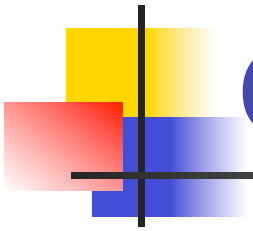
Development of New Self-Comparison Test Suites for EnergyPlus

Michael J. Witte
Robert H. Henninger
GARD Analytics, Inc., Arlington Hts., IL

Drury B. Crawley
U.S. Department of Energy, Washington, DC

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

Testing reports on www.EnergyPlus.gov

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 m^2 (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

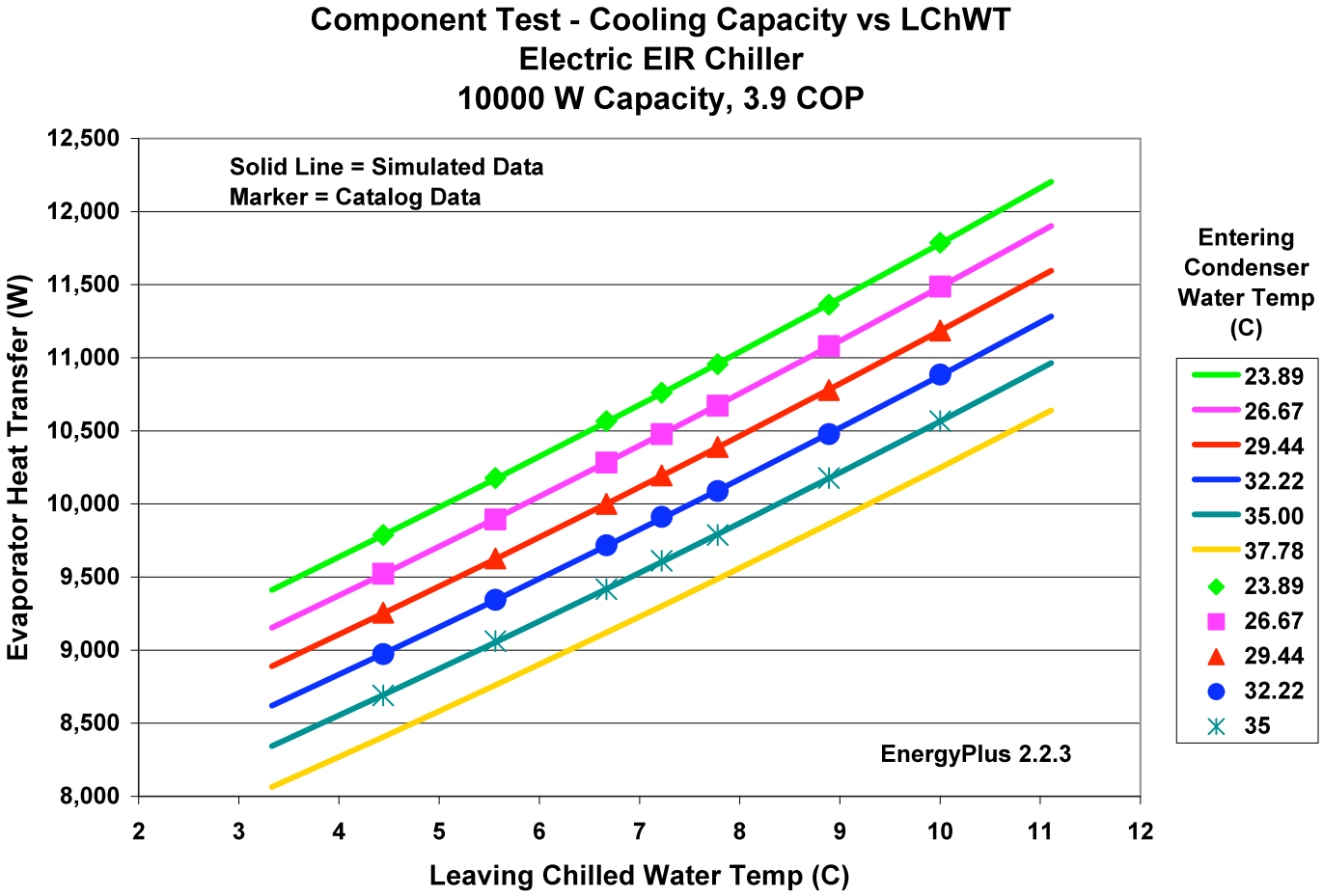
HVAC Component Tests

Results and Issues

- Sample Results
- Software Errors
- Other issues

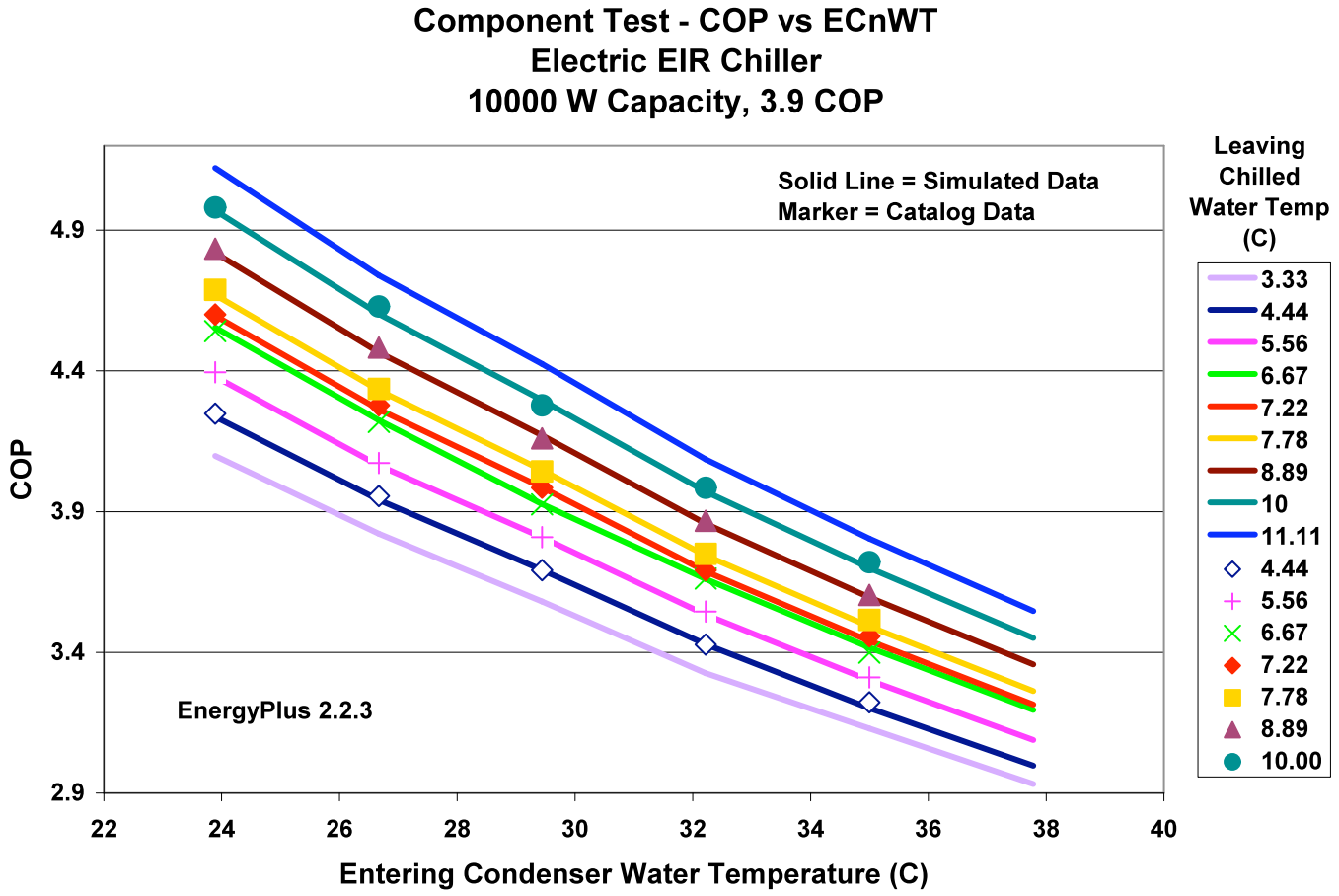
HVAC Component Tests

Sample Results - Capacity



HVAC Component Tests

Sample Results - COP



HVAC Component Tests

Sample Results - Diffs

CAPACITY %Difference (E-Plus - Catalog)/Catalog
EnergyPlus 2.2.0.023

Leaving Chilled Water Temp. (C)	Entering Condenser Water Temp. (C)				
	23.89	26.67	29.44	32.22	35.00
4.44	-0.02%	-0.02%	-0.07%	0.01%	0.03%
5.56	-0.06%	0.05%	-0.05%	-0.04%	-0.09%
6.67	-0.05%	0.00%	0.01%	-0.04%	0.03%
7.22	-0.04%	-0.01%	-0.03%	-0.12%	-0.08%
7.78	0.03%	0.03%	-0.02%	0.04%	0.05%
8.89	0.02%	-0.03%	0.03%	0.03%	-0.02%
10.00	-0.06%	-0.02%	-0.01%	-0.07%	-0.01%

CONSUMPTION %Difference (E-Plus - Catalog)/Catalog
EnergyPlus 2.2.0.023

Leaving Chilled Water Temp. (C)	Entering Condenser Water Temp. (C)				
	23.89	26.67	29.44	32.22	35.00
4.44	0.25%	0.34%	-0.09%	0.00%	0.69%
5.56	0.28%	0.27%	-0.05%	0.28%	0.20%
6.67	-0.33%	-0.14%	0.00%	0.00%	-0.52%
7.22	0.05%	0.32%	-0.06%	0.00%	0.41%
7.78	0.41%	0.16%	-0.12%	0.20%	0.75%
8.89	0.34%	0.35%	-0.21%	0.29%	0.21%
10.00	0.17%	0.57%	-0.45%	0.27%	0.57%

HVAC Component Tests

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 46.1C 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

		Zone Cooling Requirement - - - - - - - - - - >				Cooling Coil Requirement - - - - - - - - - - >			Cooling Coil Output - - - - - - - - - - - - - - >		
Test Case	Month	Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)	Fan Heat Added to Air Stream (Wh)	DX Coil Total Cooling Req'd (Wh)	DX Coil Latent Cooling Req'd (Wh)	DX Coil Sensible Cooling Req'd (Wh)	DX Coil Total Cooling Energy (Wh)	DX Coil Latent Cooling Energy (Wh)	DX Coil Sensible Cooling Energy (Wh)
M	May	744,000	223,200	520,800	25,334	769,334	223,200	546,134	766,381	222,135	544,246
N	Jun	720,000	216,000	504,000	25,488	745,488	216,000	529,488	743,708	215,989	527,720
O	Jul	744,000	223,200	520,800	26,778	770,778	223,200	547,578	768,979	223,197	545,782
P	Aug	744,000	223,200	520,800	26,431	770,431	223,200	547,231	768,594	223,182	545,412
Q	Sep	720,000	216,000	504,000	24,965	744,965	216,000	528,965	743,204	216,046	527,159

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 - >

Test Case	Month	Difference (DX Coil Total Output - DX Coil Total Req'd) (Wh)	Difference (DX Coil Latent Output - DX Coil Latent Req'd) (Wh)	Difference (DX Coil Sensible Output - DX Coil Sensible Req'd) (Wh)	Difference (DX Coil Total Output vs. DX Coil Total Req'd) (%)	Difference (DX Coil Latent Output vs. DX Coil Latent Req'd) (%)	Difference (DX Coil Sensible Output vs. DX Coil Sensible Req'd) (%)
M	May	-2,952.9	-1,065.0	-1,887.9	-0.38%	-0.48%	-0.35%
N	Jun	-1,779.8	-11.4	-1,768.4	-0.24%	-0.01%	-0.33%
O	Jul	-1,798.7	-3.3	-1,795.4	-0.23%	0.00%	-0.33%
P	Aug	-1,837.1	-17.9	-1,819.2	-0.24%	-0.01%	-0.33%
Q	Sep	-1,760.7	45.8	-1,806.6	-0.24%	0.02%	-0.34%

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

					Comparison - - - - - - - - - - >	
Test Case	Month	Zone Heating Req'd (Wh)	Baseboard Heater Req'd (Wh)	Baseboard Heater Output (Wh)	Difference (Baseboard Output - Baseboard Req'd) (Wh)	Difference (Baseboard Output vs. Baseboard Req'd) (%)
I	Jan	-744,000	-744,000	-743,659	341.4	-0.05%
J	Feb	-672,000	-672,000	-672,000	0.0	0.00%
K	Mar	-744,000	-744,000	-744,000	0.0	0.00%
L	Apr	-720,000	-720,000	-720,000	0.0	0.00%
R	Oct	-744,000	-744,000	-744,006	-5.8	0.00%
S	Nov	-720,000	-720,000	-720,000	0.0	0.00%
T	Dec	-744,000	-744,000	-744,000	0.0	0.00%

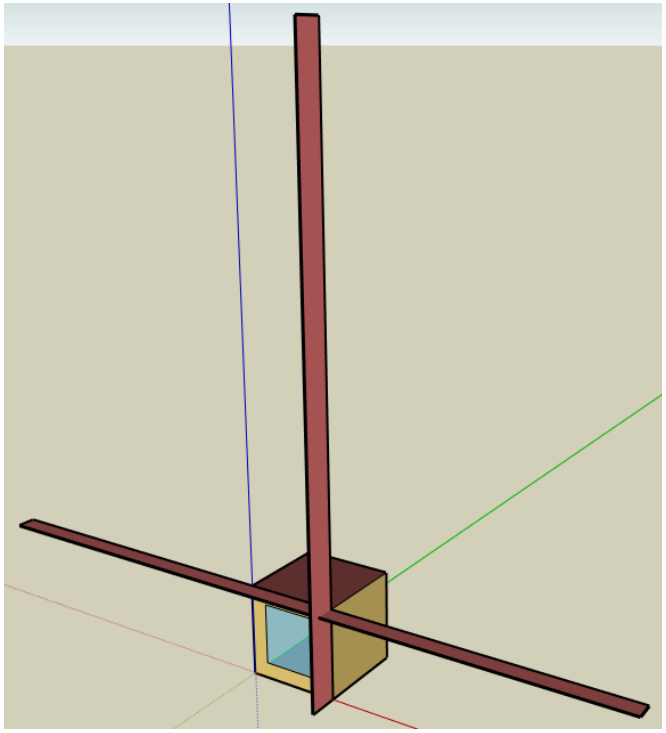
Global Energy Balance Tests

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

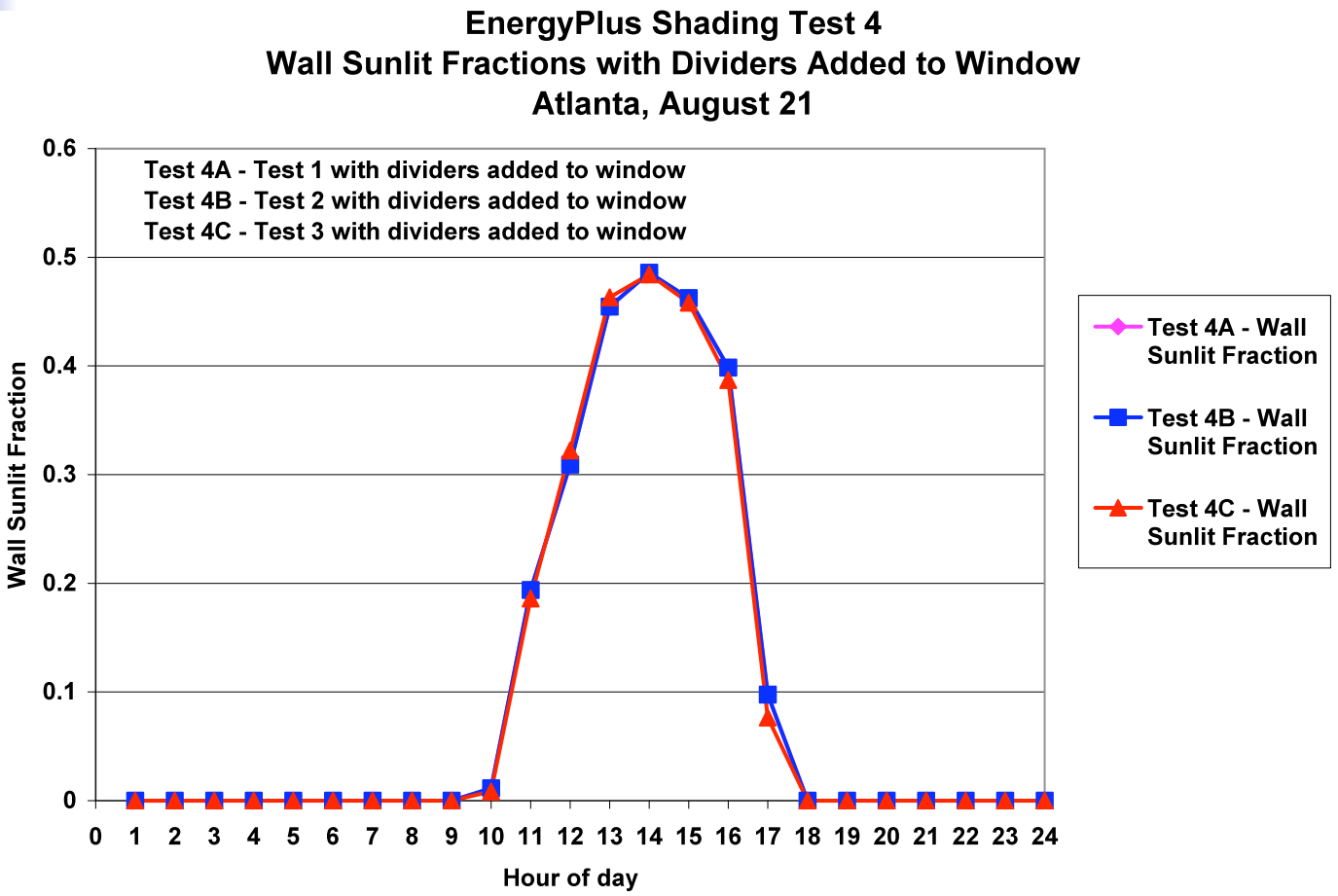
Shading Tests

Results and Issues

- Sample Results
- Software Errors
- Other issues

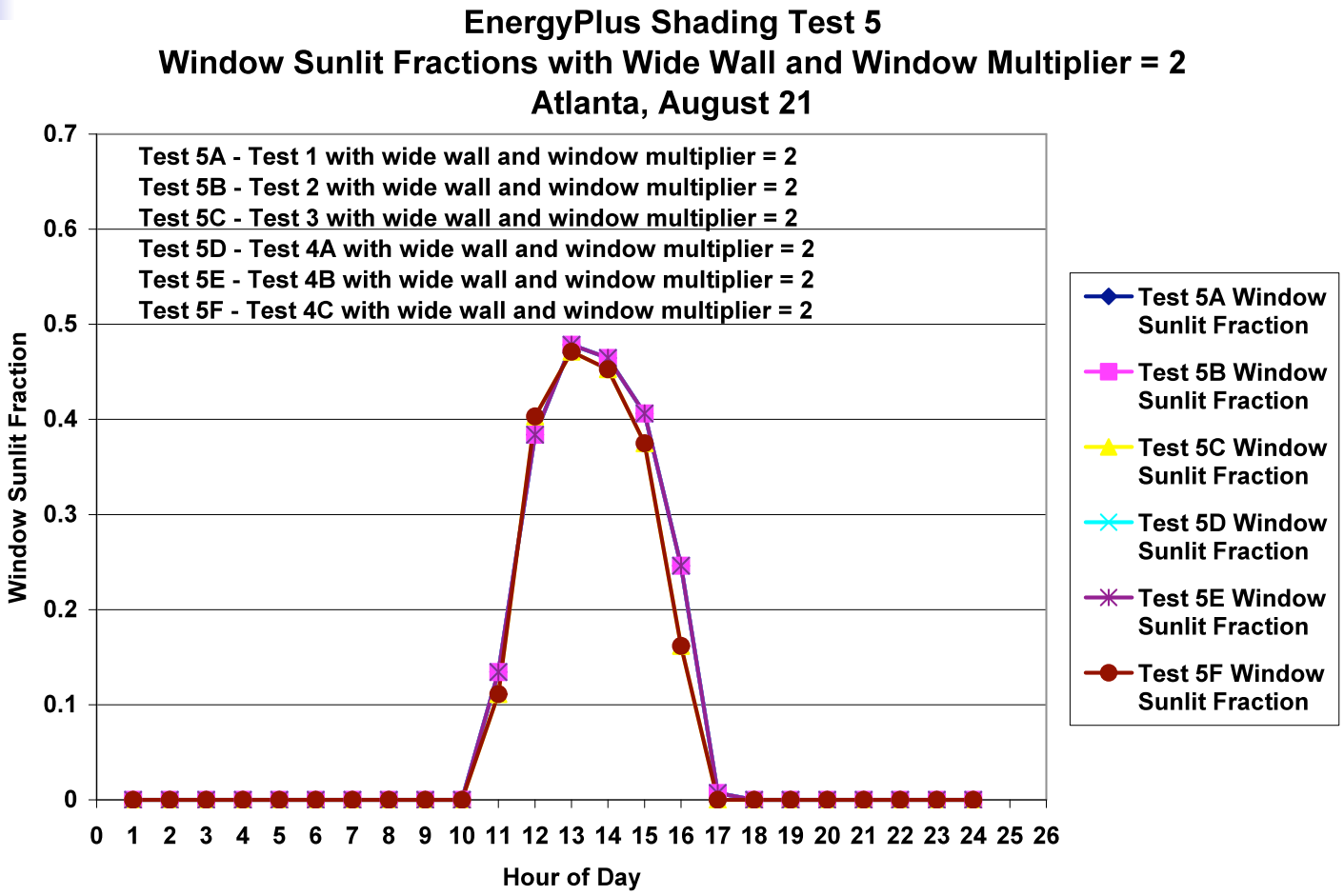
Shading Tests

Sample Results - Wall



Shading Tests

Sample Results - Window



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