual Hourly Temperature Frequency	No	Yes[1]
Single-Day Hourly Incident Sol., South	No	Yes[2]
Single-Day Hourly Incident Sol., West	No	Yes[2]
Single-Day Hourly Free Float Temp.	No	Yes[2]
Single-Day Hourly Loads	No	Yes[2]

Notes:
[1] For selected cases.
[2] For selected cases and days.

Table 6 - Reference Software,
HERS BESTEST versus IEA BESTEST

HERS BESTEST	IEA BESTEST
BLAST 3.0 Level 215	BLAST 3.0 Level 193 v.1
DOE2.1E - W54	DOE2.1D 14
SERIRES/SUNCODE 5.7	ESP-RV8
	SERIRES/SUNCODE 5.7
	SERIRES 1.2
	S3PAS
	TASE
	TRNSYS 13.1
	DEROB-LTH*
	CLIM2000*

Note:
* Results submitted later and include in separate reports.

Table 5 and **Table 6** further compare the character of example results between HERS BESTEST and IEA BESTEST regarding types of published results and software used for generating reference results. Additionally, IEA BESTEST includes diagnostic flow diagrams while HERS BESTEST does not include this "expert system" assistance.

CONCLUSION

HERS BESTEST is a comparative validation test specifically designed for simplified analysis tools commonly used for residential energy analysis. It has a variety of uses including:

- Comparing the predictions from a given simplified building energy program to the reference results from the detailed building energy simulation programs presented in HERS BESTEST.
- Systematically checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted.
- Systematically checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms.

While HERS BESTEST is not as academically rigorous as IEA BESTEST, its ability to test simplified software makes it an ideal tool for certifying Home Energy Rating System software. Additionally, it could be used in conjunction with IEA BESTEST to further test detailed software in a more typical modeling situation, and to test areas not included with IEA BESTEST.

In general, the BESTEST procedures do not by themselves comprise a complete validation methodology. They allow a given program to be compared with a number of so-called state-of-the-art programs. These state-of-the-art programs have undergone some "validation" tests, but cannot be considered fully validated. Therefore "failing" a test does not necessarily indicate a faulty program, but it does indicate a difference that should be investigated and understood. Therefore, in addition to the comparative validation procedures described above, comparison of simulation results to monitored energy use data would provide a more comprehensive validation of HERS software. However, since monitoring comparisons are more expensive than employing comparative validation, we expect comparative validation methods to remain popular.

FUTURE WORK/RECOMMENDATIONS

For future work, a third Tier of tests not currently part of HERS BESTEST is also planned as described in the *HERS Council Guidelines.* The additional tests are anticipated to include:

- Utility rate structures including demand
- HVAC simulation
- Thermostat set-back and set-up
- Whole house fan
- Domestic water heating
- Solar water heating
- Sunspace
- Trombe wall.

Many of the groups using BESTEST have been interested enough to send us suggestions for improvement. Some of these suggestions can be handled by a simple update sheet, and some would require publication of an updated document. Some of the more interesting improvements might include:

- Periodically re-running reference programs using the newest versions of the programs.
- Re-running reference programs using the new TMY2 weather data after it becomes commonly used by simulation developers.

Finally, there is a need for continuing activity to further develop all elements of an overall validation methodology including:

- Analytical Verification
- Empirical Validation
- Comparative Testing and Diagnostics.

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