DEVELOPMENT OF NEW SELF-COMPARISON TEST SUITES FOR ENERGYPLUS

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ABSTRACT

The EnergyPlus building simulation software has been tested using ANSI/ASHRAE Standard 140 comparative tests, ASHRAE 1052-RP analytical tests, IEA HVAC BESTEST analytical and comparative tests, and several other IEA test suites which are in development. Another valuable test method has been the use of “self-comparison” test suites developed specifically to test EnergyPlus against itself. These self-comparison test suites involve a series of tests which check for consistency of results using just one simulation program. There are no analytical or comparative results to compare against. While these test suites could certainly be extended to comparisons between programs, they are useful without the need to involve other modelers.

Three self-comparison test suites have been developed for EnergyPlus: HVAC Equipment Component Tests, Global Energy Balance Tests, and Shading Tests. Each test suite consists of a series of cases for which results can be compared against each other or to original specifications in order to assess whether the simulation is working properly. This paper describes these test suites for EnergyPlus and presents selected results, with an emphasis on problems found and difficulties encountered in developing the test cases. These tests may be developed further and submitted as candidates for expanding ANSI/ASHRAE Standard 140.

INTRODUCTION

The EnergyPlus building simulation software (EnergyPlus 2008) has been tested using several published test suite standards including ANSI/ASHRAE Standard 140 comparative tests for building envelope loads and HVAC systems (Henninger et al 2003, Henninger and Witte 2007c), ASHRAE 1052-RP analytical tests (Witte et al 2004), IEA HVAC BESTEST comparative tests (Witte et al 2006), IEA HVAC BESTEST Fuel-Fired Furnace test suite (Henninger and Witte 2007d) and other IEA test suites which are in development. Another valuable test method has been the use of “self-comparison” test suites developed specifically to test EnergyPlus against itself. These test suites involve a series of tests which check for consistency of results using just one simulation program. There are no analytical or comparative results to compare against. While these test suites could certainly be extended to comparisons between programs, they are useful without the need to involve other modelers. One might ask why such tests are necessary, because programs should be tested and validated when they are originally written. Whole building energy analysis programs are so complex and interactive, such tests are necessary for quality assurance as programs are updated and expanded.

Three self-comparison test suites have been developed for EnergyPlus: HVAC Equipment Component Tests (Henninger and Witte 2007a), Global Energy Balance Tests (Henninger and Witte 2007b), and Shading Tests. Each test suite consists of a series of test cases for which results can be compared against each other or to original specifications in order to assess whether the simulation is working properly. For example, in the global energy balance tests, the internal heat gain of an adiabatic zone is compared to the coil loads and plant equipment loads for a fan coil system. The cooling load at each level of the HVAC system should be equal after allowing for factors such as fan heat or pump heat. This paper describes three test suites for EnergyPlus and presents selected results, with an emphasis on problems found and difficulties encountered in developing the test cases. Each one of the self-comparison test suites discussed in this paper has resulted in the correction of at least one significant program defect.

HVAC EQUIPMENT COMPONENT TESTS

The EnergyPlus HVAC Equipment Component Test checks the accuracy of EnergyPlus component simulation results compared to published performance data over a range of operating conditions. The test procedure makes use of ANSI/ASHRAE Standard 140 (ANSI/ASHRAE 2004) procedures for generating hourly equipment loads and ANSI/ASHRAE Standard

140 weather files. Test suites have been developed thus far for one type of EnergyPlus electric chiller (object type CHILLER:ELECTRIC:EIR) and one type of EnergyPlus hot water boiler (object type BOILER:SIMPLE). Only the chiller component test will be discussed here. Complete test specifications and results may be found in (Henninger and Witte 2007a).

Chiller Component Test Description

A set of 54 test cases were used to test the water chiller's full load performance over a range of combinations of leaving chilled water temperatures and entering condenser water temperatures. The objective of each test was to determine the chiller's cooling capacity and electric consumption for the defined set of operating temperature pairs at the full load condition (PLR=1.0). In addition, 6 additional tests were used to test the chiller's part load performance at the standard condition of 6.67°C leaving chilled water temperature and entering condenser water temperatures which were held constant for each test at one of six settings which ranged from 23.89°C to 37.78°C. The cooling tower was configured with a bypass pipe and controls which allowed the cooling tower leaving water temperature to be controlled to a given setting which was always above the outdoor wet-bulb temperature of 21°C during the simulation period.

The EnergyPlus HVAC Equipment Component Test makes use of the basic test building geometry and envelope described as Case E100 in Section 5.3.1 of ANSI/ASHRAE Standard 140-2004 which uses a rectangular test building with no interior partitions and no windows. The building is intended as a near-adiabatic cell with cooling or heating load driven by user specified internal gains.

To perform the component test, cooling was provided by a water cooled electric water chiller whose full load performance was described by a typical water cooled reciprocating chiller for which there was a set of published performance data for cooling capacity and electric consumption which was normalized to the standard rated conditions of 44°F (6.67°C) leaving chilled water temperature and 95°F (29.44°C) entering condenser water temperature. The chiller rated cooling capacity was set to 10,000 W.

In order to create a cooling load for the cooling equipment, a sensible internal gain ranging from 8,400 W to 13,000 W was imposed on the building interior space according to a fixed schedule which holds the internal load constant throughout any one day but varies by day of the simulation. The sensible gains were assumed to be 100% convective. Latent internal loads were always 0.0 W. The range of internal sensible loads ensured that there would be at least one day during the simulation period when a chiller part load ratio of 1.0 (PLR=1.0) occurred for the combinations of leaving chiller water temperatures and entering condenser water temperatures that were tested. Another series of tests required that the chiller's performance over a range of part loads be varied from 5% to 100% in 5% increments. Other whole building energy analysis programs may not require a building model to impose a set of cooling loads on the chiller but instead may impose the cooling loads directly on the chiller.

A simple and ideal air distribution system with the following characteristics provided whatever cooling the space needed in order to maintain the setpoint temperature: 100% convective air system, 100% efficient with no duct losses and no capacity limitation, no latent heat extraction, zone air is perfectly mixed, no outside air; no exhaust air, indoor circulating fan uses no power (W = 0.0) and adds no heat to the air stream, and non-proportional-type thermostat, heat always off, cooling on if zone air temperature >22.2°C (72°F)

A three-month (January – March) TMY format weather file provided as part of ANSI/ASHRAE Standard 140 with the file name of HVBT350.TMY was used for the simulations required as part of this component test series. An outdoor dry-bulb temperature of 35.0°C and an outdoor wet-bulb temperature of 21°C remained constant for every hour of the three-month long period.

Problems Encountered

Two types of problems were encountered when trying to setup and run this test suite: modeling difficulties and software errors as described below.

Obtaining Chiller Full Load Results

Separate simulations were performed for each of 50 sets of leaving chilled water temperature and entering condenser water temperatures. For each simulation the cooling loads imposed on the chiller allowed the chiller to be loaded to PLRs >1.0. The challenge was to create a procedure that would generate a spreadsheet that would use functions to search the hourly output files for each simulation and find the first hour that the chiller PLR was exactly 1.0. The chiller's cooling capacity and electric consumption were then extracted for that hour and compared to published data.

Software Errors Identified

- When the chiller was specified as "constant flow" as part of the CHILLER:ELECTRIC:EIR object input, the chiller delivered more cooling than capacity with no additional energy use (corrected in EnergyPlus version 1.2.3.031)

- When the cooling load PLR was greater than the user-specified max PLR, the PLR for computing power consumption was getting clipped at 1.0, but the chiller was delivering a cooling load up to the max PLR with no increase in electric consumption (corrected in EnergyPlus version 1.3.0.008)

Sample Results

The EnergyPlus CHILLER:ELECTRIC:EIR model was simulated for higher and lower leaving chilled water temperatures and entering condenser water temperatures than were available with the published data to show that the curve fitted performance data behaves well even beyond the limits of the curve fitted data. Figure 1 showes good agreement was obtained between the simulated data and the published data although there were some small variations.

Tables 1 and 2 summarize the percent differences between the EnergyPlus results and published data for the chiller cooling capacity and COP. EnergyPlus results agreed to within 0.12% of the published data for cooling capacity and to within 0.69% for COP.

GLOBAL ENERGY BALANCE TESTS

The EnergyPlus Global Energy Balance Test checks the accuracy of EnergyPlus in regards to energy balances at various boundary volumes when simulating the operation of HVAC systems and equipment. As with the HVAC Equipment Component Test, use was made of ANSI/ASHRAE Standard 140 procedures for generating hourly equipment loads and ANSI/ASHRAE Standard 140 weather files. The global energy balance test procedure was applied to two HVAC systems types: DX package air-conditioner (modeled as a window air-conditioner in EnergyPlus) with electric baseboard heating and hydronic heating/cooling system with a boiler and chiller. Only the DX system with electirc baseboard heat will be discussed here. Complete test specifications and results may be found in (Henninger and Witte 2007b).

The Global Energy Balance Test uses the same basic test building as described earlier with the HVAC Equipment Component Test but with different internal load schedules. Two different test cases were conducted with varying internal loads: a limited daily comparison test with cooling only and an annual comparison test with cooling and heating.

For the first cooling only test, various internal gain scenarios were imposed on the building interior space according to a fixed schedule which holds the internal load constant throughout a certain test duration. Five types of internal loads (lights, electric equipment, other equipment, gas equipment and steam equipment) which can be modeled by EnergyPlus were tested for sensible, latent, radiant, convective, etc. fractions to assess the program's ability to properly transfer these space loads to the HVAC system. These are internal sources of heat that are not related to the operation of the mechanical cooling system or its air distribution fan.

The second test was performed with internal loads that created either a heating load or cooling load in the space for each month over a 12 month period. A constant space cooling load was scheduled for the cooling season which ran from May 1st through September 30th and a constant space heating load was scheduled for the heating season which ran from January 1st through April 30th and October 1st through December 31st.

The DX air-conditioner modeled was the same mechanical cooling system specified in ANSI/ASHRAE Standard 140 which is a simple unitary vapor compression cooling system with air cooled condenser and indoor evaporator coil, 100% convective air system, no outside air or exhaust air, single speed, draw-through air distribution fan, indoor and outdoor fans cycle on/off with compressor, no cylinder unloading, no hot gas bypass, crankcase heater and other auxiliary energy = 0.

For the annual comparison test, an electric baseboard convective heating system was added to the zone to provide any hourly heating that the zone required. The heating capacity of the baseboard was assumed to be 100% efficient (no loss outside the zone).

For the daily comparison simulation period the ANSI/ASHRAE Standard 140 HVBT461.TMY weather file was used. A TMY2 format weather file for Chicago O'Hare converted to EnergyPlus epw format was used for the 12-month annual simulation.

Output requirements to perform the required energy balances included hourly internal load (sensible, latent and total) for each type of internal space gain which is present, hourly space cooling load (sensible, latent and total), hourly amount of cooling performed by the DX cooling coil (sensible, latent and total), hourly HVAC system cooling (sensible, latent and total) delivered to the space, hourly space heating load, hourly amount of heating peformed by the baseboard heaters, hourly resulting space temperature, hourly electric cooling energy used by the HVAC syste , hourly electric energy used by the HVAC system supply fan, and hourly electric energy used by the baseboard heaters.

Problems Encountered

During the initial testing of EnergyPlus with the new Global Energy Balance Test suite, one software error was discovered as part of the testing which was subsequently corrected:

- The sensible and latent cooling coil loads did not agree with the sensible and latent cooling loads reported by the DX cooling system. There was agreement however with the total cooling load. This discrepancy was corrected in EnergyPlus version 1.4.0.020.

Sample Results

For the DX cooling system with baseboard heating Global Energy Balance Test energy balances were performed for the following:

- Zone Level Energy Balance
- Coil Level Energy Balance
- HVAC system Energy Balance
- Equipment Performance Summary

Only results for the coil level energy balance are presented below and in Table 3:

- Coil Level Energy Balance for Cooling Months
  a) For all five of the cooling months there were very small differences between the amount of sensible cooling performed by the cooling coil and the zone sensible cooling requirement plus fan heat. The percentage difference was less than 0.35% for these months.
  b) For the cooling months when latent cooling loads were present, the amount of latent cooling performed by the cooling coil differed from that required by less than 0.48%; the total cooling by the cooling coil differed by less than 0.38%.
- Coil Level Energy Balance for Heating Months
  a) During heating months the baseboard heater output equaled the space heating requirement within 0.00% except for January and October which showed small differences (0.05% or less).

SHADING TESTS

Some issues arose during the use of EnergyPlus involving sunlit areas of surfaces, the reporting of window areas, the reporting of window-to-wall ratios, and partially transmitting shading surfaces when frames and/or dividers are present and when window/door multipliers are used. So, there was a need to develop a new internal test suite and spreadsheets that could be used to check that each of these features were working properly and giving reasonable results. This Shading Test suite was also to be used as a QA check on future EnergyPlus releases.

The Shading Test suite makes use of ASHRAE 1052RP test cases called SolRadShade (Spitler et al 2001) which tests a programs ability to model a window surface in several modes: unshaded, shaded by horizontal overhang, shaded by vertical fins, and shaded by overhang and fins. Nine separate test cases with appropriate spreadsheets to compare results between test cases were developed as follows.

Test 1 – This basic case uses the ASHRAE 1052-RP SolRadShade test cases with horizontal and vertical shading for which EnergyPlus results were known to agree with the ASHRAE 1052-RP analytical toolkit results. This case was modeled as a south facing wall with window that was unshaded, horizontally shaded, vertically shaded, and both horizontally and vertically shaded. The tests were run with Atlanta 1052-RP weather files.

Test 2 – Same as Test 1 but add a substantial frame to the window that would cover about half the remaining wall area. Since window frames in EnergyPlus are supposed to subtract from the wall area, not the window subsurface area, results for the window should be the same as Test 1.

Test 3 - Same as Test 2 but with a smaller window such that the window plus frame area is the same as in the base case (Test 1) with no frame. Results for the wall should be identical to Test 1.

Test 4 - Take Test 1 files, Test 2 files and Test 3 files and add dividers to the window. Results for the wall should not change.

Test 5 - Take all of the above test files (Tests 1-4) and make the wall twice as wide and set the window multiplier to 2. The results for the window should remain unchanged, because it will be in the same place relative to the shading surfaces and simply multiplied by 2.

Test 6 - Same as Test 1 but add a transmittance schedule of 0.001 to the shading surface(s). All results should change only by a very small amount compared to Test 1.

Test 7 - Same as Test 6 but change the transmittance schedule to 0.999. All results should be nearly identical to the unshaded case of Test 1.

Test 8 - Same as Test 6 but change the transmittance schedule to 0.5. All shaded results should be close to halfway between the unshaded case of Test 7 and the almost fully shaded Test 6.

Test 9 - For the unshaded cases from Tests 1 through 5, confirm that the reporting of window areas, wall areas, and window-to-wall ratios in various EnergyPlus output reports is correctly accounting for the frames, dividers and multipliers.

Problems Encountered

Several of the standard output reports were reporting incorrect quantities for certain output report variables:

- With frame and divider added to window, the window area shown in the Performance/Zone Summary table was not correct. The window area in the Envelope/Window-Wall Ratio table was correct.
- Problems were found in the Surface Shadowing Summary report, for example: (1) fins and overhangs were shown as being shaded by base surface; (2) when fins and overhang were present only the fin and not the overhang was being shown as shadow casters and (3) for window subsurface neither the fin or overhang were shown as shadow casters.

These reporting problems were corrected in version 2.2.

Sample Results

A series of spreadsheets were created to compare the sunlit areas and fractions of the wall and window for various test cases. Table 4A is an example spreadsheet which shows the wall and window sunlit fractions for the simulated test day for Tests 1, 2 and 3. Directly below that is Table 4B which shows the differences between Test 1 and Tests 2 and 3 results. All results compare as expected.

CONCLUSION

The three new self-comparison tests developed for EnergyPlus, the HVAC Equipment Component Test, the Global Energy Balance Test and the Shading Test, have proved to be very useful in performing quality assurance checks of results and uncovering discrepancies with the simulation code. With further development, these test suites may be candidates for expanding ANSI/ASHRAE Standard 140.

ACKNOWLEDGMENT

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REFERENCES

ANSI/ASHRAE 2004. Standard 140-2004, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, ASHRAE.

EnergyPlus 2008. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies. http://www.energyplus.gov/

Henninger, R.H., M.J. Witte and D.B. Crawley. 2003. *Experience Testing EnergyPlus with the IEA HVAC BESTEST E100-E200 Series*, Proceedings of Building Simulation 2003, Eindhoven, Netherland, August 2003, IBPSA.

Henninger, R.H., and M.J. Witte. 2007a. *EnergyPlus Testing with HVAC Equipment Component Tests*, November 2007. http://www.eere.energy.gov/buildings/energyplus/pdfs/energyplus_hvac_component_tests.pdf

Henninger, R.H., and M.J. Witte. 2007b. *EnergyPlus Testing with Global Energy Balance Test*, November 2007. http://www.eere.energy.gov/buildings/energyplus/pdfs/energyplus_hvac_global_tests.pdf

Henninger, R.H., and M.J. Witte. 2007c. *EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2004*, November 2007. http://www.eere.energy.gov/buildings/energyplus/pdfs/energyplus_ashrae_140_envelope.pdf

Henninger, R.H., and M.J. Witte. 2007d. *EnergyPlus Testing with Fuel-Fired Furnace HVAC BESTEST*, November 2007. http://www.eere.energy.gov/buildings/energyplus/pdfs/energyplus_hvac_furnace.pdf

Spitler, J.D., Rees, S.J., and Dongyi, X., 2001. Development of an Analytical Verification Test Suite for Whole Building Energy Simulation Programs - Building Fabric, ASHRAE 1052-RP Final Report, April 2001.

Witte, M.J., R.H. Henninger and D.B. Crawley. 2001. *Testing and Validation of a New Building Energy Simulation Program*, Proc. of Building Simulation 2001, Rio de Janeiro, Brazil, August 2001, IBPSA.

Witte, M.J, R.H. Henninger and D.B. Crawley. 2004. *Experience Testing EnergyPlus with the ASHRAE 1052-RP Building Fabric Analytical Tests*, Proceedings of SimBuild 2004, Boulder, Colorado, August 2004, IBPSA-USA.

Witte, M.J., R.H. Henninger and D.B. Crawley. 2006. *Experience Testing EnergyPlus with IEA BESTEST E300-E545 Series and IEA HVAC BESTEST Fuel-Fired Furnace Series*, Proc. of SimBuild 2006, Cambridge, Mass., August 2006, IPBSA-USA.

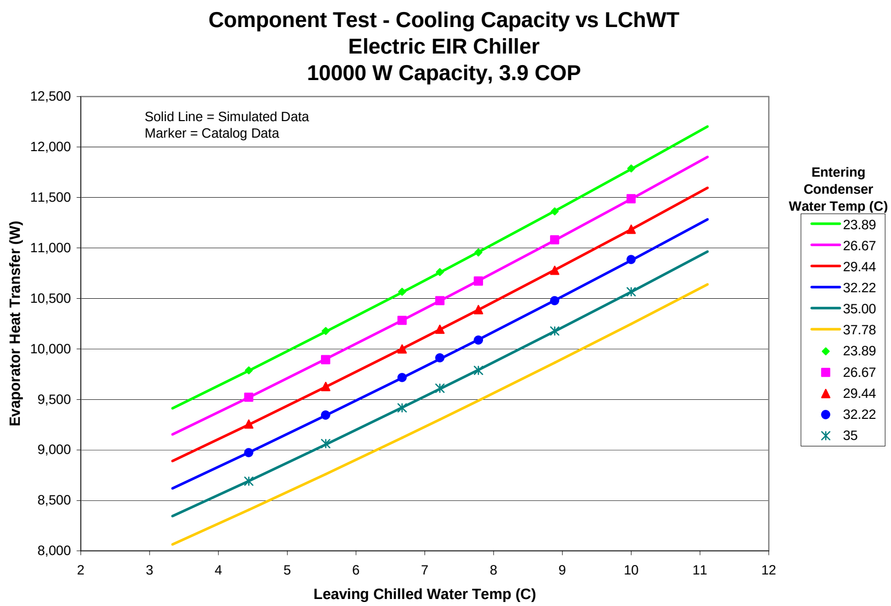

Figure 1 Chiller Cooling Capacity Versus Leaving Chilled Water Temperature – EnergyPlus Model Versus Published Data (EnergyPlus 2.1.0.023)

Table 1 Chiller Cooling Capacity Comparison Results for HVAC Equipment Component Test (EnergyPlus 2.1.0.023)

CAPACITY %Difference (E-Plus - Published)/Published

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%

Table 2 Chiller COP Comparison Results for HVAC Equipment Component Test (EnergyPlus 2.1.0.023)

COP %Difference (E-Plus - Published)/Published

Leaving Chilled Water Temp. (C)	Entering Condenser Water Temp. (C)				
	23.89	26.67	29.44	32.22	35
4.44	-0.27%	-0.36%	0.03%	0.01%	-0.65%
5.56	-0.34%	-0.22%	-0.01%	-0.32%	-0.29%
6.67	0.28%	0.14%	0.01%	-0.04%	0.56%
7.22	-0.08%	-0.34%	0.03%	-0.12%	-0.48%
7.78	-0.38%	-0.13%	0.10%	-0.16%	-0.69%
8.89	-0.31%	-0.38%	0.24%	-0.26%	-0.23%
10.00	-0.23%	-0.58%	0.44%	-0.33%	-0.58%

Table 3 Sample Results for Global Energy Balance Test for Window AC System with Baseboard Heating – Coil Level Energy Balance for Annual Test Cases (EnergyPlus 2.1.0.023)

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

		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	220,158	546,223
N	Jun	720,000	216,000	504,000	25,488	745,488	216,000	529,488	743,708	214,138	529,570
O	Jul	744,000	223,200	520,800	26,778	770,778	223,200	547,578	768,979	221,316	547,663
P	Aug	744,000	223,200	520,800	26,431	770,431	223,200	547,231	768,594	221,278	547,316
Q	Sep	720,000	216,000	504,000	24,965	744,965	216,000	528,965	743,204	214,157	529,047

		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	-3,041.7	88.8	-0.38%	-1.36%	0.02%
N	Jun	-1,779.8	-1,861.9	82.2	-0.24%	-0.86%	0.02%
O	Jul	-1,798.7	-1,883.8	85.1	-0.23%	-0.84%	0.02%
P	Aug	-1,837.1	-1,922.2	85.1	-0.24%	-0.86%	0.02%
Q	Sep	-1,760.7	-1,843.0	82.3	-0.24%	-0.85%	0.02%

Window AC with Baseboard Heat
Coil Level Energy Balance for Annual Test Cases
For Heating Months

						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%

Table 4A Shading Test Example Results Comparing Window and Wall Sunlit Fractions for Shading Test 1 versus Test Case 2 (window frame added) and Test Case 3 (smaller window)

EnergyPlus Shading Tests

2.1.0.020

Case SolRadShade-South from 1052-RP

	Case 1				Case 1				Case 2				Case 2				Case 3				Case 3			
	Window				**Wall**				**Window**				**Wall**				**Window**				**Wall**			
	NoShade	Ver	Hor	HorVer	NoShade	Ver	Hor	HorVer	NoShade	Ver	Hor	HorVer	NoShade	Ver	Hor	HorVer	NoShade	Ver	Hor	HorVer	NoShade	Ver	Hor	HorVer
	NoFrame	NoFrame	NoFrame	NoFrame	NoFrame	NoFrame	NoFrame	NoFrame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame
																	Small Win	Small Win	Small Win	Small Win	Small Win	Small Win	Small Win	Small Win
Date/Time	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)
08/21 01:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 02:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 03:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 04:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 05:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 06:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 07:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 08:00:00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00
08/21 09:00:00	1.00	0.00	0.00	0.00	1.00	0.00	0.03	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.03	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.02	0.00
08/21 10:00:00	1.00	0.00	0.18	0.00	1.00	0.03	0.37	0.01	1.00	0.00	0.18	0.00	1.00	0.03	0.37	0.01	1.00	0.00	0.11	0.00	1.00	0.02	0.35	0.01
08/21 11:00:00	1.00	0.33	0.39	0.13	1.00	0.43	0.45	0.19	1.00	0.33	0.39	0.13	1.00	0.43	0.45	0.19	1.00	0.29	0.35	0.11	1.00	0.42	0.45	0.19
08/21 12:00:00	1.00	0.84	0.46	0.38	1.00	0.64	0.48	0.31	1.00	0.84	0.46	0.38	1.00	0.64	0.48	0.31	1.00	0.91	0.44	0.40	1.00	0.66	0.48	0.32
08/21 13:00:00	1.00	1.00	0.48	0.48	1.00	0.92	0.49	0.45	1.00	1.00	0.48	0.48	1.00	0.92	0.49	0.45	1.00	1.00	0.47	0.47	1.00	0.94	0.49	0.46
08/21 14:00:00	1.00	1.00	0.46	0.46	1.00	1.00	0.49	0.49	1.00	1.00	0.46	0.46	1.00	1.00	0.49	0.49	1.00	1.00	0.45	0.45	1.00	1.00	0.48	0.48
08/21 15:00:00	1.00	1.00	0.41	0.41	1.00	1.00	0.46	0.46	1.00	1.00	0.41	0.41	1.00	1.00	0.46	0.46	1.00	1.00	0.37	0.37	1.00	1.00	0.46	0.46
08/21 16:00:00	1.00	1.00	0.25	0.25	1.00	1.00	0.40	0.40	1.00	1.00	0.25	0.25	1.00	1.00	0.40	0.40	1.00	1.00	0.16	0.16	1.00	1.00	0.39	0.39
08/21 17:00:00	1.00	1.00	0.01	0.01	1.00	1.00	0.10	0.10	1.00	1.00	0.01	0.01	1.00	1.00	0.10	0.10	1.00	1.00	0.00	0.00	1.00	1.00	0.08	0.08
08/21 18:00:00	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00
08/21 19:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 20:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 21:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 22:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 23:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 24:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4B Shading Test Example Results Comparing Window and Wall Sunlit Fraction Deltas for Shading Test 1 versus Test Case 2 (window frame added) and Test Case 3 (smaller window)

EnergyPlus Shading Tests

2.1.0.020

	Case 1 - Case 2				Case 1 - Case 2				Case 1 - Case 3				Case 1 - Case 3			
	17Base Case - 17Frame				17Base Case - 17Frame				17Base Case - 17SmallWin				17Base Case - 17SmallWin			
	Wall				**Window**				**Wall**				**Window**			
	NoShade	Ver	Hor	VerHor	NoShade	Ver	Hor	VerHor	NoShade	Ver	Hor	VerHor	NoShade	Ver	Hor	VerHor
	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame	Frame
Date/Time	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SURFACE SOUTH:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)	ZONE SUBSURFACE 1:Surface Ext Sunlit Fraction [](Hourly)
08/21 01:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 02:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 03:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 04:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 05:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 06:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 07:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 08:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 09:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
08/21 10:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.08	0.00
08/21 11:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.04	0.04	0.02
08/21 12:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	0.00	-0.01	0.00	-0.07	0.01	-0.02
08/21 13:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00	-0.01	0.00	0.00	0.01	0.01
08/21 14:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
08/21 15:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
08/21 16:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.08	0.08
08/21 17:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.01	0.01
08/21 18:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 19:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 20:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 21:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 22:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 23:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21 24:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00