Development of New Self-Comparison Test Suites for EnergyPlus

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IBPSA-USA SimBuild 2008
July 30, 2008
Berkeley, California
Overview

- EnergyPlus Testing
- HVAC Component Tests
- Global Energy Balance Tests
- Shading Tests
EnergyPlus Testing

ANSI/ASHRAE Std. 140

- Envelope Tests 195 – 960
  - Comparative, building envelope
  - Building Simulation 2001 paper

- HVAC Tests CE100 and CE200 series
  - Comparative and analytical, DX cooling systems
  - Building Simulation 2003 paper

- HVAC Tests CE300 thru CE500 series
  - Comparative, further tests for DX cooling systems
  - SimBuild 2006 paper

- HVAC Tests HE100 and HE200 series
  - Comparative and analytical, fuel-fired furnace systems
  - SimBuild 2006 paper
EnergyPlus Testing

Other Tests

- ASHRAE 1052RP Analytical Building Fabric Tests
  - Analytical, building envelope
  - SimBuild 2004 paper
- IEA In-Depth Ground-Coupling
  - Comparative, ground-coupled heat transfer
- IEA Multi-Zone Non-Airflow
  - Comparative, building envelope
- IEA Multi-Zone Airflow
  - Analytical, airflow between zones
- IEA Mechanical Equipment and Control Strategies – Chilled Water System and Heating Water System
  - Comparative, chilled water cooling coil
  - Comparative, hot water heating coil
EnergyPlus Testing

Self-Comparison Tests

- HVAC Component Tests
  - Comparative, chiller and boiler
  - Compare against catalog performance data

- Global Energy Balance Tests
  - Comparative, HVAC
  - Confirm conservation of energy

- Shading Tests
  - Comparative, shading scenarios
  - Compare against similar cases

Why Self-Comparisons?

- Such tests seem trivial and obvious . . .
- But . . . whole-building energy analysis programs are complex
  - Many interactions within program
  - Complex data management and reporting functions
- Necessary for quality assurance
  - Initial development
  - Ongoing development
HVAC Component Tests

- Start with equipment performance tables
- Generate curve fits and other required inputs to model the equipment
- Compare component simulation results back to original performance data over a range of operating conditions
- EnergyPlus objects tested
  - CHILLER:ELECTRIC:EIR
  - BOILER:SIMPLE
HVAC Component Tests

Building Characteristics

- Single zone
- 196 m² (14 m x 14 m x 3 m high)
- No interior partitions or windows
- Adiabatic surfaces
- Ideal 100% convective air distribution system
- Cooling load driven by
  - Scheduled daily internal gains over 2 month period loads chiller to create loads 80% to 130% capacity
- Standard 140 weather file CE200A.TM2 (constant 35C outdoor temp)
HVAC Component Tests

Chiller Characteristics

- Electric reciprocating
- Water cooled
- Catalog performance data available for 10F range for leaving chilled water and entering condenser water temps

Assumptions
- Constant water flows
- No heat added to water loops by pumps, etc.
HVAC Component Tests

Test Cases

- Full load tests
  - 54 combinations of leaving chilled water temps (3.3C to 11.1C in 9 increments) and entering condenser water temps (23.9C to 37.8C in 6 increments)
  - Ramp up load until chiller is overloaded

- Part load tests
  - 6 tests ranging from 5% to 110% part load
HVAC Component Tests

EnergyPlus Chiller Curves

- Catalog data for cooling capacity and electric consumption
- Generate curve fit coefficients in spreadsheet
  - Cooling capacity bi-quadratic function of temperatures
  - Energy input to cooling output ratio bi-quadratic function of temperatures
  - Energy input to cooling output ratio quadratic function of part load
HVAC Component Tests

Output Data

- Steady state hourly cooling capacity in at PLR=1.0
- Steady state hourly electric consumption at PLR=1.0
- Calculated COP
HVAC Component Tests

Results and Issues

- Sample Results
- Software Errors
- Other issues
HVAC Component Tests

Sample Results - Capacity

Component Test - Cooling Capacity vs LChWT
Electric EIR Chiller
10000 W Capacity, 3.9 COP

Solid Line = Simulated Data
Marker = Catalog Data

Entering Condenser Water Temp (C)
- 23.89
- 26.67
- 29.44
- 32.22
- 35.00
- 37.78

EnergyPlus 2.2.3
HVAC Component Tests

Sample Results - COP

Component Test - COP vs ECnWT
Electric EIR Chiller
10000 W Capacity, 3.9 COP

Entering Condenser Water Temperature (°C)

Leaving Chilled Water Temp (°C)

Solid Line = Simulated Data
Marker = Catalog Data

EnergyPlus 2.2.3

2.9  3.4  3.9  4.4  4.9
22  24  26  28  30  32  34  36  38  40
# HVAC Component Tests

## Sample Results - Diffs

### CAPACITY %Difference (E-Plus - Catalog)/Catalog

*EnergyPlus 2.2.0.023*

<table>
<thead>
<tr>
<th>Leaving Chilled Water Temp. (C)</th>
<th>Entering Condenser Water Temp. (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.89</td>
</tr>
<tr>
<td>4.44</td>
<td>-0.02%</td>
</tr>
<tr>
<td>5.56</td>
<td>-0.06%</td>
</tr>
<tr>
<td>6.67</td>
<td>-0.05%</td>
</tr>
<tr>
<td>7.22</td>
<td>-0.04%</td>
</tr>
<tr>
<td>7.78</td>
<td>0.03%</td>
</tr>
<tr>
<td>8.89</td>
<td>0.02%</td>
</tr>
<tr>
<td>10.00</td>
<td>-0.06%</td>
</tr>
</tbody>
</table>

### CONSUMPTION %Difference (E-Plus - Catalog)/Catalog

*EnergyPlus 2.2.0.023*

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<td>-0.33%</td>
</tr>
<tr>
<td>7.22</td>
<td>0.05%</td>
</tr>
<tr>
<td>7.78</td>
<td>0.41%</td>
</tr>
<tr>
<td>8.89</td>
<td>0.34%</td>
</tr>
<tr>
<td>10.00</td>
<td>0.17%</td>
</tr>
</tbody>
</table>
Software Errors & Issues

- Initial tests showed that chiller could deliver more cooling than available capacity with no additional energy use (corrected in EnergyPlus 1.2.3)

- When cooling load PLR was greater than user-specified max PLR, the PLR for computing power consumption was getting clipped at 1.0 but chiller was delivering a cooling load up to the max PLR with no increase in power consumption (corrected in EnergyPlus 1.3.0)
Global Energy Balance Tests

- Is the simulation conserving energy?
- Checks accuracy of energy balances at various boundary volumes when simulating operation of HVAC systems and equipment
Global Energy Balance Tests

Building Characteristics

- Same as in HVAC Component Test but with different internal load schedules
- EnergyPlus systems tested
  - DX package air-conditioner with electric baseboard heating
  - 4-pipe fan coil HVAC system with hydronic heating/cooling system with hot water boiler and water chiller
Global Energy Balance Tests

Test Cases

- **Daily Test**
  - 8 two-day tests with different combinations of internal load types and forms (sensible, latent, radiant, convective, etc.).
    - Electric lights
    - Electric equipment
    - Other equipment
    - Gas equipment
    - Steam equipment
  - Standard 140 weather file CE100A.TM2 (constant 46.1°C outdoor temp)
Global Energy Balance Tests

Test Cases (cont’d)

- Annual Test
  - Scheduled heating (Oct thru Apr)
  - Scheduled cooling (May thru Sept)
  - TMY2 weather file for Chicago O’Hare
Global Energy Balance Tests

Energy Balances Checked

- Zone level – internal loads (+/-) generated vs. zone cooling/heating requirement
- Coil level – zone cooling/heating requirement vs. cooling/heating coil output
- HVAC system level – cooling/heating delivered vs. cooling/heating required, including fan heat
- Water loops – hot water loop, chilled water loop and condenser water loop energy transferred vs. chiller/boiler/pump/tower outputs and pump heat
- Equipment performance – COPs and efficiencies vs. expected values
Global Energy Balance Tests

Results and Issues

- Sample Results
- Software Errors
- Other issues
## Global Energy Balance Tests

### Sample Results

Window AC with Baseboard Heat
Coil Level Energy Balance for Annual Test Cases
For Cooling Months
EnergyPlus 2.2.0.023

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Month</th>
<th>Zone Cooling Requirement</th>
<th>Cooling Coil Requirement</th>
<th>Cooling Coil Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Zone Internal Gain (Wh)</td>
<td>Zone Internal Latent Gain (Wh)</td>
<td>Zone Internal Sensible Heat Gain (Wh)</td>
</tr>
<tr>
<td>M</td>
<td>May</td>
<td>744,000</td>
<td>223,200</td>
<td>520,800</td>
</tr>
<tr>
<td>N</td>
<td>Jun</td>
<td>720,000</td>
<td>216,000</td>
<td>504,000</td>
</tr>
<tr>
<td>O</td>
<td>Jul</td>
<td>744,000</td>
<td>223,200</td>
<td>520,800</td>
</tr>
<tr>
<td>P</td>
<td>Aug</td>
<td>744,000</td>
<td>223,200</td>
<td>520,800</td>
</tr>
<tr>
<td>Q</td>
<td>Sep</td>
<td>720,000</td>
<td>216,000</td>
<td>504,000</td>
</tr>
</tbody>
</table>
# Global Energy Balance Tests

## Sample Results – DX Coil

**Window AC with Baseboard Heat**

Coil Level Energy Balance for Annual Test Cases
For Cooling Months
EnergyPlus 2.2.0.023

## Comparison

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Month</th>
<th>Total Output - DX Coil (Wh)</th>
<th>Latent Output - DX Coil (Wh)</th>
<th>Total Output vs. DX Coil Sensible (Wh)</th>
<th>Latent Output vs. DX Coil Sensible (Wh)</th>
<th>Total Output vs. DX Coil Total (Wh)</th>
<th>Latent Output vs. DX Coil Total (Wh)</th>
<th>Total Output vs. DX Coil Sensible Req'd (%)</th>
<th>Latent Output vs. DX Coil Sensible Req'd (%)</th>
<th>Total Output vs. DX Coil Total Req'd (%)</th>
<th>Latent Output vs. DX Coil Total Req'd (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>May</td>
<td>-2,952.9</td>
<td>-1,065.0</td>
<td>-1,887.9</td>
<td>-0.38%</td>
<td>-0.48%</td>
<td>-0.35%</td>
<td>-0.38%</td>
<td>-0.48%</td>
<td>-0.35%</td>
<td>-0.38%</td>
</tr>
<tr>
<td>N</td>
<td>Jun</td>
<td>-1,779.8</td>
<td>-11.4</td>
<td>-1,768.4</td>
<td>-0.24%</td>
<td>-0.01%</td>
<td>-0.33%</td>
<td>-0.24%</td>
<td>-0.01%</td>
<td>-0.33%</td>
<td>-0.24%</td>
</tr>
<tr>
<td>O</td>
<td>Jul</td>
<td>-1,798.7</td>
<td>-3.3</td>
<td>-1,795.4</td>
<td>-0.23%</td>
<td>0.00%</td>
<td>-0.33%</td>
<td>-0.23%</td>
<td>0.00%</td>
<td>-0.33%</td>
<td>0.00%</td>
</tr>
<tr>
<td>P</td>
<td>Aug</td>
<td>-1,837.1</td>
<td>-17.9</td>
<td>-1,819.2</td>
<td>-0.24%</td>
<td>-0.01%</td>
<td>-0.33%</td>
<td>-0.24%</td>
<td>-0.01%</td>
<td>-0.33%</td>
<td>-0.24%</td>
</tr>
<tr>
<td>Q</td>
<td>Sep</td>
<td>-1,760.7</td>
<td>45.8</td>
<td>-1,806.6</td>
<td>-0.24%</td>
<td>0.02%</td>
<td>-0.34%</td>
<td>-0.24%</td>
<td>0.02%</td>
<td>-0.34%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>
## Global Energy Balance Tests

### Sample Results - Heating

**Window AC with Baseboard Heat**

Coil Level Energy Balance for Annual Test Cases
For Heating Months
EnergyPlus 2.2.0.023

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Month</th>
<th>Zone Heating Req'd (Wh)</th>
<th>Baseboard Heater Req'd (Wh)</th>
<th>Baseboard Heater Output (Wh)</th>
<th>Difference (Baseboard Output - Baseboard Req'd) (Wh)</th>
<th>Difference (Baseboard Output vs. Baseboard Req'd) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Jan</td>
<td>-744,000</td>
<td>-744,000</td>
<td>-743,659</td>
<td>341.4</td>
<td>-0.05%</td>
</tr>
<tr>
<td>J</td>
<td>Feb</td>
<td>-672,000</td>
<td>-672,000</td>
<td>-672,000</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td>K</td>
<td>Mar</td>
<td>-744,000</td>
<td>-744,000</td>
<td>-744,000</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td>L</td>
<td>Apr</td>
<td>-720,000</td>
<td>-720,000</td>
<td>-720,000</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td>R</td>
<td>Oct</td>
<td>-744,000</td>
<td>-744,000</td>
<td>-744,006</td>
<td>-5.8</td>
<td>0.00%</td>
</tr>
<tr>
<td>S</td>
<td>Nov</td>
<td>-720,000</td>
<td>-720,000</td>
<td>-720,000</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
<tr>
<td>T</td>
<td>Dec</td>
<td>-744,000</td>
<td>-744,000</td>
<td>-744,000</td>
<td>0.0</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Global Energy Balance Tests

Software Errors & Issues

- Sensible and latent cooling coil loads did not agree with sensible and latent cooling loads reported by DX cooling system  
  (corrected in EnergyPlus 1.4.0)
Shading Tests - Building

- ASHRAE 1052RP test case SolRadShade
- Model a shoebox with one window
- Four shading configurations
  - Unshaded
  - Horizontal overhang
  - Vertical fin
  - Horizontal overhang with vertical fin
Shading Tests - Variables

- For each building shade option, test 9 options
  - With/without window frame
  - With/without window dividers
  - Window multipliers
  - Shading surface transmittances

- Compare shadowing algorithm outputs
  - Sunlit area
  - Sunlit fraction
  - For wall
  - For window

- Location/Date: Atlanta, GA, August 21
Shading Tests

Test Cases

- 1. Base case – wall (3m x 3m) with window (2m x 2m) and no frame or dividers
- 2. Case 1 with substantial window frame
  - Expected Result: since frame area subtracts from wall area, results for window should be same as case 1
- 3. Case 2 with smaller window with frame but window/frame total area same as Case 1
  - Expected Result: wall should have same results as in Case 1
Shading Tests

Test Cases (cont’d)

4. Add dividers to window in Cases 1, 2 and 3
   Expected Result: wall results should not change

5. For Cases 1 thru 4, double wall width and set window multiplier = 2
   Expected Result: results for window should remain unchanged since window relative to shading surfaces does not change

6. Case 1 with shading surface transmittance = 0.1
   Expected Result: all results should change only a small amount
Shading Tests

Test Cases (cont’d)

- 7. Case 6 with shading surface transmittance = 0.999
  - Expected Result: identical to unshaded case
- 8. Case 6 with shading surface transmittance = 0.5
  - Expected Result: all shaded results should be nearly halfway between Cases 6 and 7
- 9. For Cases 1 thru 5, confirm the reporting of window area, wall area and window/wall ratio are correct
Shading Tests

Results and Issues

- Sample Results
- Software Errors
- Other issues
Shading Tests

Sample Results - Wall

EnergyPlus Shading Test 4
Wall Sunlit Fractions with Dividers Added to Window
Atlanta, August 21

Test 4A - Test 1 with dividers added to window
Test 4B - Test 2 with dividers added to window
Test 4C - Test 3 with dividers added to window
Shading Tests

Sample Results - Window

EnergyPlus Shading Test 5
Window Sunlit Fractions with Wide Wall and Window Multiplier = 2
Atlanta, August 21

Test 5A - Test 1 with wide wall and window multiplier = 2
Test 5B - Test 2 with wide wall and window multiplier = 2
Test 5C - Test 3 with wide wall and window multiplier = 2
Test 5D - Test 4A with wide wall and window multiplier = 2
Test 5E - Test 4B with wide wall and window multiplier = 2
Test 5F - Test 4C with wide wall and window multiplier = 2
Shading Tests

Software Errors & Issues

- With frame and divider added to window, the window area shown in Performance/Zone Summary report was not correct
- In Surface Shadowing Summary report
  - Fins/overhangs were shown as being shaded by base surface
  - For wall with fins and overhangs present, only fins and not overhangs were shown as shadow casters
  - For window with fins or overhangs neither were shown as shadow casters

*Problems corrected in EnergyPlus 2.2*
Conclusions

- These test suites have been very useful
  - Confirming accuracy
  - Bug detection
  - Feature additions

- These test suites and others are run before every release to ensure results do not stray