EXPERIENCE TESTING ENERGYPLUS WITH THE ASHRAE 1052-RP BUILDING FABRIC ANALYTICAL TESTS

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ABSTRACT

The EnergyPlus building energy simulation software has been tested using the Building Fabric Analytical Verification Test Suite for Whole Building Energy Simulation Programs which was developed in ASHRAE research project 1052-RP. This test suite is a series of analytical tests for various components of the building fabric.

This test suite was initially used to test EnergyPlus beginning with beta versions prior to its official public release, and it is also applied prior to each new public release. The application of these tests proved to be very useful in several ways:

- Revealed algorithmic errors which were fixed.
- Revealed algorithmic shortcomings which were improved or eliminated through the use of more rigorous calculations for certain components.
- In later versions, caught newly introduced bugs before public release of updates.

INTRODUCTION

Formal independent testing has been an integral component in the development of EnergyPlus, a new building energy simulation program recently released by the U.S. Department of Energy (EnergyPlus 2004). Comprehensive testing of building energy analysis software is a difficult task given the infinite combinations of inputs that may be entered and the difficulties in establishing truth standards for all but the simplest cases. Testing has been guided by a comprehensive test plan which includes the following types of tests:

- Analytical tests which compare against mathematical solutions,
- Comparative tests which compare against other software,
- Sensitivity tests which compare small input changes versus a baseline run,
- Range tests which exercise the program over wide ranges of input values, and
- Empirical tests which compare against experimental data.

Published test suites which include reference results have been applied as much as possible in order to take advantage of the efforts of others to develop well-defined, reproducible tests.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) sponsored research project 1052-RP to develop analytical tests for the building fabric (Spitler 2001, Rees 2002). Documentation is available describing 16 tests and a software toolkit can be used to generate analytical results. The tests cover a variety of building envelope mechanisms including conduction, convection, solar gains, shading, infiltration, internal gains, radiant transfer, and ground coupling. While a variety of analytical conduction tests have been published before, this is the first test suite to provide analytical solutions for the other areas. These tests were applied to EnergyPlus as part of the review process for the research project. Several bugs were found in EnergyPlus while applying the tests, and the results of some of the tests have raised questions requiring further investigation. A complete report presenting the EnergyPlus results for all of the 1052-RP toolkit tests will be soon available on the EnergyPlus web site (Henninger, et. al., 2004). Due to space limitations in this paper, only selected test results are presented below along with discussion of lessons learned.

SUMMARY OF SIMULATION TESTS

The following tests were performed as specified in the ASHRAE 1052-RP test suite instructions:

A. Convection & conduction tests
   SSConv – steady state convection

SSCond – steady state conduction
TC1 – transient conduction, adiabatic wall
TC2 – transient conduction, step response
TC3 – transient conduction, sinusoidal driving temperature and multi-layer wall

B. Solar gains & shading tests
ExtSolRad – exterior solar radiation, opaque surfaces
SolRadGlazing – solar radiation, glazed surfaces
SolRadShade – solar radiation, window shading
WinReveal – solar radiation, window reveal shading
IntSolarDist – solar radiation, internal solar distribution

C. Infiltration tests
Infil-1 – fixed infiltration
Infil-2 – stack effect

D. Long wave radiation tests
IntLWRad – interior long wave radiation
ExtLWRad – exterior long wave radiation

E. Other tests
IntHeatGain – internal heat gains, convective and radiative
GrdCoup – ground coupling, slab-on-grade floor.

The test suite uses a cube shaped zone of 3m x 3m x 3m internal dimensions. Depending on which test is being performed, the surfaces of the zone are either exposed to ambient or are adiabatic. For one of the tests, IntLWRad, the aspect ratio of the zone is varied. The toolkit user is prompted for inside and outside temperatures, inside and outside convection coefficients, exterior envelope properties (for opaque surfaces and windows), shading parameters, location (4 cities available) and date (2 dates available), and internal load level.

Output from each test takes the form of a text file listing the analytical results which usually include the inside and outside surface temperatures and the steady state zone load. A weather file in the user chosen format is also created for use with the test program.

Prior to EnergyPlus version 1.1.0 Build 18 released in April 2003, the user was not allowed to specify the inside and outside convection coefficients for surfaces when running test suites like ASHRAE 1052-RP where the toolkit fixed the inside and outside surface coefficients at the same values for all surfaces. In accordance with ASHRAE accepted methodology, EnergyPlus recognized the difference between horizontal and vertical heat transfer through surfaces and assigned different convection coefficient values for walls, ceiling and floors depending on the type of convection coefficient algorithm chosen. So up until recently, when using the 1052-RP toolkit to compare to EnergyPlus results, the following procedure had to be used:

1. Prepare the EnergyPlus input (IDF) file which will simulate the Zone Description and Test Parameters as specified for a particular test
2. Run the 1052 toolkit software for a particular test to create a weather file in TMY2 format for the location chosen
3. Convert the TMY2 weather file for use with EnergyPlus using the EnergyPlus weather conversion software
4. Run EnergyPlus for the required time-step and simulation period to create a CSV output file containing surface temperature data, surface fluxes, zone load and surface convection coefficient data for each time step.
5. Rerun the 1052 toolkit using the inside and outside surface coefficients used by EnergyPlus. For cases where the EnergyPlus internal surface convection coefficients varied between surfaces, the area weighted average of the interior convection coefficients was used with the 1052 toolkit.
6. Compare results

With the release of EnergyPlus version 1.1.0. in April 2003, a new object was made available that allowed the user to fix the interior and exterior surface coefficients for a simulation. This made it much easier to set conditions required by such test suites as ASHRAE 1052-RP. Use of this option improved the comparison of the EnergyPlus results with the 1052-RP toolkit results. User defined exterior surface coefficients were specified for any tests which were run using EnergyPlus versions 1.1.0 and higher.

During the process of using the ASHRAE 1052-RP toolkit procedure to check EnergyPlus accuracy, several errors were discovered and corrected and are discussed below.

DISCUSSION OF RESULTS

Inverted Coordinates for Shade Fins

EnergyPlus and the 1052-RP toolkit were run for four SolRadShade test cases for a south facing 3m x 3m window which had:

1. No shading
2. a 0.6m semi-infinite overhang which extends out from the window along the top edge

3. 1.0m semi-infinite vertical fin which extends outward along the right edge of the window
4. both the overhang and fin (see Figure 1 for schematic of test model for this case) as described in (2) and (3) above.

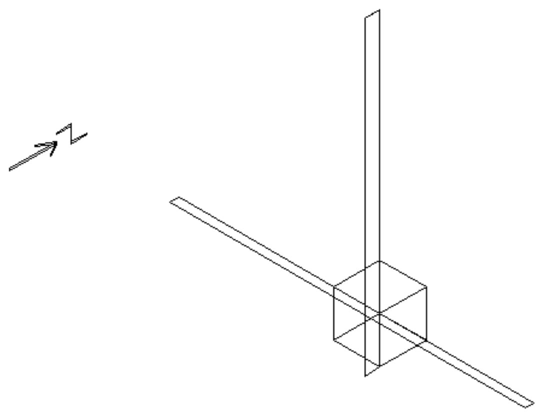

Figure 1 View of SolRadShade Test Model with South Facing Window and Semi-Infinite Overhang and Right Fin

The results of the tests are shown in Figure 2. The simulations were done for an August 21st day in Atlanta. The EnergyPlus simulation time step was set to 10 minutes (6 times per hour) so that a direct comparison could be made with the 1052-RP results which were also for 10 minute increments. A comparison with the 1052-RP results for these cases quickly indicated that the EnergyPlus results were not correct since the vertical fin cases were showing no significant reduction in zone load for any hours of the day compared to the no shading case. The two cases with overhangs did show the expected reduction in zone loads. Obviously, the vertical fin only case should have also showed some reduction in zone solar heat gain for some of the hours of the day. Further investigation revealed that EnergyPlus was not setting the coordinates of the fin vertices correctly. It had internally switched the length and width dimensions of the vertical fin which inverted the fin coordinates. This is an error that propagated from BLAST (Building Systems Laboratory, 1999) where the EnergyPlus shading calculation code originated. Figure 3 shows results once corrections were made to the EnergyPlus code. Figure 4 shows comparison with the 1052-RP results for the latest version of EnergyPlus.

Sunlit Areas of Surfaces

The SolRadShade test discussed above also allows the user to make a comparison of sunlit area calculations for shaded surfaces. Figure 5 presents the 1052-RP and EnergyPlus comparison for 3m x 3m window with a west orientation and an overhang along the top edge and vertical fin along the right edge. Prior to EnergyPlus version 1.0.1 Build 10, in order to save calculation time the sunlit area calculation was performed only once each hour at the beginning of the hour even though the simulation time step might be sub-hourly. This meant that the sunlit area calculated at the beginning of each hour for a shaded surface remained constant for the rest of the time steps within the hour until at the beginning of the next hour it was recalculated. A comparison of the total window sunlit area over the one day period of simulation to that of the 1052-RP toolkit indicated that EnergyPlus was predicting the sunlit area to be 7.2% higher than the toolkit value. Subsequently, beginning with EnergyPlus 1.0.1 Build 10, the shade calculation frequency was changed to be done for every time step. As shown in Figure 6, this greatly improved the comparison with the toolkit values for each time step. The total sunlit area calculated by EnergyPlus was now within 1% of the 1052-RP results on a daily basis.

Solar Time Shift

Figure 7 shows results for one of the window solar gain tests (SolRadGlazing) with south facing glass on August 21. The solar incident on the exterior and the solar transmitted by the window are compared throughout the day. Note the time shift between the simulated and analytical results for this case. This was observed for many of the solar-related tests. Initially this was thought to be a daylight savings time error, but that was ruled out. It was determined that the problem was attributed to the manner in which hourly weather data was being interpolated for sub-hourly time steps. Data recorded on weather files are in one hour increments where for solar radiation the values are the total or average for the hour. Prior to EnergyPlus 1.0.1 Build 8 the solar radiation value taken from the weather file was assumed to be for the beginning of the hour and interpolation was then used to get the solar radiation for the sub-hourly time steps during the hour. This approach resulted in the time shift shown in Figure 7. Things improved when a "half" solar radiation interpolation technique was adopted where the solar radiation value read from the weather file was assumed to be at the half-hour point and then interpolated to get the values at the other time steps within the hour. This technique resulted in very good correlation pattern with the 1052-RP toolkit results as shown in Figure 8 but the peak cooling load for EnergyPlus was 4.6% lower than that predicted by 1052-RP.

Underestimating Peak Cooling Loads with Windows

Like that demonstrated above, for most of the 1052-RP tests with windows EnergyPlus version 1.0 releases and earlier were predicting peak cooling loads that were smaller than those predicted by the 1052-RP toolkit. This difference was traced back to how EnergyPlus was handling solar transmittance through glass. Algorithm changes were made to the window calculation of transmittance and reflectance vs. angle of incidence for a single glass layer to correspond to what is currently in WINDOW 4 and WINDOW 5. The original routine was based on the method by E.U. Finlayson (Finlayson, et al) which is not used in either WINDOW 4 or WINDOW 5 and underestimated transmittance for angles of incidence >60 degrees. The current routine is based on an ASHRAE methodology (ASHRAE 2001). As shown in Figure 9 for the same SolRadGlazing case discussed in the previous section, excellent agreement was obtained with the 1052-RP analytical results with the new algorithm. The peak cooling load is now within 2% of the 1052-RP result.

CONCLUSION

Formal independent testing during the development of EnergyPlus has helped produce and ensure a more robust and credible tool. Application of published analytical test suite ASHRAE 1052-RP Building Fabric Analytical Verification Test Suite for Whole Building Energy Simulation Programs has been very useful in detecting bugs and confirming that basic modeling algorithms are working properly. Significant bugs found include:

- Inverted coordinates for shading fins
- Sunlit surface area calculation
- Solar time shift
- Window solar transmittance.

ACKNOWLEDGMENT

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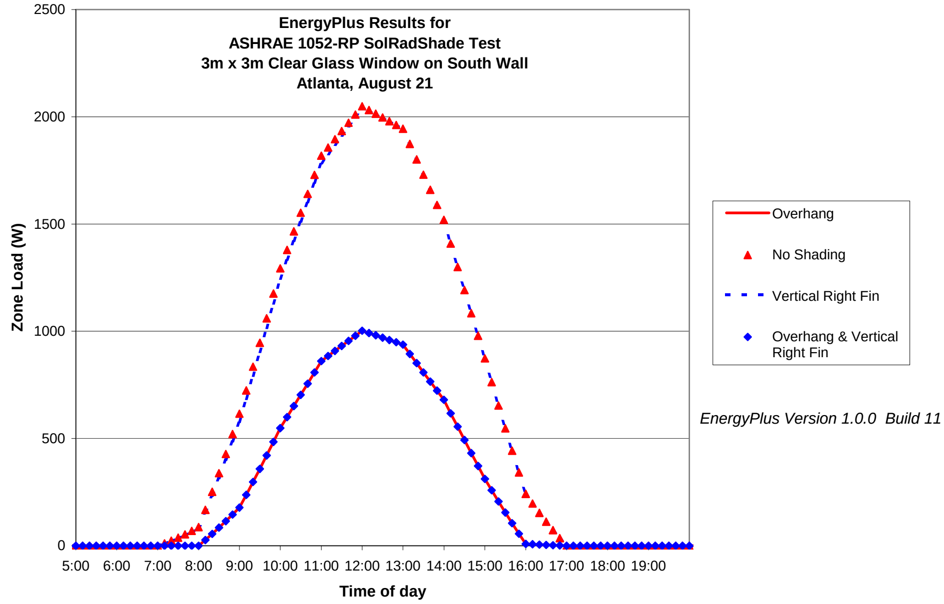

Figure 2 Results from ASHRAE 1052-RP SolRadShade Test – Window Solar Gain Indicating Error with Shade Fin Calculation. *In an early 1.0.0 version of EnergyPlus, the ASHRAE 1052-RP SolRadShade test uncovered a shade calculation problem with vertical fins. The case with a vertical fin along the right edge of a south window gave nearly the same results as the case with no fin. Cases with overhang did show a reduced zone load however.*

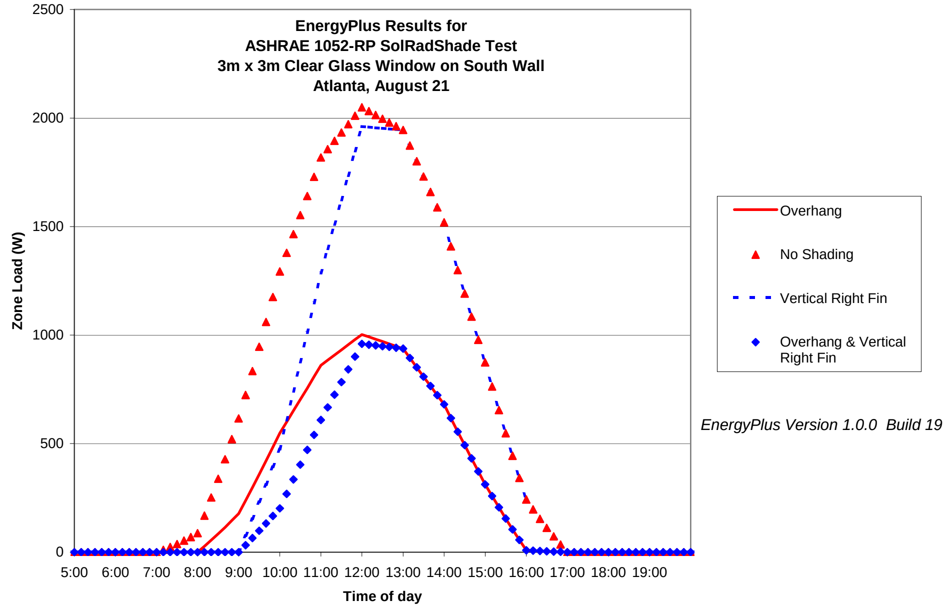

Figure 3 Results from ASHRAE 1052-RP SolRadShade Test – Window Solar Gain with Shade Fin Problem Corrected. *With the shade fin problem corrected, EnergyPlus is now showing a reduced zone load during the morning hours when a portion of the south window is shaded by the fin along the right edge of the window.*

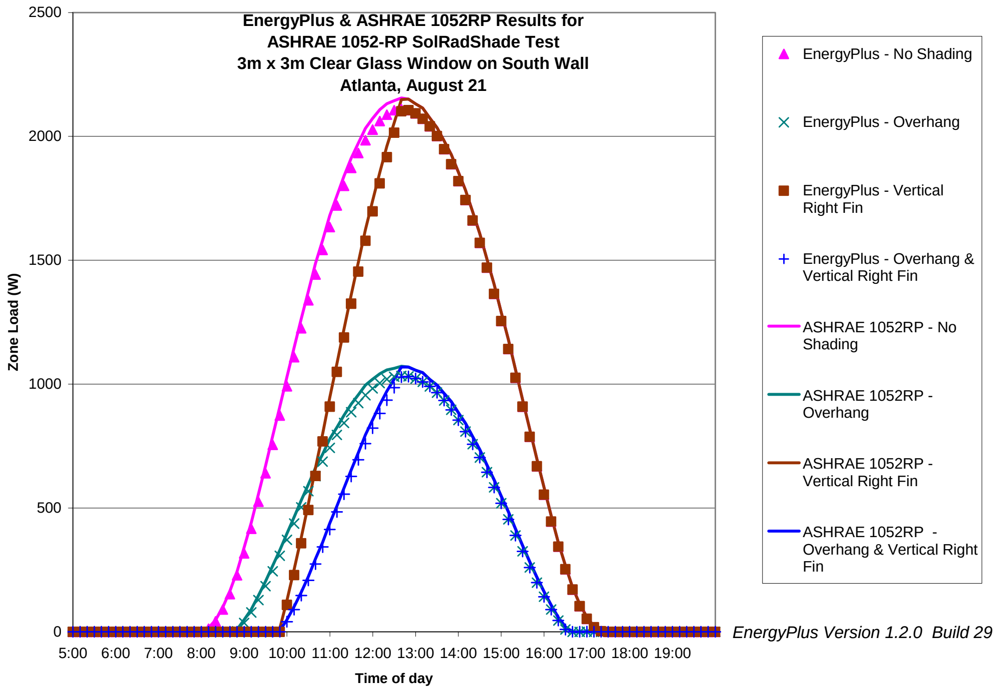

Figure 4 Comparison of EnergyPlus and ASHRAE 1052-RP Results for SolRadShade Test – Window Solar Gain with Latest Version of EnergyPlus. *Various improvements in EnergyPlus have resulted in excellent agreement with the 1052-RP analytical results. Note the smoother curves result from other changes discussed below.*

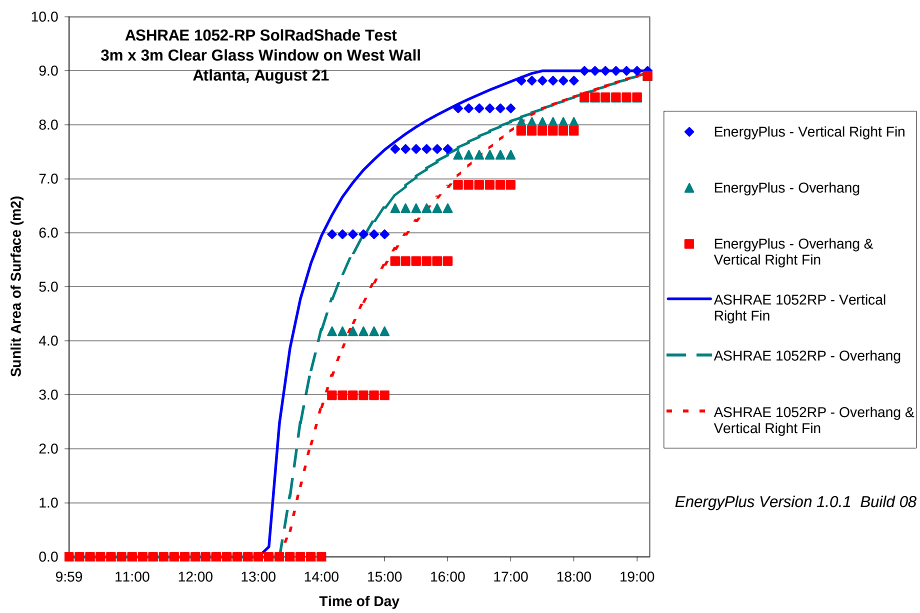

Figure 5 Results from ASHRAE 1052-RP SolRadShade Test – EnergyPlus Window Sunlit Area Calculated Once Each Hour. *Early versions of EnergyPlus calculated the sunlit area of a surface only at the beginning of each hour, holding it constant for the remainder of the hour. ASHRAE 1052-RP toolkit calculated the sunlit area for each 10 minute time step.*

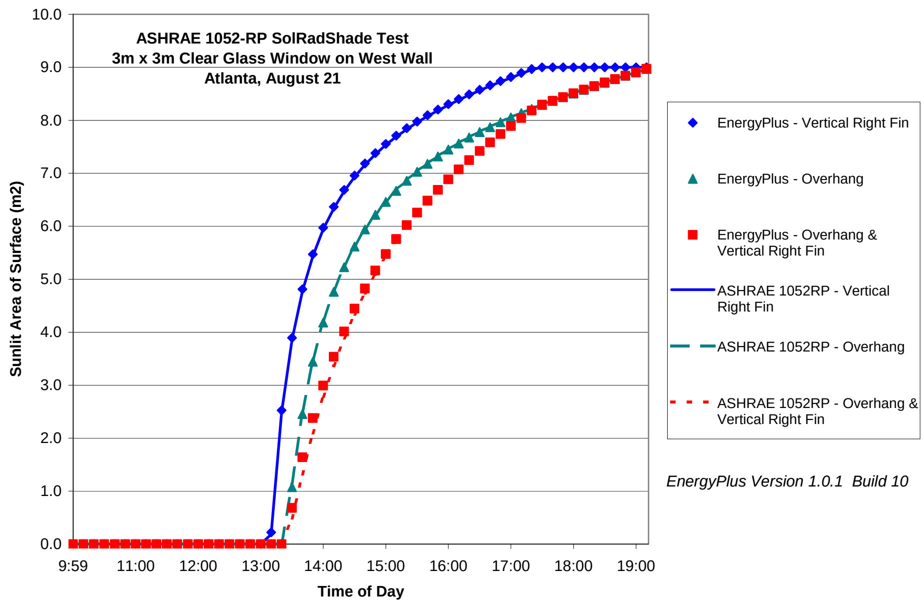

Figure 6 Results from ASHRAE 1052-RP SolRadShade Test – EnergyPlus Window Sunlit Area Calculated for Each Time Step. *Once EnergyPlus was changed to calculate the sunlit area of a surface for each time step of the simulation, good agreement resulted between EnergyPlus and the ASHRAE 1052-RP toolkit.*

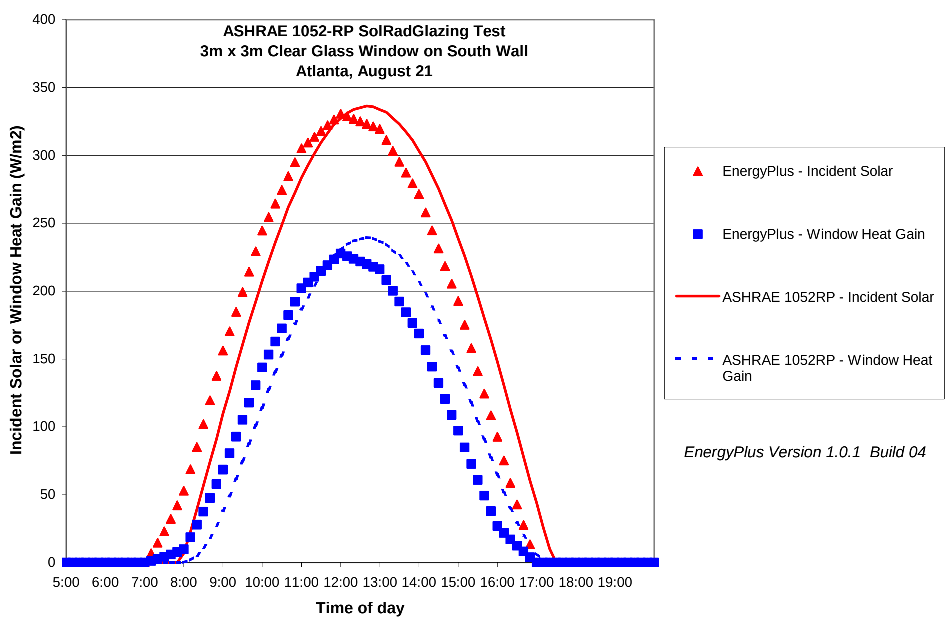

Figure 7 Results from ASHRAE 1052RP SolRadGlazing Analytical Test - Window Solar Gain, Atlanta, August 21, South Facing Clear Single-Pane Glass. *Note the time shift between the simulated and analytical results. Cause attributed to interpolation between hourly weather data for sub-hourly time steps.*

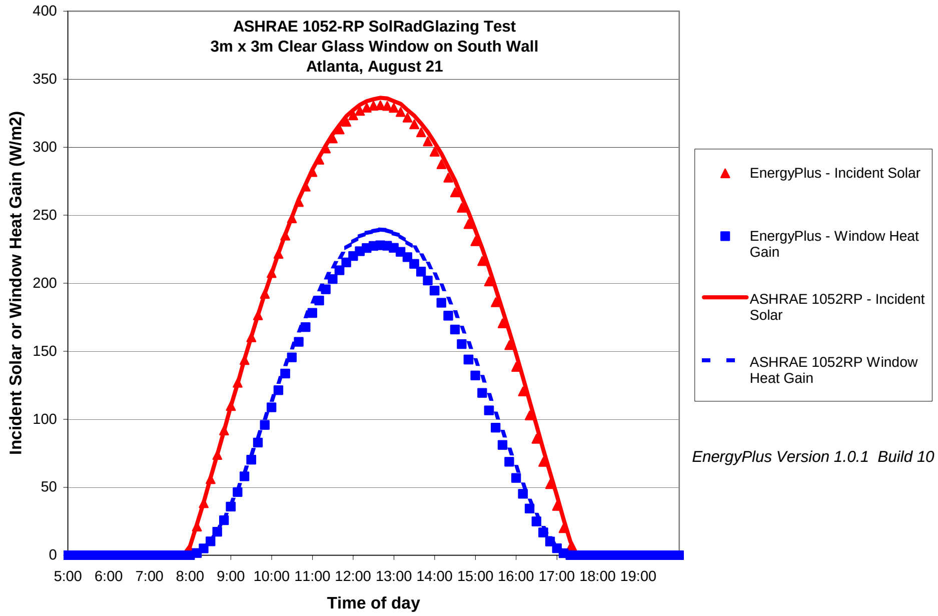

Figure 8 Results from ASHRAE 1052RP SolRadGlazing Analytical Test - Window Solar Gain, Atlanta, August 21, South Facing Clear Single-Pane Glass with Solar Time Shift Corrected. *Changing to a "half" solar interpolation technique for determining solar radiation values for sub-hourly time steps corrected the solar time shift.*

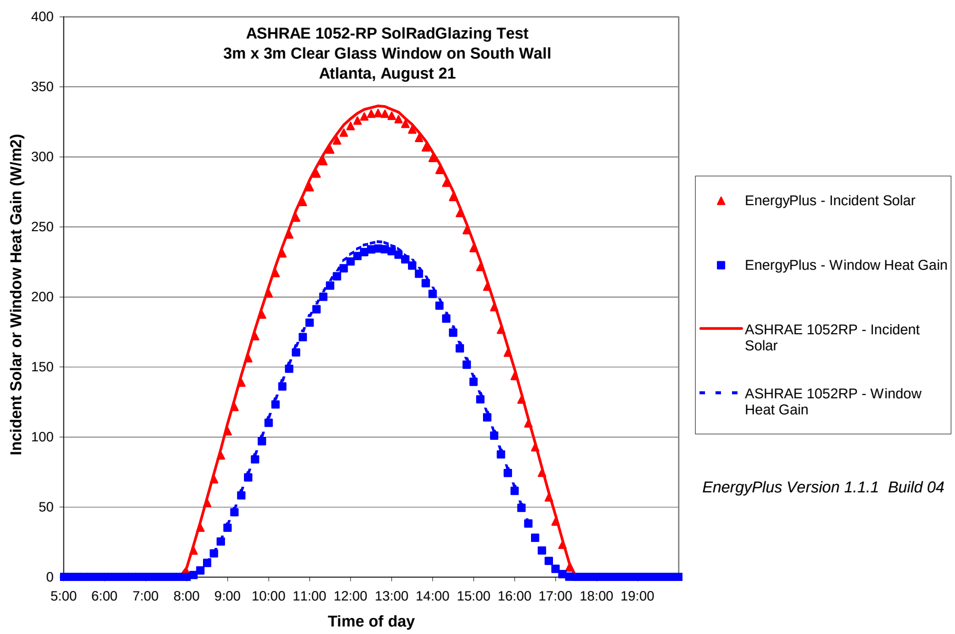

Figure 9 Results from ASHRAE 1052RP SolRadGlazing Analytical Test - Window Solar Gain, Atlanta, August 21, South Facing Clear Single-Pane Glass with Window Solar Transmittance Corrected. *Change in the window solar transmittance calculation improved the prediction of peak cooling loads for test cases with windows.*