# DOMUS Testing with ASHRAE 1052-RP Toolkit – Building Fabric Analytical Tests

**DOMUS – PROCEL EDIFICA Version Beta**

September 2010

Prepared for:

ELETROBRÁS/APC-PUCPR (Grant # ECV 283/2008)

Prepared by:

M.O. Abadie

Thermal Systems Laboratory (LST), Pontifical Catholic University of Paraná (PUCPR) , Rua Imaculada Conceicão, 1155 Curitiba, PR 80215-901, Brazil. http://www.pucpr.br/LST, www.domus.pucpr.br

Coordinated by: Prof. Nathan Mendes

**Preliminary Notes:**

This report is based upon work supported by ELETROBRÁS/APC-PUCPR in the frame of the research project "DOMUS – Software for Supporting the National Building Energy Efficiency Code: Validation, Research and Dissemination" (Grant # ECV 283/2008).

The structure and parts of text of the present report are based on the validation of EnergyPlus v4.0.0.024 document (Henninger and Witte, 2009).

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# 1 TEST OBJECTIVES AND OVERVIEW

## 1.1 Introduction

This report describes the modeling methodology and results for testing DOMUS according to ASHRAE 1052 – RP Toolkit “Building Fabric Analytical Tests”. This Toolkit is a suite of analytical tests to be used in testing the building fabric aspects of building energy analysis programs.

## 1.2 Test Type: Analytical

As pointed out in the report (Spitler *et al.*, 2001), “analytical solutions, in order to be tractable, have to be limited in scope and make a number of simplifying assumptions. Their purpose is to help in verification of the proper functioning of certain models and sub-models, rather than validation of the whole test program’s ability to model real situations”. In this way, they are the first step for testing building energy analysis programs, before validating the programs performing ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI/ASHRAE, 2007).

## 1.3 Test Suite: ASHRAE 1052 – RP

### 1.3.1 Overview

The test suite consists of 16 individual tests. The tests are organized into groups relating to particular heat transfer phenomena as follows:

- Group 1 – Convection and Conduction,
- Group 2 – Solar Gains and Shading,
- Group 3 – Infiltration,
- Group 4 – Long Wave Radiation, and
- Group 5 – Miscellaneous.

There is also some inter-relationship between some of the tests. In particular convection heat transfer is involved in nearly all the tests. It is generally not possible, for example, to remove convective resistances from a wall or window conductance, due to the organization of the input data structures of most programs. This makes it important that the steady state convection test is carried out first, and its results analyzed prior to the other tests.

The complete list of test is given in Table 1-1.

### 1.3.2 Test Zone

The tests series is based around a cube shaped of 3x3x3m internal size which surfaces are exposed or adiabatic vary from test to test. Only in two tests, IntRad and IntSolarDist, the aspect ratio requires to be varied. In some of the tests it is assumed that the zone load is instantaneously related to an internal surface temperature (e.g. tests TC1-3). In other words, the zone air is assumed to have no thermal mass. This assumption is often made in whole building energy simulation programs.

Table 1-1: List of the suite tests.

| Test Group | Test Title | Abbreviation |
|---|---|---|
| Group 1 | Steady-state Convection | SSConv |
| | Steady-state Conduction | SSCond |
| | Transient Conduction – Adiabatic Wall | TC1 |
| | Transient Conduction – Step Response | TC2 |
| | Transient Conduction – Sinusoidal Driving Temperature and Multi-layer Wall | TC3 |
| Group 2 | Exterior Solar Radiation – Opaque Surfaces | ExtSolRad |
| | Solar Radiation – Glazed Surfaces | SolRadGlazing |
| | Solar Radiation – Window Shading | SolRadShade |
| | Solar Radiation – Window Reveal Shading | WinReveal |
| | Solar Radiation – Internal Solar Distribution | IntSolarDist |
| Group 3 | Infiltration – Fixed Infiltration Rate | Infiltration 1 |
| | Infiltration – Stack Effect | Infiltration 2 |
| Group 4 | Interior Long Wave Radiation | IntRad |
| | External Long Wave Radiation | ExtLWRad |
| Group 5 | Internal Heat Gains – Convective and Radiant | IntHeatGain |
| | Ground Coupling – Slab on Ground Floor | GrdCoup |

### 1.3.3 Convective Heat Transfer Coefficients

An important issue is related to the existence of, or feasibility of "analytical" solutions for many phenomena. In the case of Convective Heat Transfer Coefficients (CHTC), there is no one universally acceptable "right" coefficient or correlation. Most convection correlations used for exterior and interior building heat transfer should be reducible to the form (e.g. that given by Yazdanian and Klems 1994 at zero air speed),

$$h = A + C\left(\left|T_s - T_\infty\right|\right)^n \tag{1}$$

Where $h$ is the CHTC (W/m$^2$.K), $A$ is a constant (W/m$^2$.K), $C$ is a constant (unit vary depending on n), $n$ is an exponent (-), $T_s$ is the surface temperature (K) and $T_\infty$ is the air temperature (K).

### 1.3.4 Surface Properties

In a number of the tests it is necessary to eliminate long-wave and/or solar radiation from the interior and/or exterior surface of the zone. This requires careful specification of the zone surface properties in the test program input data. It may be possible to achieve these goals in more than one way, depending on the exact input data requirements. A common approach would be to set solar absorptivity and long-wave emissivity for the relevant surfaces to zero.

### 1.3.5 Thermal Mass

Several of the tests rely on the fact that some or all of the zone fabric has zero thermal mass i.e. the product of the density and specific heat is zero. This is done so that certain heat gains can be assumed to be instantaneous. If program input does not allow specification of purely resistive walls it is important that the density and specific heat be set to zero, or as low as possible if for numerical reasons zero cannot actually be specified.

Some of the tests also require that certain elements of the zone fabric be heavyweight. This means that the density and heat capacity of the fabric materials must be significant. This can be achieved using building material thermal properties within the normal range.

### 1.3.6 Weather files

Whole building energy simulation programs generally require weather data input to run a simulation. To this end the test suite software will generate weather files corresponding to the test parameter values for each test. Weather parameters that do not require any variation as part of the test are kept fixed at default values (e.g. zero wind speed, fixed standard pressure) in the weather files. These files can be generated in either TMY2, WYEC2, or IWEC formats.

### 1.3.7 Solar Data

Arriving at tests involving solar algorithms and data that can be considered as truly 'analytical' is problematic. This is mainly because of the empirical nature of all models of diffuse solar radiation. In view of this all the solar radiation tests in this series involve only direct beam solar radiation. In each of the solar radiation tests it is therefore necessary that diffuse radiation and radiation reflected from surroundings are eliminated. The weather files accordingly only contain data for direct normal radiation at ground level. Zeros are inserted for extraterrestrial and diffuse radiation.

Each of the solar radiation tests involves the testing of the program models associated with calculation of solar position. Rather than generate reference data by use of an algebraic model (of which there are several), reference data have been obtained for two sites and two dates from the U.S. Naval Observatory. This data and that reported in the test output and weather files are recorded at standard times for the time zone appropriate to the location. Correction for daylight savings time should be disabled in the program to be tested, or the results should be shifted by one hour.

## 1.4 MODELING NOTES

### 1.4.1 Weather file

ATLANTA.TMY2 weather file provided by the ASHRAE 1052 – RP Toolkit has then been converted to DOMUS weather file (DRYCOLD.DWF) using DOMUS weather converter.

### 1.4.2 Material thermal properties

Material thermal properties needed in the tests suite have been added to DOMUS material library.

### 1.4.3 Window

The window is single-glazed made up of one NFRC 102 glass. The extinction coefficient and refractive index of the glazed surface have been calculated for the NFRC 102 glass and used in the ASHRAE 1052 – RP Toolkit to generate results according to this particular glass. The resistive model (DOMUS default model) has been used here.

### 1.4.4 Infiltration

Constant Infiltration has been set up using DOMUS "Direct ventilation" option. Pressure-driven infiltration has been modeled via the Single-Sided Ventilation model proposed by ASHRAE that handles the case of multiple apertures on the same wall.

### 1.4.5 Internal gain

Internal gain of 3000W (with different convective/radiative proportions) has been added to the zone through DOMUS "Heat Gain" option.

### 1.4.6 Convective Heat Transfer Coefficients

DOMUS provides three options for the calculation of the Convective Heat Transfer Coefficient (CHTC):

1. Fixed value,
2. Automatic calculation according to the wind velocity and direction (Emmel *et al.*, 2007) for the external CHTC and to the surface temperature and local air velocity (Mc Adams, 1954) for the internal one,
3. Automatic calculation according to the surface temperature (Yazdanian and Klems, 1994 ) with adjustable coefficients.

The last option has been implemented to perform the current tests suite.

### 1.4.7 Internal long-wave radiation treatment

The "Mean Radiant Temperature/Balanced" algorithm developed by Walton (1980) has been used. The main advantage of this algorithm is that it does not require any calculation of view factors while it provides good results for simple shape zones (cubic and parallelepipedic zones).

### 1.4.8 Internal short-wave radiation treatment

The algorithm implemented in DOMUS treats the absorption/reflection of short-wave radiation in a zone as follow:

1. Direct solar radiation initially hits the floor. The reflected portion is absorbed by the other surfaces in proportion to their area-absorptance products.
2. Diffuse solar radiation is absorbed by all the surfaces in proportion to their area-absorptance products.
3. Radiative part of the internal heat gain is absorbed by all the surfaces in proportion to their area-absorptance products.

The treatment of the internal solar distribution is performed once in Test IntSolarDist. Due to DOMUS algorithm, floor was assigned as massless instead of the west wal.

### 1.4.9 Simulation settings

All results presented here have been obtained using a time step of 1 minute and a spatial discretization of 1 volume/cm for the finite volume discretization of opaque walls. Note that for most cases, a time step of 10 min provides similar results.

# 2 RESULTS AND DISCUSSION

## 2.1 Group 1

### 2.1.1 Steady-state Convection – Test SSConv

The test zone is made up of 5 adiabatic surfaces and one external surface which is constructed of a single homogeneous layer (thickness = 0.1 m, conductivity = 1.0 W/m.K) with inside temperature held constant at 10°C and outside temperature held constant at 40°C. Effects of solar irradiation, long-wave radiation, infiltration and internal heat gains are eliminated. Table 2-1 presents the inputs to the simulation. Results are given in Table 2-2. DOMUS results for Test SSConv are identical to ASHRAE 1052 – RP analytical results.

Table 2-1: Inputs – Test SSConv.

| Test Parameter | Value | Units |
|---|---|---|
| Thermal conductivity | 1 | W/m.K |
| Thickness | 0.1 | m |
| Inside temperature | 10 | °C |
| Outside Temperature | 40 | °C |
| Outside correlation coefficient ‘A’ | 0 | $W/m^2.K$ |
| Outside correlation coefficient ‘C’ | 0.84 | - |
| Outside correlation exponent ‘n’ | 0.333 | - |
| Inside correlation coefficient ‘A’ | 0 | $W/m^2.K$ |
| Inside correlation coefficient ‘C’ | 1.49 | - |
| Inside correlation exponent ‘n’ | 0.345 | - |

Table 2-2: Results – Test SSConv.

| Test Parameter | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| Heat Flux | $W/m^2$ | 34.46 | 34.46 | 0.00% |
| Zone Load | W | 310.14 | 310.13 | 0.00% |
| Inside Surface Temperature | °C | 20.3329 | 20.33 | -0.01% |
| Outside Surface Temperature | °C | 23.7789 | 23.78 | 0.00% |
| Inside convection coefficient | $W/m^2.K$ | 3.3349 | 3.3349 | |
| Outside convection coefficient | $W/m^2.K$ | 2.1244 | 2.1244 | |

* Differences are relative to ASHRAE 1052 – RP values.

### 2.1.2 Steady-state Conduction – Test SSCond

The test zone is made up of one external surface which is a multi-layer homogeneous slab which is massless to avoid transient effects. The slab had properties are described in Table 2-3. The inside temperature held constant at 10°C and outside temperature held constant at 40°C. The effects of solar irradiation, long wave radiation, infiltration and internal heat gains are eliminated. Table 2-4 presents the analytical and DOMUS results. DOMUS results for Test SSCond are identical to ASHRAE 1052 – RP analytical results.

Table 2-3: Inputs – Test SSCond.

| Test Parameter | Value | Units |
|---|---|---|
| Number of fabric layers | 3 | - |
| Thermal conductivity: Layer 1 | 0.1 | W/m.K |
| Thickness: Layer 1 | 0.1 | m |
| Thermal conductivity: Layer 2 | 0.05 | W/m.K |
| Thickness: Layer 2 | 0.05 | m |
| Thermal conductivity: Layer 3 | 0.25 | W/m.K |
| Thickness: Layer 3 | 0.05 | m |
| Inside temperature | 10 | °C |
| Outside Temperature | 40 | °C |
| Outside correlation coefficient 'A' | 0 | $W/m^2.K$ |
| Outside correlation coefficient 'C' | 0.84 | - |
| Outside correlation exponent 'n' | 0.333 | - |
| Inside correlation coefficient 'A' | 0 | $W/m^2.K$ |
| Inside correlation coefficient 'C' | 1.49 | - |
| Inside correlation exponent 'n' | 0.345 | - |

Table 2-4: Results – Test SSCond.

| Test Parameter | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| Heat Flux | $W/m^2$ | 9.1554 | 9.155 | 0.00% |
| Zone Load | W | 82.4 | 82.395 | -0.01% |
| Inside Surface Temperature | °C | 13.8568 | 13.85 | -0.05% |
| Outside Surface Temperature | °C | 33.9987 | 33.99 | -0.03% |
| Inside convection coefficient | $W/m^2.K$ | 2.3737 | 2.3737 | |
| Outside convection coefficient | $W/m^2.K$ | 1.5255 | 1.5255 | |

* Differences are relative to ASHRAE 1052 – RP values.

### 2.1.3 Transient Conduction – Adiabatic Wall – Test TC1

The test zone has one external surface of homogeneous construction. All other surfaces are adiabatic but remain convectively coupled. The external temperature undergoes a 30°C step change from 10°C to 40°C while the inside temperature is allowed to float in response to the inside surface of the test construction in order to simulate adiabatic conditions at the inside surface of the test wall (Table 2-5). The effects of solar irradiation, long wave radiation, infiltration and internal heat gains are eliminated. DOMUS results for Test TC1 are very close to ASHRAE 1052 – RP analytical results (Figure 2-1).

Table 2-5: Inputs – Test TC1.

| Test Parameter | Value | Units |
|---|---|---|
| Thermal conductivity | 0.14 | W/m.K |
| Density | 500 | $Kg/m^3$ |

| | | |
|---|---|---|
| Specific heat capacity | 2500 | J/kg.K |
| Thickness | 0.1 | m |
| Initial temperature ($T_0$) | 10 | °C |
| Temperature step ($\Delta T$) | 30 | °C |
| External convection coefficient | 20 | $W/m^2.K$ |
| Internal convection coefficient | 20 | $W/m^2.K$ |

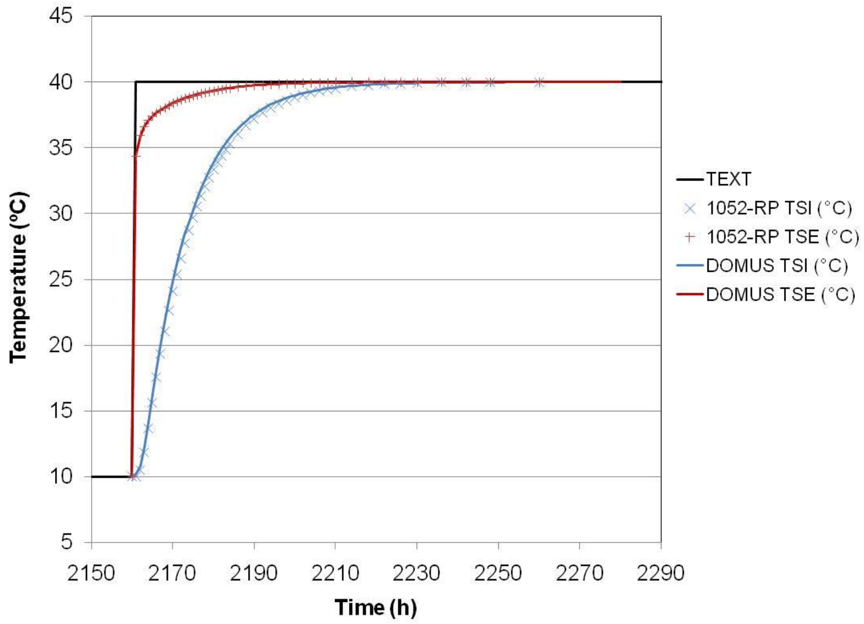


Figure 2-1: External and internal surface temperatures versus time – Test TC1.

### 2.1.4 Transient Conduction – Step Response – Test TC2

The test zone is identical to the TC1 test zone. The internal zone air temperature is held constant at 20°C. The external temperature is initially set at the same temperature. Then the external temperature undergoes a 30°C step change up from 10°C to 40°C where it is held constant for a long period of time after which it undergoes a step change down to -20°C. The effects of solar irradiation, long wave radiation, infiltration and internal heat gains are eliminated. DOMUS results for Test TC2 are very close to ASHRAE 1052 – RP analytical results (Figure 2-2 and Figure 2-3).

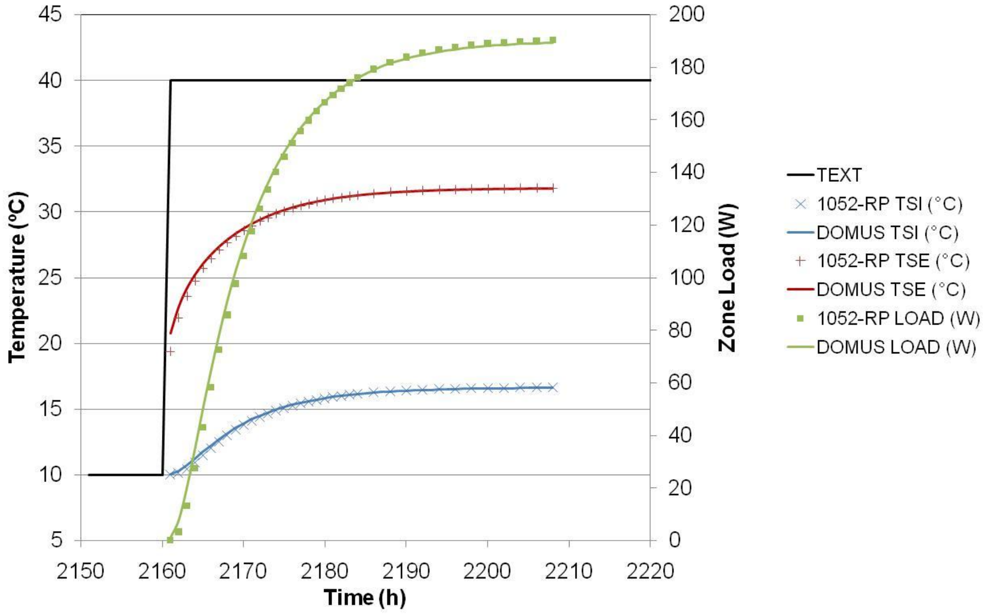


Figure 2-2: Response to an external temperature step up – Test TC2.

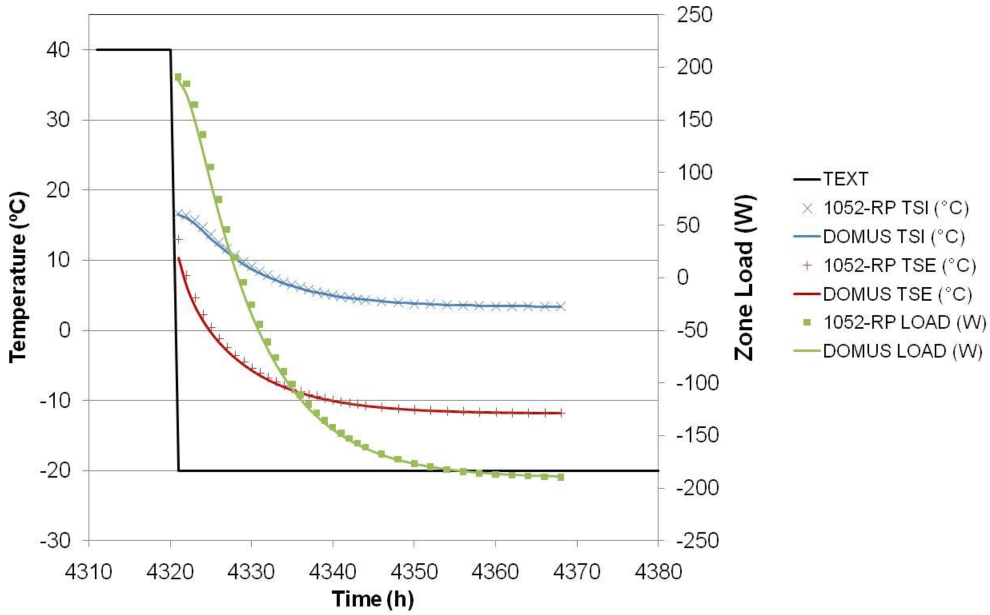


Figure 2-3: Response to an external temperature step down – Test TC2.

### 2.1.5 Transient Conduction – Sinusoidal Driving Temperature and Multi-layer Wall – Test TC3

The test zone is the same than the two previous cases. The external temperature is a steady-periodic sinusoidal change about a 20°C mean temperature with amplitude of +15°C and a period of fluctuation of 24 hours. All other surfaces are adiabatic but remain convectively coupled. The internal zone air temperature is held constant at the mean external temperature (20°C). The effects of solar irradiation, long wave radiation, infiltration and internal heat gains are eliminated. DOMUS results for Test TC3 are identical to ASHRAE 1052 – RP analytical results (Figure 2-4).

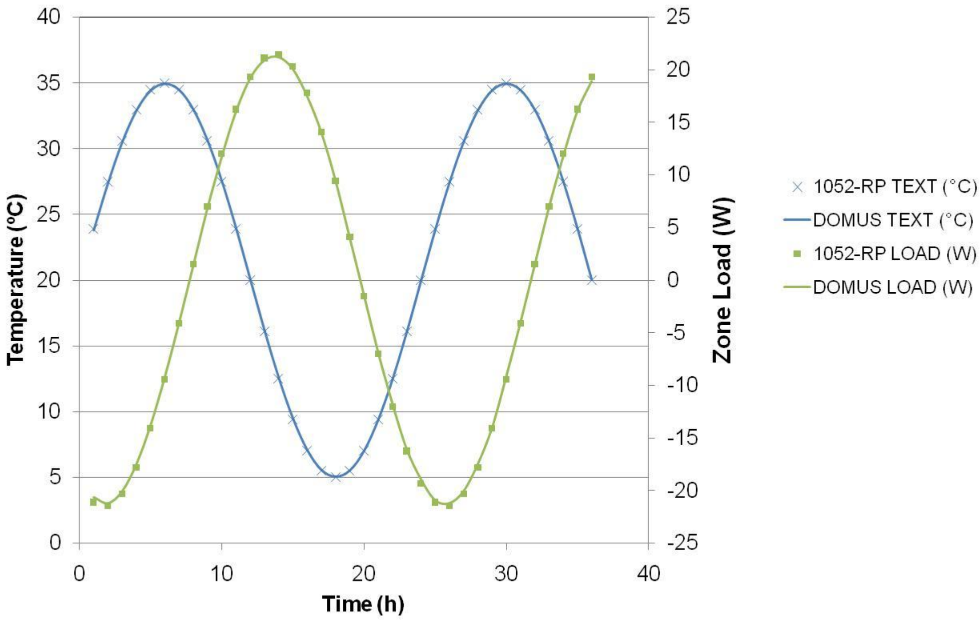


Figure 2-4: Response to a sinusoidal external temperature – Test TC3.

## 2.2 Group 2

**Preliminary comments for Group 2 tests:** as discussed and demonstrated by Henninger and Witte (2009) for EnergyPlus program, results show some differences in the shape of the curves. *The curves for the 1052 – RP Toolkit have a smooth shape while the EnergyPlus curves are more jagged. It was thought that this difference in shape is due to the interpolation that EnergyPlus must do to get 10 minute increment weather for the simulation. Usually each test contained with the ASHRAE 1052 – RP Toolkit produces two out files – one with analytical results on a 10 minute increment basis and a weather file containing hourly weather data in TMY2 format. EnergyPlus then must interpolate the hourly temperature and solar data from the weather file to get weather data for the 10 minute timestep simulation periods. This creates anomalies between the weather data used by the 1052-RP Toolkit and EnergyPlus.* Those small discrepancies are also observed for DOMUS and should be accounted for the results analysis. The reader should be also aware that the current version of DOMUS does not allowed to save the results regarding Solar Radiation and Heat Flux through Glazing with time step smaller than 1 hour even if the simulation itself can be performed with any time step value.

### 2.2.1 Exterior Solar Radiation – Opaque Surfaces – Test ExtSolRad

The test zone is similar to that described in Test SSCond with a multi-layer external surface (Table 2-6). Except for the external surface, all other surfaces are adiabatic and have no thermal mass. The inside and outside temperatures are fixed at 20°C. The effects of long wave radiation, infiltration and internal heat gains are eliminated. The location was chosen as Atlanta and date set at August 21. Direct normal solar radiation at ground level was taken from ASHRAE 1052 – RP weather files provided with the software. The external test surface was chosen as having a 90° tilt (vertical) and two orientations: 180° azimuth (facing South) and 270° azimuth (facing West). Figure 2-5 and Figure 2-6 present the evolution of the incident solar flux (ISF) and internal heat flux (FS) for south and west orientation, respectively. Considering the “Preliminary comments for Group 2 tests”, DOMUS results for Test ExtSolRad are close to ASHRAE 1052 – RP analytical results.

Table 2-6: Inputs – Test ExtSolRad.

| Test Parameter | Value | Units |
|---|---|---|
| Solar absorption of the surface | 0.4 | - |
| Number of layers | 3 | - |
| Thermal conductivity: layer 1 | 1.15 | W/m.K |
| Thickness: layer 1 | 0.1 | M |
| Thermal conductivity: layer 2 | 1.05 | W/m.K |
| Thickness: layer 2 | 0.1 | M |
| Thermal conductivity: layer 3 | 1.15 | W/m.K |
| Thickness: layer 3 | 0.1 | M |
| External air temperature | 20 | °C |
| Internal air temperature | 20 | °C |
| Outside correlation coefficient ‘A’ | 0.0 | $W/m^2.K$ |
| Outside correlation coefficient ‘C’ | 0.84 | - |
| Outside correlation exponent ‘n’ | 0.333 | - |
| Inside correlation coefficient ‘A’ | 0.0 | $W/m^2.K$ |
| Inside correlation coefficient ‘C’ | 1.49 | - |
| Inside correlation exponent ‘n’ | 0.345 | - |

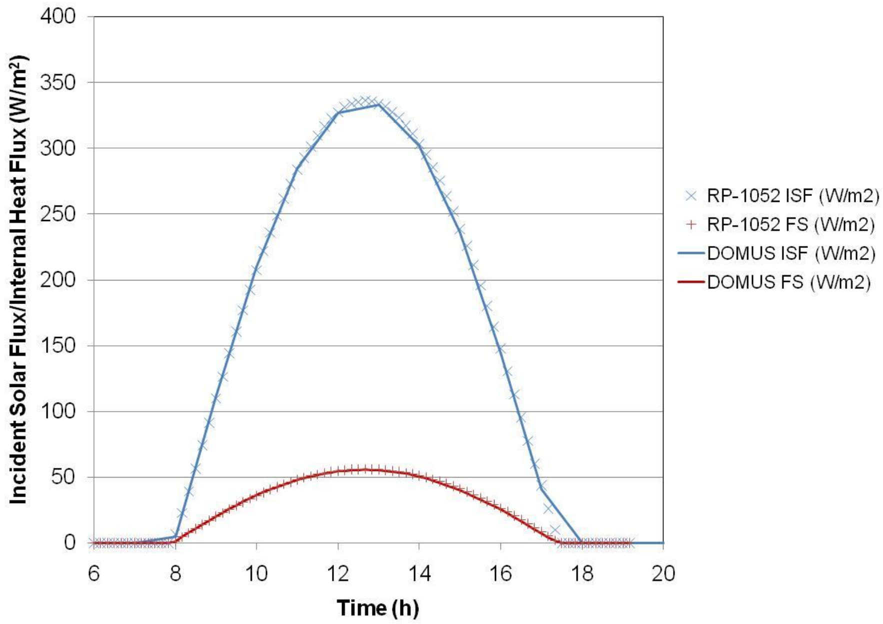


Figure 2-5: Incident solar flux (ISF) and internal heat flux (FS) – South Wall – Test ExtSolRad.

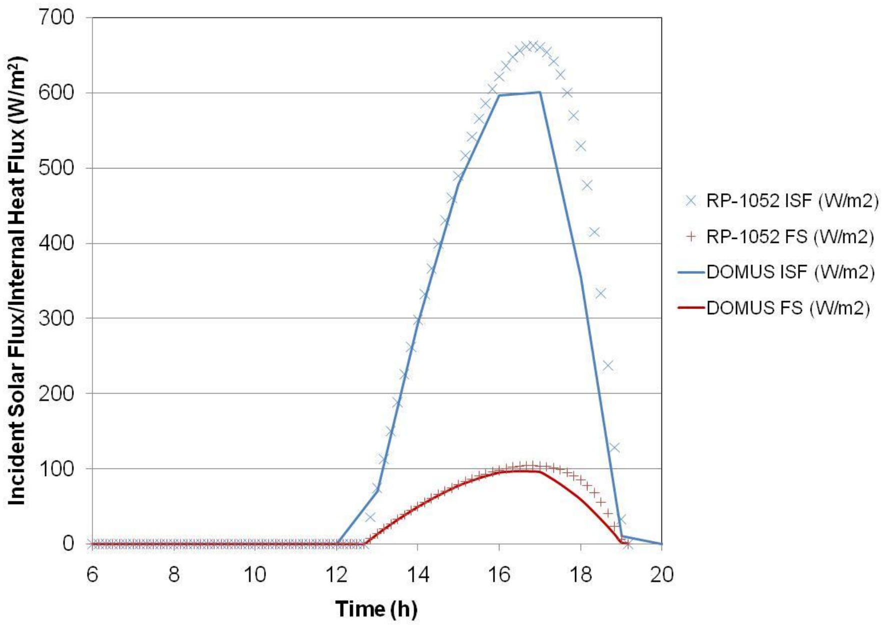


Figure 2-6: Incident solar flux (ISF) and internal heat flux (FS) – West Wall – Test ExtSolRad.

### 2.2.2 Solar Radiation – Glazed Surfaces – Test SolRadGlazing

The test zone is a 3 m x 3 m x 3 m cube with one external surface which is entirely glazed. The window system is a single pane of clear glass with no frame or reveal (Table 2-7). It is assumed that the glazed surface has no thermal mass and high conductivity so that it will be of uniform temperature. All other surfaces are black, adiabatic and have no thermal mass. Diffuse radiation is locked out. The inside and outside temperatures are fixed at 20°C. The effects of long wave radiation, infiltration and internal heat gains are eliminated. The location was chosen as Atlanta and date set at August 21. Direct normal solar radiation at ground level was taken from ASHRAE 1052 – RP weather files provided with the software. The external test surface was chosen as having a 90° tilt (vertical) and two orientations: 180° azimuth (facing South) and 270° azimuth (facing West). Considering the "Preliminary comments for Group 2 tests", DOMUS results for Test SolRadGlazing are close to ASHRAE 1052 – RP analytical results (Figure 2-7 and Figure 2-8).

Table 2-7: Inputs – Test SolRadGlazing.

| Test Parameter | Value | Units |
|---|---|---|
| Thickness of the surface | 0.003048 | m |
| Extinction coefficient of the surface | 31.66368 | /m |
| Refractive index of the surface | 1.519759 | - |
| External air temperature | 20 | °C |
| Internal air temperature | 20 | °C |
| Outside correlation coefficient 'A' | 0.0 | $W/m^2.K$ |
| Outside correlation coefficient 'C' | 0.84 | - |
| Outside correlation exponent 'n' | 0.333 | - |
| Inside correlation coefficient 'A' | 0.0 | $W/m^2.K$ |
| Inside correlation coefficient 'C' | 1.49 | - |
| Inside correlation exponent 'n' | 0.345 | - |

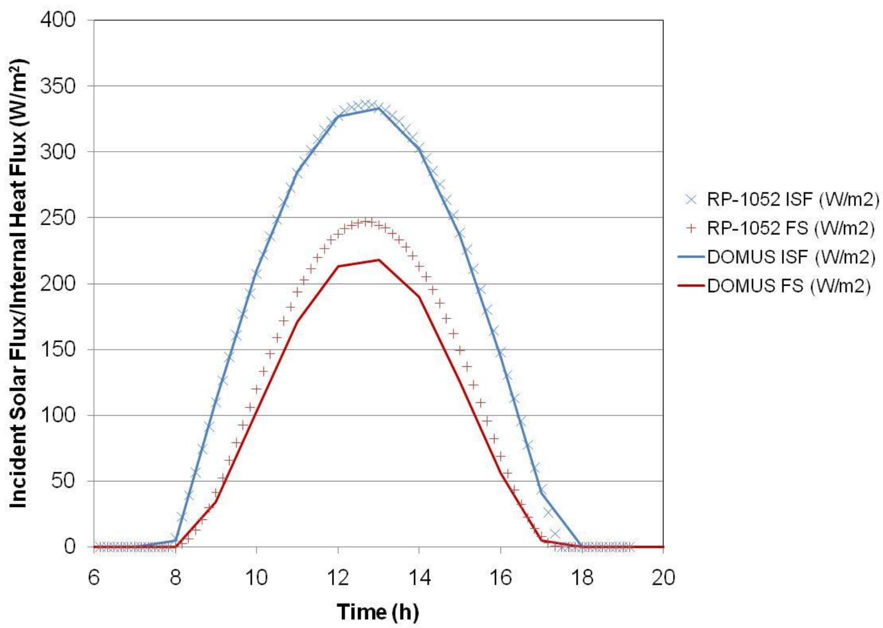


Figure 2-7: Incident solar flux (ISF) and internal heat flux at glazing surface (FS) – South Wall – Test SolRadGlazing.

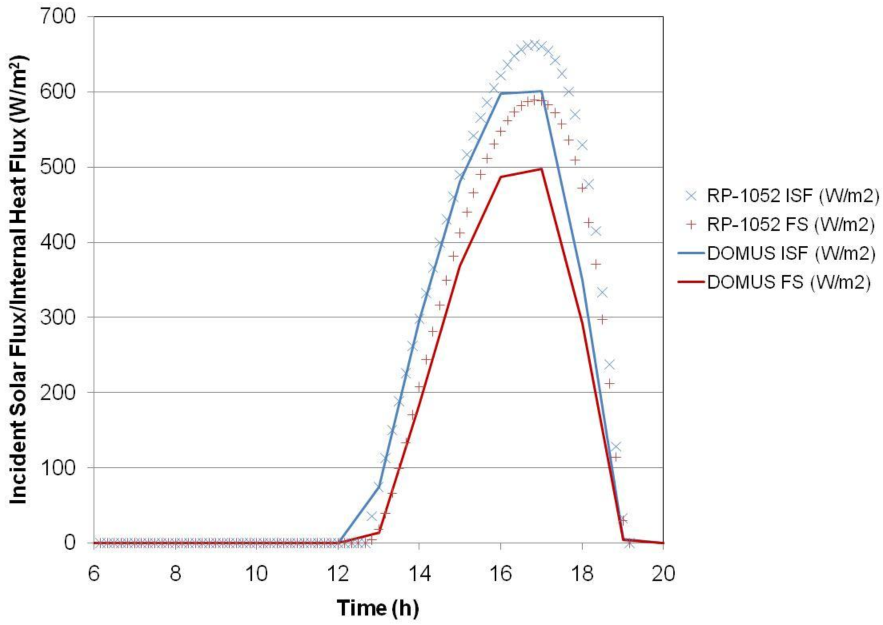


Figure 2-8: Incident solar flux (ISF) and internal heat flux at glazing surface (FS) – West Wall – Test SolRadGlazing.

### 2.2.3 Solar Radiation – Window Shading – Test SolRadShade

The test zone is a 3m x 3m x 3m cube with one external surface which is entirely glazed. External shading surfaces are attached to the glazed surface. Three different shade configurations are tested: semi-infinite horizontal fin (overhang, 0.6m depth), semi-infinite vertical fin (1.0m depth), and combination of semi-infinite horizontal and vertical fins (Figure 2-9). The test surface was chosen to have a tilt angle of 90° (vertical) and two orientations – an azimuth of 180° (facing south) and an azimuth of 270° (facing west). The vertical fin was assumed to be attached to the right edge of the glazed surface. Table 2-7 presents the values of the glazing characteristics and convective heat transfer coefficient coefficients. Figure 2-10 and Figure 2-11 present the evolution of the sunlit area during the day for the south and west windows, respectively. There is a perfect agreement between DOMUS and ASHRAE 1052 – RP analytical results. Figure 2-12 and Figure 2-13 illustrate the variation of the zone load during the day. Considering the "Preliminary comments for Group 2 tests", DOMUS results for Test SolRadShade are close to ASHRAE 1052 – RP analytical results.

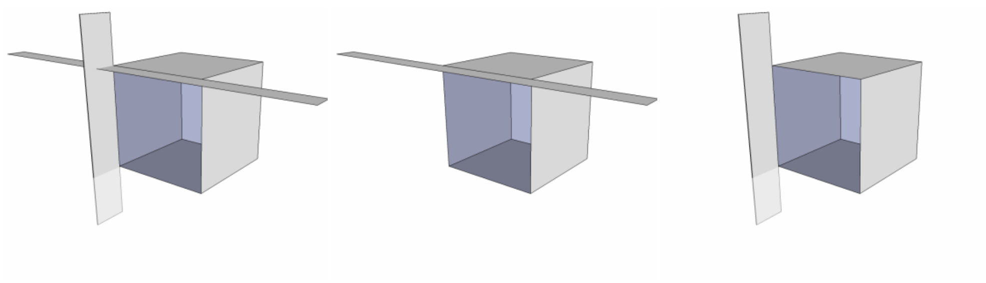

Figure 2-9: Shading configurations: HorVert, Hor and Vert – Test SolRadShade.

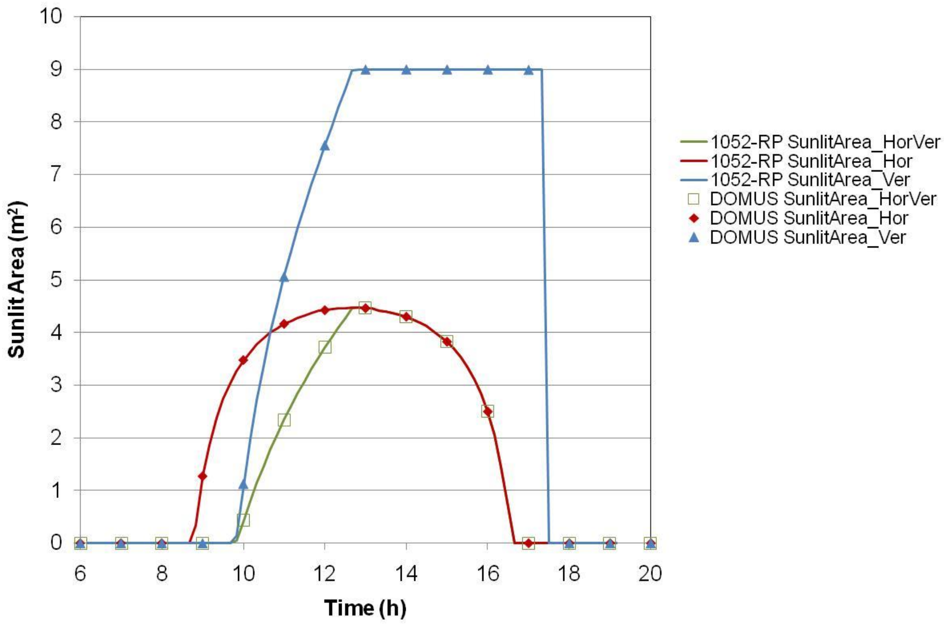


Figure 2-10: Sunlit area – South Wall – Test SolRadShade.

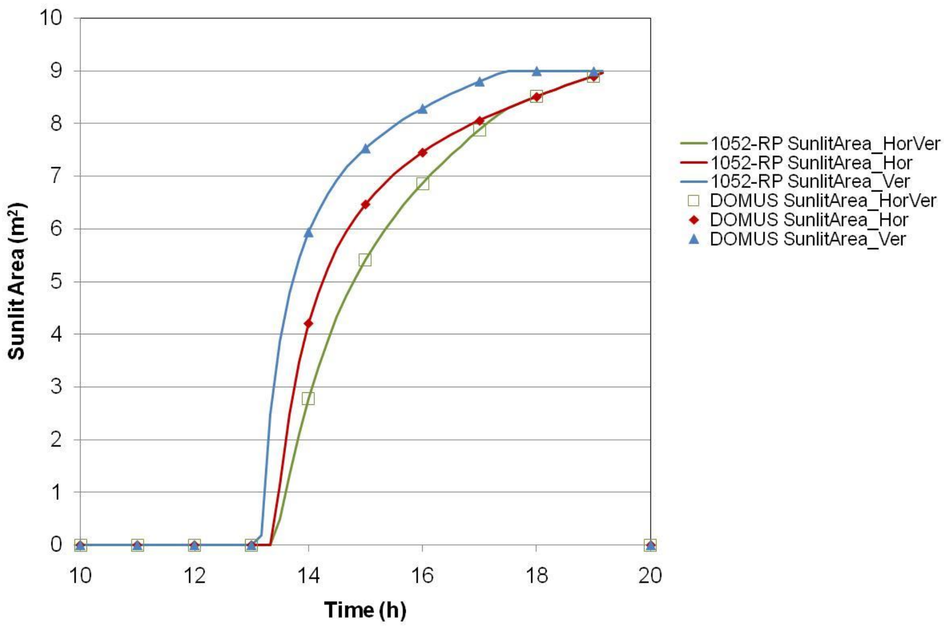


Figure 2-11: Sunlit area – West Wall – Test SolRadShade.

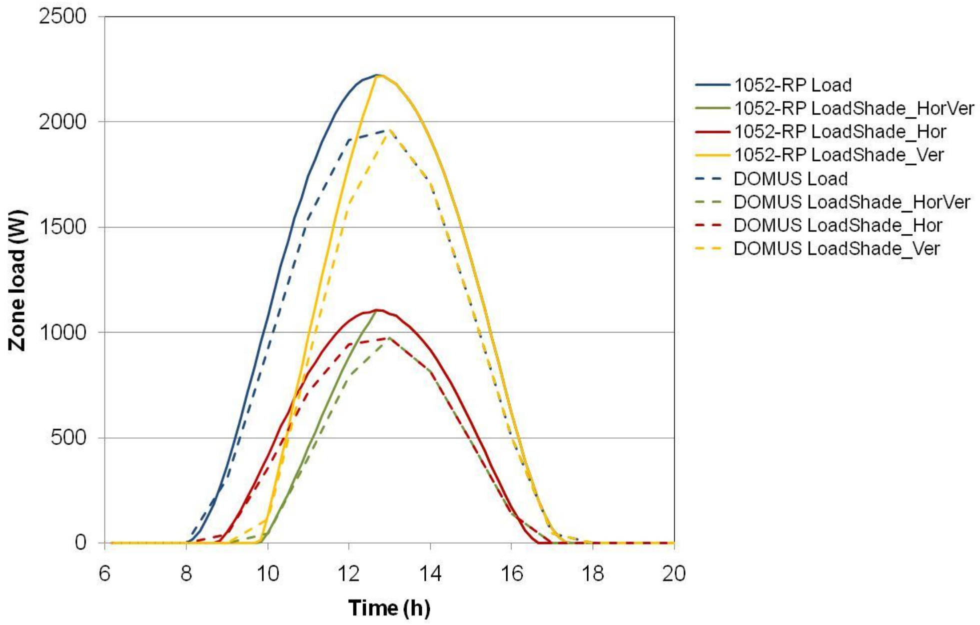


Figure 2-12: Zone load – South Wall – Test SolRadShade.

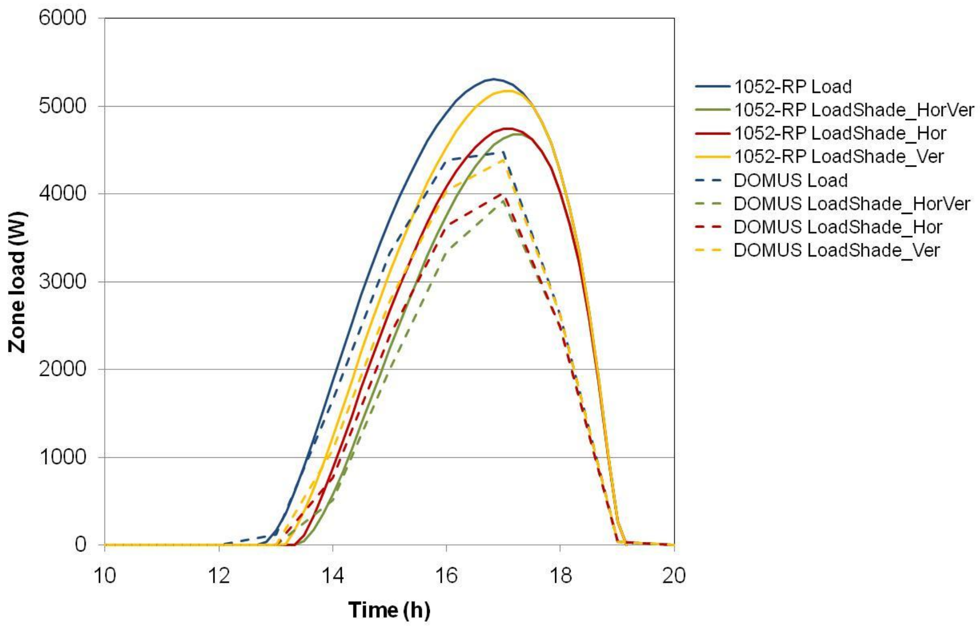


Figure 2-13: Zone load – West Wall – Test SolRadShade.

### 2.2.4 Solar Radiation – Window Reveal Shading – Test WinReveal

This test is similar to the SolRadShade test described in the previous section except that the test surface is a 3 m x 3 m opaque wall with a 2 m x 2 m window which is setback into the window opening by 0.3 m. The test surface here was chosen to be south facing. Table 2-7 presents the values of the glazing characteristics and convective heat transfer coefficient coefficients. Window reveal is modeled in DOMUS using horizontal and vertical fins of 0.3 m depth. As before, there is a perfect agreement between DOMUS and ASHRAE 1052 – RP analytical results for the sunlit area (Figure 2-14). Figure 2-15 presents the evolution of the zone load during the day. Same trends are observed between DOMUS and ASHRAE 1052 – RP analytical results. Differences are caused by the use of hourly-based weather file (see "Preliminary comments for Group 2 tests").

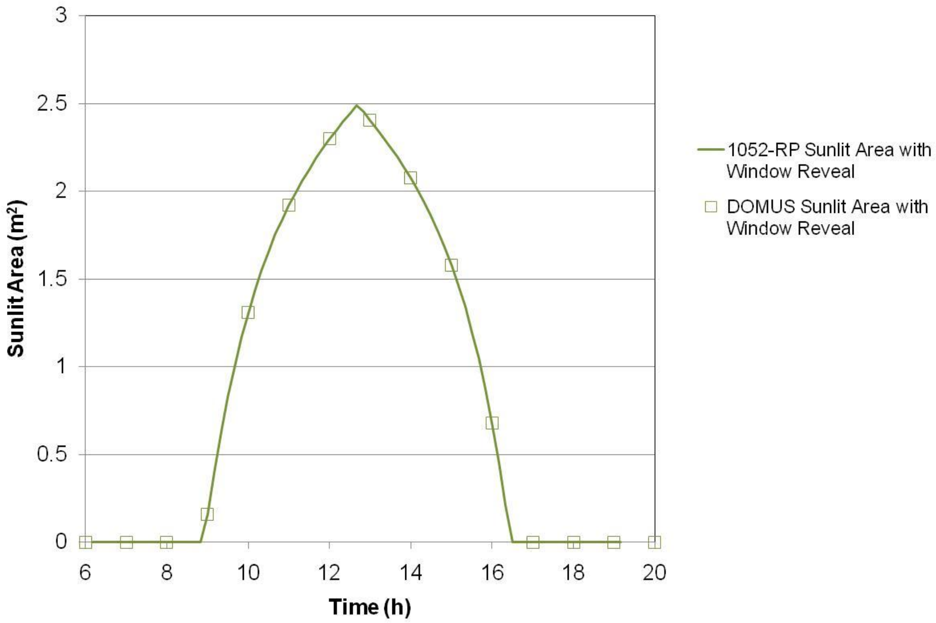


Figure 2-14: Sunlit area – South Wall – Test WinReveal.

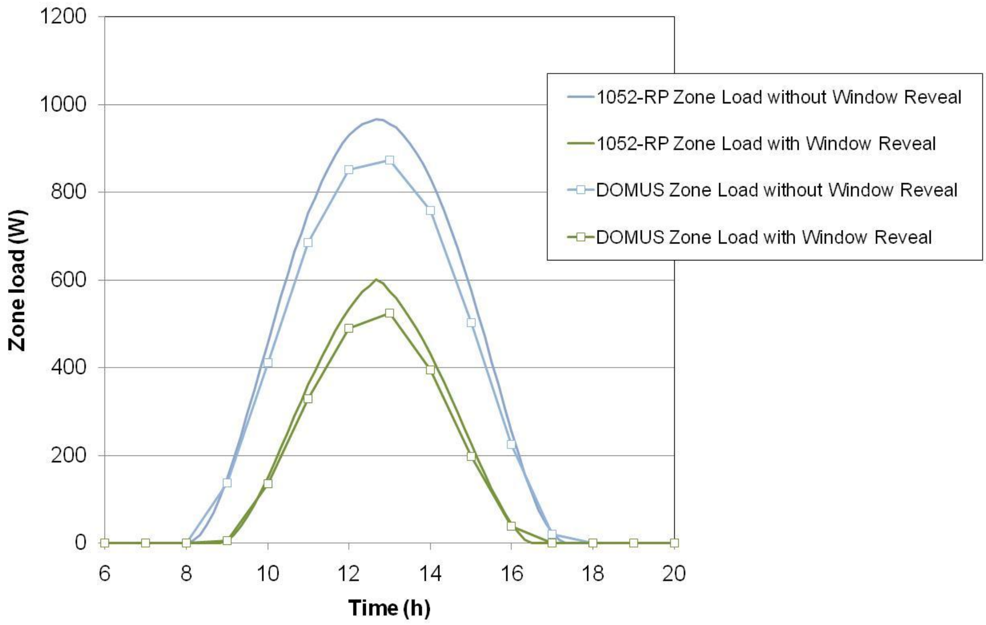


Figure 2-15: Zone load – South Wall – Test WinReveal.

### 2.2.5 Solar Radiation – Internal Solar Distribution – Test IntSolarDist

The test zone is 3 m wide x 0.5 m deep x 3 m high. One of the 3 m x 3 m surfaces is chosen as the test surface and has a 1 m x 1 m window centered in the surface. The window has a 0.5 m overhang and 0.5 m fins on either side. Table 2-7 presents the values of the glazing characteristics and convective heat transfer coefficient coefficients. This configuration allows solar radiation to impinge only on the internal surface of the wall opposite the window. The surface opposite the window is assumed massless and no internal redistribution of solar radiation occurs. All other surfaces are of heavyweight construction and are assumed adiabatic. The heavyweight surfaces test to see if the program is redistributing the solar gains which for this test it should not. The inside and outside temperatures are held constant at 20°C. The location and date were set for Atlanta, August 21. The test surface with the window was chosen as east facing. DOMUS treats entering solar radiation as impinging first on the floor. In this way, the floor has been chosen as massless to simulate the current problem. As before, there is a perfect agreement between DOMUS and ASHRAE 1052 – RP analytical results for the sunlit area (Figure 2-16). Results regarding the variation of the zone load are similar between the two solutions (Figure 2-17) considering the “Preliminary comments for Group 2 tests”.

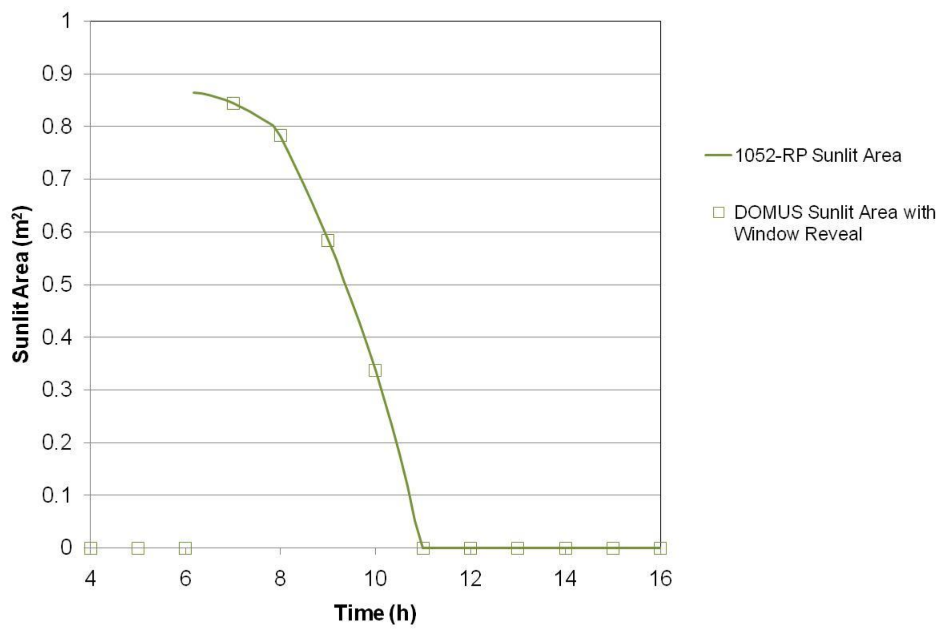


Figure 2-16: Sunlit area – East Wall – Test IntSolarDist.

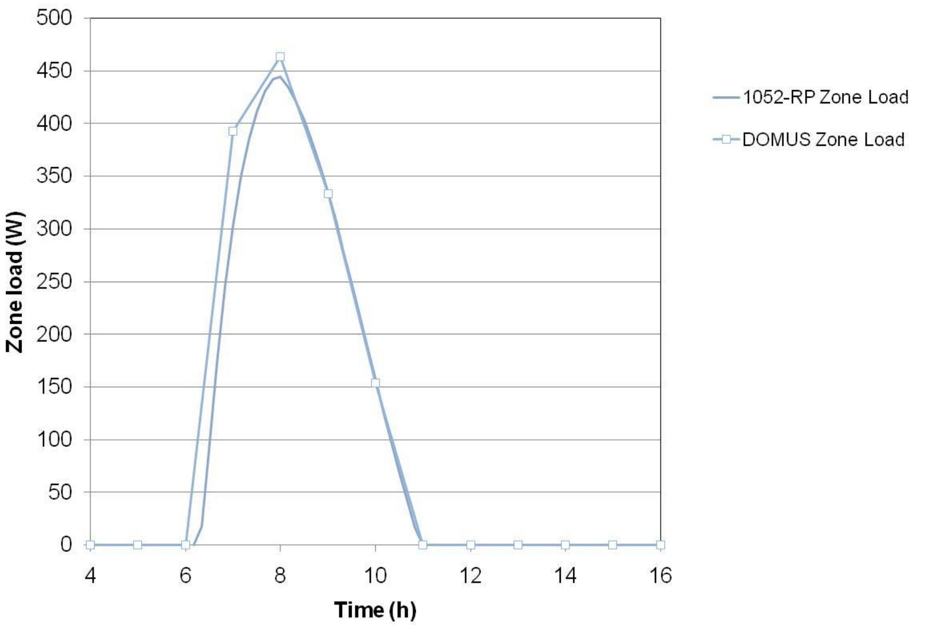


Figure 2-17: Zone load – East Wall – Test IntSolarDist.

## 2.3 Group 3

### 2.3.1 Infiltration – Fixed Infiltration Rate – Test Infiltration 1

The test zone is the same as test TC1. All surfaces are assumed adiabatic. The inside temperature is held constant at 20°C and outside temperature is constant at 10°C. Infiltration occurs at a constant rate of 0.5 $m^3/s$ (Table 2-8). DOMUS results for Test TC2 are very close to ASHRAE 1052 – RP analytical results (Table 2-9).

Table 2-8: Inputs – Test Infiltration 1.

| Test Parameter | Value | Units |
|---|---|---|
| Outside air temperature | 10 | °C |
| Inside air temperature | 20 | °C |
| Outside humidity ratio | 0.0046 | - |
| Infiltration rate | 0.5 | $m^3/s$ |
| Ambient pressure | 101.32 | kPa |

Table 2-9: Results – Test Infiltration 1.

| Test Parameter | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| Zone Load | W | 6304.718 | 6281.28 | -0.37% |
| Outside air density | $kg/m^3$ | 1.24316 | 1.24746 | 0.35% |
| Mass flow rate of the air | kg/s | 0.62158 | 0.62376 | 0.35% |
| Inside air enthalpy | J/kg | 31790.66 | 31596.76 | -0.61% |
| Outside air enthalpy | J/kg | 21647.63 | 21547.05 | -0.46% |

* Differences are relative to ASHRAE 1052 – RP values.

### 2.3.2 Infiltration – Stack Effect – Test Infiltration 2

The objective of Test Infiltration 2 is to test the treatment of infiltration under the pressure difference due to density and height differences resulting from fixed openings in the building fabric. This is done for a single zone with openings at high and low levels. The test zone is a tall cubic measuring 3m x 3m x 10m. Two 0.5m x 0.2m openings are placed symmetrically at the top and bottom of the same external wall. All surfaces are adiabatic. The inside temperature is held constant at 20°C and outside temperature is constant at 10°C (Table 2-10). The case is treated in DOMUS using the ASHRAE model for natural single-sided ventilation (the only one that can treat flows through multiple apertures located on a unique wall). DOMUS results for Test TC2 are very close to ASHRAE 1052 – RP analytical results (Table 2-11). The small discrepancy is attributed to the approximation used in DOMUS for the calculation of the height of the neutral plan that is based on air densities/opening areas and distances weighted correlation.

Table 2-10: Inputs – Test Infiltration 2.

| Test parameters | Value | Units |
|---|---|---|
| Outside air temperature | 10 | °C |
| Inside air temperature | 20 | °C |
| Outside air humidity ratio | 0.0046 | - |
| Discharge coefficient “Cd” | 0.6 | - |
| Flow exponent “x” | 0.65 | - |

Table 2-11: Results – Test Infiltration 2.

| Test parameters | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| Height of neutral pressure level | m | 4.9345 | 4.8979 | -0.74% |
| Mass flow rate | kg/s | 0.1489 | 0.1531 | 2.80% |
| Zone load | W | 1510.301 | 1538.323 | 1.86% |

* Differences are relative to ASHRAE 1052 – RP values.

## 2.4 Group 4

### 2.4.1 Exterior Long Wave Radiation – Test ExtRad

The test zone is same as the TC1 problem. The external surface to be tested is a horizontal roof made of a single layer with thickness of 0.1 m, thermal conductivity of 1.00 W/m.K and surface emissivity of 0.9. All other surfaces are adiabatic and have no thermal mass. The effects of solar irradiation, internal long wave radiation, infiltration and internal heat gains are eliminated. Inside and outside temperatures are fixed at 20°C (Table 2-12). DOMUS results for Test ExtRad are identical to ASHRAE 1052 – RP analytical results (Table 2-13); small differences are due to rounded values used in DOMUS result reports.

Table 2-12: Inputs – Test ExtRad.

| Test parameters | Value | Units |
|---|---|---|
| Emissivity of the external surface | 0.9 | - |
| Thermal conductivity of the external surface | 1.0 | W/m.K |
| Thickness of the external surface | 0.1 | m |
| Sky temperature | 5.0 | °C |
| External air temperature | 20 | °C |
| Internal air temperature | 20 | °C |
| Outside correlation coefficient 'A' | 0.0 | $W/m^2.K$ |
| Outside correlation coefficient 'C' | 0.84 | - |
| Outside correlation exponent 'n' | 0.333 | - |
| Inside correlation coefficient 'A' | 0.0 | $W/m^2.K$ |
| Inside correlation coefficient 'C' | 1.49 | - |
| Inside correlation exponent 'n' | 0.345 | - |

Table 2-13: Results – Test ExtRad.

| Test parameters | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| Heat flux | $W/m^2$ | -17.794 | -17.9 | 0.60% |
| Zone load | W | -160.1457 | -161.1 | 0.60% |
| Inside surface temperature | °C | 13.6787 | 13.68 | 0.01% |
| Outside surface temperature | °C | 11.8993 | 11.9 | 0.01% |
| Inside convection coefficient | $W/m^2.K$ | 2.8149 | | |
| Outside convection coefficient | $W/m^2.K$ | 1.6858 | | |

* Differences are relative to ASHRAE 1052 – RP values.

### 2.4.2 Interior Long Wave Radiation – Test IntRad

The test zone is same as the TC1 problem. No windows are present. Only one surface of the cuboid is selected to be exterior surface and all other surfaces are adiabatic. The exterior surface (Wall 1) and opposite surface (Wall2) are square, with width and height 3m. Aspect ratio is defined as the width (or height) of the exterior wall to the length of the adjacent surfaces. Hence the adjacent surfaces are 3 x Aspect Ratio (m) long. Both the inside and outside dry bulb temperatures and the convection coefficients have to be specified as constant values. A number of combinations of inside surface emissivities are to be tested (Table 2-14).

The effects of solar radiation, infiltration and internal heat gains are eliminated in this test. Figure 2-18 presents the evolution of the zone load according to the zone aspect ratio for the three configurations of emissivity. DOMUS results for Test IntRad are identical to ASHRAE 1052 – RP analytical results.

Table 2-14: Inputs – Test IntRad.

| Test parameters | Value | | | Units |
|---|---|---|---|---|
| Width of the cuboid | 3 | | | m |
| Outside air temperature | 40 | | | °C |
| Inside air temperature | 20 | | | °C |
| External convection coefficient | 21.16 | | | $W/m^2K$ |
| Internal convection coefficient | 3.18 | | | $W/m^2K$ |
| | Case 1 | Case 2 | Case 3 | |
| Emissivity Wall 1 | 0.9 | 0.9 | 0.9 | - |
| Emissivity Wall 2 | 0.1 | 0.1 | 0.9 | - |
| Emissivity Wall 3 | 0.3 | 0.1 | 0.9 | - |
| Emissivity Wall 4 | 0.3 | 0.1 | 0.9 | - |
| Emissivity Wall 5 | 0.3 | 0.1 | 0.9 | - |
| Emissivity Wall 6 | 0.3 | 0.1 | 0.9 | - |
| Aspect Ratio | 1, 2, 5, 10 and 20 | | | - |

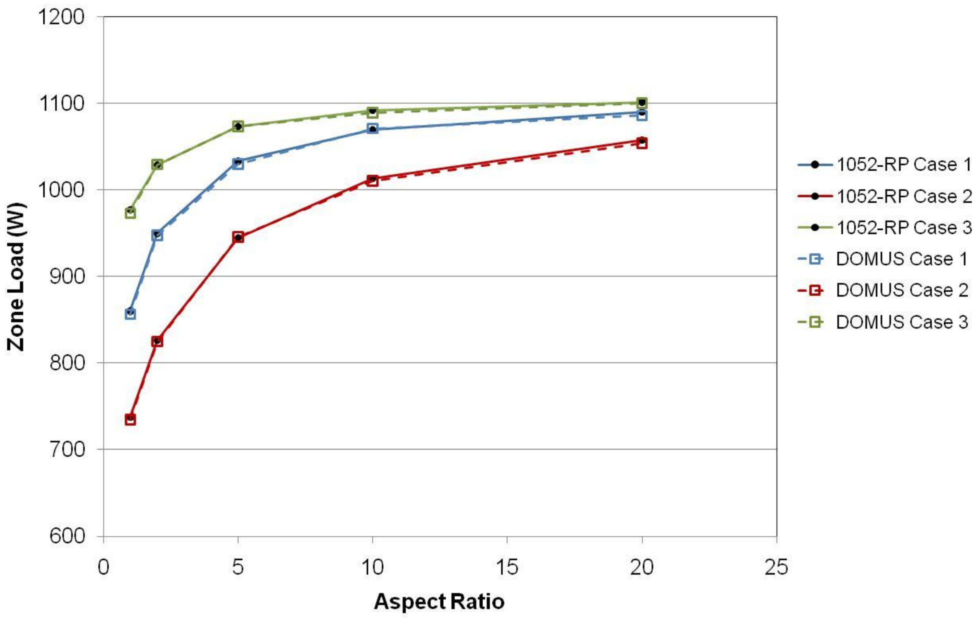


Figure 2-18: Zone loads versus zone aspect ratio for the three cases of emissivity distribution – Test IntRad.

## 2.5 Group 5

### 2.5.1 Internal Heat Gains – Convective and Radiant – Test IntHeatGain

The test zone is same as the TC1 problem. All surfaces of the zone are single layer and of the same construction and are adiabatic. The inside temperature is held constant at 20°C. A 3000 W internal load is turned on for 168 hours and then is turned off. Tests are run for three different situations assuming the internal loads are 100% radiative, 50% radiative and 0% radiative (100% convective) (Table 2-15). Results are presented when internal heat gain is on as schedules are daily-based in the current version of DOMUS. Figure 2-19 and Figure 2-20 present the evolution of the internal surface temperature and the zone load, respectively. Table 2-16 presents the total zone (sum over 168h) and the peak load for the three cases. DOMUS results for Test IntHeatRad are identical to ASHRAE 1052 – RP analytical results.

Table 2-15: Inputs – Test IntHeatGain.

| Test parameters | Value | Units |
|---|---|---|
| Thermal conductivity | 0.14 | W/mK |
| Thickness | 0.1 | m |
| Density | 500 | $Kg/m^3$ |
| Specific heat capacity | 2500 | J/kgK |
| Internal air temperature | 20.0 | °C |
| Internal convection coefficient | 3.20 | $W/m^2K$ |
| Step size of the internal heat gain | 3000 | W |

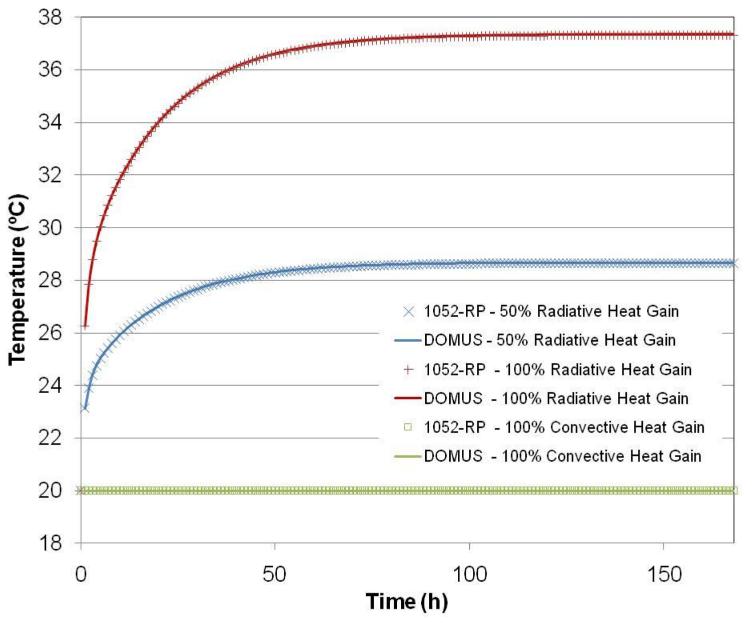


Figure 2-19: Internal surface temperature evolution versus time – Test IntHeatRad.

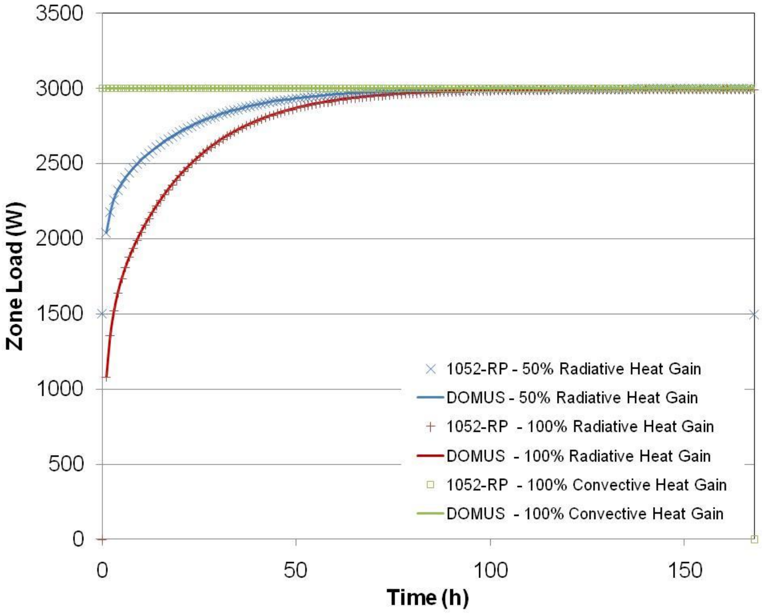


Figure 2-20: Zone load evolution versus time – Test IntHeatRad.

Table 2-16: Results – Test IntHeatGain.

| Test parameters | Units | 1052 – RP | DOMUS | Difference*, % |
|---|---|---|---|---|
| 50% Radiative | | | | |
| Total Zone Load | Wh | 484764 | 485294 | 0.11% |
| Peak Load | W | 2996 | 3000 | 0.12% |
| 100% Radiative | | | | |
| Total Zone Load | Wh | 468864 | 469612 | 0.16% |
| Peak Load | W | 2995 | 3000 | 0.17% |
| 100% Convective | | | | |
| Total Zone Load | Wh | 501000 | 501000 | 0.00% |
| Peak Load | W | 3000 | 3000 | 0.00% |

### 2.5.2 Ground Coupling – Slab on Ground Floor – Test GrdCoup

The test zone is same as the TC1 problem. All surfaces except the floor are adiabatic. The effects of solar irradiation, long wave radiation and infiltration are eliminated. The floor and ground are treated as a uniform semi-infinite slab. The inside air temperature is constant at 25°C while the ground temperature is constant at 2°C. The problem is a 2D problem that cannot be modeled with the current version of DOMUS.

Table 2-17: Inputs – Test GrdCoup.

| Test parameters | Value | Units |
|---|---|---|
| Thermal conductivity of the slab | 1.00 | W/m.K |
| Thickness of the wall | 0.24 | M |
| Inside air temperature | 25 | °C |
| Ground temperature | 2 | °C |
| Inside film correlation coefficient ‘A’ | 0.0 | $W/m^2.K$ |
| Inside film correlation coefficient ‘C’ | 1.49 | - |
| Inside film correlation exponent ‘n’ | 0.345 | - |

# 3 CONCLUSION

DOMUS was used to model a range of basic heat and mass transfer problems as specified in ASHRAE 1052-RP Toolkit – Building Fabric Analytical Tests. As shown by Table 3-1, the ability of DOMUS to reproduce the analytical results has been demonstrated. Most of results show insignificant differences between the numerical and analytical results. In the case of the Solar Radiation Tests, only trends can be compared for heat fluxes and zone loads because of different inputs between the two methods i.e. the use of hourly-based weather file and linear interpolation for DOMUS and 10 min-based weather file for the ASHRAE 1052-RP. However, it has been proved during those tests that DOMUS correctly handles shadows on windows due to the presence of horizontal and vertical fins. Only one test of the present suite has not been model using DOMUS because of the 2D treatment needed to properly calculate the heat transfer within the ground. Overall, DOMUS results compared very closely with the analytical results obtained from the ASHRAE 1052-RP Toolkit.

Table 3-1: Summary of DOMUS results.

| Test Group | Test Title | Results compared to ASHRAE 1052 – RP |
|---|---|---|
| Group 1 | Steady-state Convection | Similar |
| | Steady-state Conduction | Similar |
| | Transient Conduction – Adiabatic Wall | Similar |
| | Transient Conduction – Step Response | Similar |
| | Transient Conduction – Sinusoidal Driving Temperature and Multi-layer Wall | Similar |
| Group 2 | Exterior Solar Radiation – Opaque Surfaces | Similar |
| | Solar Radiation – Glazed Surfaces | Similar /Trend |
| | Solar Radiation – Window Shading | Similar /Trend |
| | Solar Radiation – Window Reveal Shading | Similar /Trend |
| | Solar Radiation – Internal Solar Distribution | Similar /Trend |
| Group 3 | Infiltration – Fixed Infiltration Rate | Similar |
| | Infiltration – Stack Effect | Similar |
| Group 4 | Interior Long Wave Radiation | Similar |
| | External Long Wave Radiation | Similar |
| Group 5 | Internal Heat Gains – Convective and Radiant | Similar |
| | Ground Coupling – Slab on Ground Floor | Cannot be modeled |

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