SBEED Validation Against ASHRAE Standard 140-2014

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Tools and Materials for Zero Net Energy California Buildings,
SBEED: Small Building Energy Efficient Design

INTRODUCTION

SBEED (Small Building Energy Efficient Design) is an easy-to-use day-one design tool that helps owners, builders, and architects create a more energy efficient non-residential building. ASHRAE Standard 140-2014 is a method for evaluating a building energy analysis computer program by running 35 variations of a small building design then comparing the results of using eight different energy performance programs. The current release of SBEED 1.0 (Build 4) could run 27 of these cases and the heating and cooling loads were reported and compared for each.

BACKGROUND

SBEED uses the Solar-5 computation engine, developed at UCLA beginning in 1978 for its thermal analysis kernel. Solar-5 calculates an hourly heat balance similar to the method used in EnergyPlus. It finds the heat gain or heat loss for each of the 8760 hours in a year using standard ASHRAE algorithms, the Mackey and Wright time lag and decrement factor method of accounting for heat flow through external mass walls, the Admittance Factor Method to account for internal thermal mass, and the California Energy Commission’s ACM method to calculate the performance of basements. To find the hourly heat balance it uses a successive approximation method to calculate the indoor air temperature. Thus it can integrate loads and energy calculations at each hourly time step, which means that the HVAC system only adds heating or cooling energy if the indoor air temperature has floated beyond the upper or lower comfort limits.

ANSI/ASHRAE Standard 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs was developed by the American National Standards Institute (ANSI) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). This standard is updated periodically, and the version from 2014 has been used to test the recently released version of SBEED 1.0 Build 4.

Test Procedures:
Standard 140 specifies test procedures to evaluate the results produced by software designed to calculate the thermal performance of a building and its environmental control systems. The tests are based on the principle of comparing the performance of one program against the performance of other programs, and while the tests are not intended to evaluate all aspects of the software, they are designed to indicate any serious flaws or limitations.
Standard 140 uses a small reference building of 48 square meters (26.25 by 19.69 feet) that has 35 variations of envelope, windows, internal loads, and infiltration. For each case its performance was reported for eight simulation programs: ESP, BLAST, DOE2, SRES/SUN, SERIRES, S3PAS, TRANSYS, and TASE. For each case the overall minimum and maximum value is reported for heating load and for cooling load among these eight programs. The annual heating and cooling load was also calculated for each case using SBEED, and whether it falls within the minimum and maximum acceptance range of all the other eight simulation programs.

SBEED, like most U.S. energy simulation programs, uses Inch-Pound units, while Standard 140 is reported in SI (metric) units of MWh per year, which in this report is converted to MBTU per year. The annual performance of SBEED is reported in MBTU/year on the Building Energy Performance (BEPS) screen and is reported here in Table 1 and 2. These results are also plotted graphically in Figures 1 and 2.

The 35 cases in Standard 140 range from quite realistic to extremely abstract. Eight cases are not included here because using SBEED some test variables can not be changed: interior infrared emittance, interior shortwave absorption, exterior combined radiative and convective surface coefficients, cavity albedo, solid opaque windows, and adding a sunspace. The results of the remaining 27 cases are plotted graphically in Figure 1 for Annual Heating Loads and in Figure 2 for Annual Cooling Loads, and are reported numerically in Table 1 and Table 2.

RESULTS

It is important to emphasize that in Standard 140 no formal validation criteria are established to determine the range of acceptable results (ANSI/ASHRAE 2007, Section 4.4.1). Thus while this study does not demonstrate official acceptance ranges, it does show that SBEED closely follows the same pattern of performance as these other eight simulation programs (Fig. 1 and 2). Standard 140 is used here in part because it was also used previously in the development of our earlier design tool HEED (Home Energy Efficient Design) which also uses the Solar-5 computation engine, but for residential buildings. Comparing the performance reported for both SBEED and HEED also shows that they both closely follow the same pattern of performance (Henkhaus, 2012).

SBEED fell within the normative range on 33 of the 54 cases that it ran. This includes 18 of the 27 heating load comparisons (Figure 1), and 15 of 27 cooling load comparisons (Figure 2). Note that in all cases SBEED tends to be conservative, in that it estimates that a higher heating or cooling load is needed compared to the average of the other eight programs. Thus, an actual building would likely use less annual energy than SBEED predicted. This means that when
designing a Zero Net Energy building SBEED will have a higher probability of meeting that goal.

Compared to the eight reference programs, SBEED showed the same magnitude and direction of performance of in each successive case. This implies that when SBEED is used as a design tool, each incremental design change to a building should produce changes in heating and cooling energy that are of the correct magnitude and direction.

Figure 1: Annual Heating Loads Comparison
DISCUSSION OF RESULTS

Reference Programs:
Note that Standard 140 is based on results of eight reference computer programs that are now 20 or more years old, most of which are no longer considered state of the art in building simulation. Missing from this list is EnergyPlus, which is now considered by many in the U.S. to be the standard of the industry. In 2006 and 2010 EnergyPlus was run against these same eight reference simulation programs, plus three more that were added (BLAST 3.0, DOE2.1E, and DOE2.1E-RevWindow). In the 2010 test series using EnergyPlus 6.0.0.023 the test files generate results which lay outside bounds for eight the 62 cases. To date
Standard 140 has not been revised to include these three new versions of the original eight programs or to include EnergyPlus or to include SBEED or HEED.

Weather Data:
All the eight original reference programs were run using an 8760 hour climate data file called DRYCOLD.TMY, but since then the weather data formats have been revised, corrected, and updated to TMY2 and now to TMY3. This file apparently originally used the Denver-Stapleton Airport, Colorado TMY data.

SBEED could not use the original DRYCOLD.TMY file because it is not in EPW format, so instead used the Denver-Stapleton Airport, Colorado TMY data in its currently published EPW format (USA_CO_Denver-Stapleton.724690_TMY) available from the EnergyPlus Weather site. (https://energyplus.net/weather). Thus weather data used in this current SBEED study may be slightly revised from what was used in the original eight simulation programs.

EnergyPlus validation analysis was originally done using a BLAST weather file which in turn had been converted into EnergyPlus format using the EnergyPlus weather converter. Since then, the DRYCOLD.TMY weather file provided with Standard 140 has been directly converted into the EnergyPlus format using the EnergyPlus weather converter. This produced significant changes in results for some test cases using EnergyPlus with both the originally converted weather file and results with the new weather file.

The EnergyPlus validation study reported that a comparison of the two weather files shows several differences. First, the BLAST version has Daylight Savings Time option turned on while the EnergyPlus version of the BESTEST weather file has the Daylight Savings Time option turned off. This created differences in results for those test cases which have schedules which change throughout the day, i.e. thermostat setback and nighttime ventilation cases (Cases 640, 650). Secondly, there were differences in the hourly outdoor wet-bulb temperature, sky temperature, and diffuse and direct solar radiation. These changes are undoubtedly due to differences in the psychrometric and solar radiation routines between the BLAST and the EnergyPlus weather conversion programs.

Modeling Issues:
The specifications for Case 220 say that the opaque surface radiation properties should be applied to all exterior opaque surface solar and infrared absorptances, and infrared emittances. However the SOLAR5 engine in HEED and in SBEED applies these to the roof only.

Also in ASHRAE standard 140 the thermostat specifications say that heat shall be on when the indoor temperature is less than 68 degrees, but SBEED turns heat on when interior temperature is
less than or equal to 68 degrees, so this will add a small amount of energy consumption to Heating Energy.

CONCLUSIONS

SBEED (Small Building Energy Efficient Design) Version 1.0 Build 4 was used to model a range of buildings as specified in ANSI/ASHRAE Standard 140-2014, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. The ability of SBEED to predict heating and cooling loads was tested using a test suite of 54 cases which included buildings with both low mass and high mass construction, without windows and with windows on various exposures, with and without exterior window shading, with and without temperature setback, with and without night ventilation, and with and without free floating space temperatures. The annual heating and cooling loads predicted by SBEED were compared to results from eight other whole building energy simulation programs. SBEED was within the normative range for 18 of the 27 annual heating load cases and within the normative range for 15 of the 27 annual cooling load cases. The nine heating cases that were out of range averaged less than 6.5% overheating. The twelve cooling cases that were out of range averaged less than 10.4% overcooling. Thus 61% of the test cases were within the normative range, and all cases that fell outside the range were on the safe side. This means that an actual building analyzed using SBEED would likely use slightly less heating energy and slightly less cooling energy than predicted.

Acknowledgements:

SBEED (Small Building Energy Efficient Design) was developed under contract with the California Energy Commission by Murray Milne and Robin Liggett, Principal Investigators, with Carlos Francisco Gomez, Senior Research Associate, and Donald Leeper, Senior Systems Specialist. Testing and Evaluation was by Tim Kohut and Pablo LaRoche plus dozens of colleagues around the country.

References:


HEED Validation Reports: HEED 4.0, Build 27 and Build 29, Alicyn Henkhaus, EIT, UCLA Department of Architecture and Urban Design, October 2012, HEED Summary Validation Report 2012 includes the following validation reports:

- HEED Validation Against ASHRAE /BESTEST Standard 140, 2012
- HEED Validation Against HERS BESTEST Standard, 2012
- Comparison of HEED and EnergyPlus, 2012
- Validation Results Validation of PV Power Simulation in HEED, 2012


SBEED is available at no cost from http://www.energy-design-tools.aud.ucla.edu/SBEED
<table>
<thead>
<tr>
<th>Case Description</th>
<th>ASHRAE 140 Example Results</th>
<th>SBEED Test</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Min MWh/yr</td>
<td>Max MWh/yr</td>
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<tr>
<td>620: 600 w/ East and West Windows</td>
<td>4.613</td>
<td>5.944</td>
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<tr>
<td>630: 620 w/ E&amp;W Window Overhang+Fins</td>
<td>5.050</td>
<td>6.469</td>
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<td>650: 600 w/ Night Ventilation</td>
<td>0.000</td>
<td>0.000</td>
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<td>910: 900 w/ South Window Overhang</td>
<td>1.575</td>
<td>2.282</td>
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<tr>
<td>930: 920 w/ E&amp;W Window Overhang+Fins</td>
<td>4.143</td>
<td>5.335</td>
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<td>940: 900 w/ Night Setback Thermostat</td>
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<td>950: 900 w/ Night Ventilation</td>
<td>0.000</td>
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<tr>
<td>220: 600 w/ Opaque Window Low Mass</td>
<td>6.944</td>
<td>8.787</td>
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<tr>
<td>230: 220 w/ Infiltration Restored</td>
<td>10.376</td>
<td>12.243</td>
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<td>250: 220 w/ Exterior Shortwave Absorptance</td>
<td>4.751</td>
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<td>290: 270 w/ South Window Overhang</td>
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<td>300: 270 w/ East and West Windows</td>
<td>4.761</td>
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<tr>
<td>310: 300 w/ E&amp;W Window Overhang+Fins</td>
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<td>320: 270 w/ Thermal Deadband Restored</td>
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<tr>
<td>430: 420 w/ Extior Shortwave Absorptance</td>
<td>5.429</td>
<td>7.827</td>
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</table>

Eight cases are not included in this table because SBEED does not allow changes in the variables being tested: Solid Opaque Windows, Surface Convection Coefficient, Interior Surface Radiation, Cavity Albedo, and Added Sunspace.
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