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EnergyPlus Testing with HERS BESTEST Tests from ANSI/ASHRAE Standard 140-2011

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1 Test Objectives and Overview

1.1 Introduction

This report describes the modeling methodology and results for testing done of building thermal loads tests described in Section 7 of ANSI/ASHRAE Standard 140-2011 titled *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* with the EnergyPlus Version 8.3.0-b45b06b780. The results of EnergyPlus are also compared with results from several other whole building energy analysis programs that simulated the same test cases.

1.2 Test Type: Comparative - Loads

Comparative tests compare a program to itself or to other simulation programs. This type of testing accomplishes results on two different levels, both validation and debugging.

From a validation perspective, comparative tests will show that EnergyPlus is computing solutions that are reasonable compared to other energy simulation programs. This is a very powerful method of assessment, but it is no substitute for determining if the program is absolutely correct since it may be just as equally incorrect as the benchmark program or programs. The biggest strength of comparative testing is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation. The ANSI/ASHRAE Standard 140-2011 procedures discussed below take advantage of the comparative test method and have the added advantage that for the specific tests included in ANSI/ASHRAE Standard 140-2011 have already been run by experts of the other simulation tools.

Comparative testing is also useful for field-by-field input debugging. Energy simulation programs have so many inputs and outputs that the results are often difficult to interpret. To ascertain if a given test passes or fails, engineering judgment or hand calculations are often needed. Field by field comparative testing eliminates any calculational requirements for the subset of fields that are equivalent in two or more simulation programs. The equivalent fields are exercised using equivalent inputs and relevant outputs are directly compared.

1.3 Test Suite: ANSI/ASHRAE Standard 140-2011

The tests described in Section 7 of ANSI/ASHRAE Standard 140-2011, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (ANSI/ASHRAE 2011), were performed. This suite of tests is based on work previously performed under an earlier project sponsored by the International Energy Agency (IEA) titled *Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)* (NREL 1995). As stated in its Foreword, Standard 140-2011 is a standard method of test that “can be used for identifying and diagnosing predictive differences from whole building energy simulation software that may possibly be caused by algorithmic differences, modeling limitations, input differences, or coding errors.”

The following tests (Table 1) were performed as specified with modeling notes and other reports generated as shown in the Standard:

- Tier I Tests – includes a base building which is a single story house with conditioned first floor, unconditioned attic, raised floor and typical glazing and insulation with variations in:
    - Infiltration
    - Wall and ceiling R-Value
    - Glazing properties, area and orientation
    - Shading by south overhang
    - Internal loads
    - Exterior surface color
    - Energy efficient building features
- Tier II Tests – includes passive solar design elements applied to the base building with variations in:
    - Mass
    - Glazing Orientation
    - East and west shading
    - Glazing area
    - South overhang

The EnergyPlus test results are compared to the results of other programs that completed and reported test results, including BLAST 3.0, DOE 2.1E and SERIRES.

A brief description of the BASE Case and other test cases are presented in the following sections. For further details refer to ANSI/ASHRAE Standard 140.

Table 1 HERS Case Descriptions (ANSI/ASHRAE 2011, Table B1-5)

CASE #/ Test Tier	SUB-FLOOR	INFIL. (ACH)	R-VALUE (h ft² F/Btu) WALLS, (Note 2) CEILING	FLOOR	WINDOW DATA TYPE	AREA (ft²) (Note 3)	ORIENT	SHADE	COMMENTS (Note 1)
L100A/ T1	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Base building. Simple construction with typical glazing and insulation. Represents average of US building stock.
L110A/ T1	RF	**1.5**	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests infiltration.
L120A/ T1	RF	0.67	**24,60**	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests wall and ceiling R-value together.
L130A/ T1	RF	0.67	12,21	14	**DLEW**	Gross: 270 Net: 197	AVG DIST	NO	Tests glazing physical properties together.
L140A/ T1	RF	0.67	12,21	14	**None**	**0**	**N/A**	NO	Tests glazing area.
L150A/ T1	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	**1.0 S**	NO	Tests glazing orientation.
L155A/ T1	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	**1.0 S**	**H**	Tests South opaque overhang.
L160A/ T1	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	**0.5E,0.5W**	NO	Tests E/W glazing orientation.
L165A/ T2	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	**0.5E,0.5W**	**HV**	Tests E/W shading.
L170A/ T1	RF	0.67	12,21	14	SATB	Gross: 270 Net: 197	AVG DIST	NO	**Internal loads = 0.**Tests internal loads.
L200A/ T1	RF	**1.5**	**5,12**	**4**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Lumped sensitivity low efficiency. Tests HERS ability to cover wide range of construction
L202A/ T1	RF	**1.5**	**5,12**	**4**	SATB	Gross: 270 Net: 197	AVG DIST	NO	**Exterior Solar Absorptance = 0.2.** Tests low solar absorptance.
L302A/ T1	**SLAB**	0.67	12,21	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated slab using ASHRAE perimeter method.
L304A/ T1	**SLAB**	0.67	12,21	**EDGE INS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests perimeter insulated slab using ASHRAE perimeter method.
L322A/ T1	**BASE-MENT**	0.67	12,21 **(Note 4)**	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with uninsulated full basement using ASHRAE method.
L324A/ T1	**BASE-MENT**	0.67	12,21 **(Note 4)**	**UNINS**	SATB	Gross: 270 Net: 197	AVG DIST	NO	Tests ground coupling with insulated full basement using ASHRAE method.
P100A/ T2	RF	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	NO	**High mass passive solar construction.** Base building for P-series cases.
P105A/ T2	RF	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	**H**	Tests South opaque overhang.
P110A/ T2	RF	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	**1.0 S**	NO	**Low mass version of passive base case.**Tests mass effect.
P140A/ T2	RF	0.67	**24,60**	**23**	**None**	**0**	**N/A**	NO	Tests glazing area.
P150A/ T2	RF	0.67	**24,60**	**23**	**DW**	**Gross: 325 Net: 237**	AVG DIST	NO	Tests glazing orientation.

ABBREVIATIONS
Test Tier: T1 = Tier 1, T2 = Tier 2
SUBFLOOR = construction below main floor,RF = raised floor,SLAB = slab on grade, BASEMENT = full basement.
INFIL.(ACH) = Infiltration (Air Changes per Hour)
R-VALUE, FLOOR: UNINS = slab or basement coupled to ground, EDGE INS = 4 ft. deep perimeter slab insulation.
WINDOW DATA: SATB = single pane, clear gla ss, aluminum frame with thermal break; DLEW = double pane, low-e glass, wood frame, insulated spacer;
DW = double pane, clear glass, wood frame, metal spacer.
ORIENT = Orientation; AVG DIST = window area distributed over walls in proportion to total exte rior wall area.
N/A = not applicable; 1.0 S = all windows on south wall; 0.5E, 0.5W = 50% of window area on east wall and 50% of window area on west wall.
SHADE = window shading device; H = horizontal shade (overhang); HV = horizontal and vertical shadi ng (overhang and fins).
ASHRAE = American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

NOTES
Note1: Changes to Case L100A are highlighted with bold font.
Note 2: These are composite R-values including all materials,films, and the presence of the attic for ceiling R-value; see Section 7.2 for more detail.
Note 3: Gross area is the total window area including the frame; net area is the area of just the glass portion of the window .
Note 4: Basement below-grade wall R-values including the ground are: L322A = R -8, L324A = R-19.

1.3.1 Tier I Test Cases

1.3.1.1 Case L100A – Base Case Building

The basic test building (Figure 1) is a rectangular single-story house (27’ wide x 57’ long x 8’ high) with one conditioned zone (main floor, Figure 2), an unconditioned attic, and a raised floor exposed to air. The house has single-pane windows on all four exposures. For further details regarding wall, roof and floor constructions refer to ANSI/ASHRAE Standard 140-2011, Section 7.2.1. For windows details see Figure 4 and Table 2.

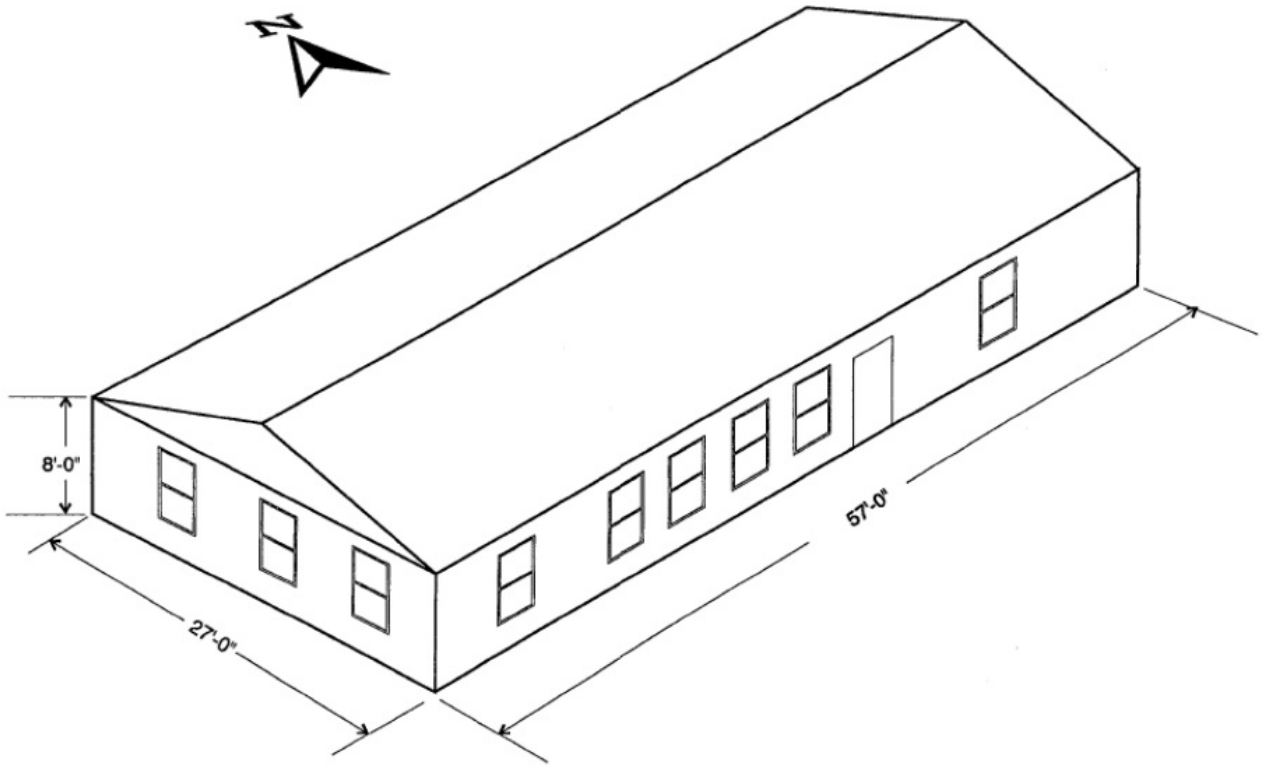
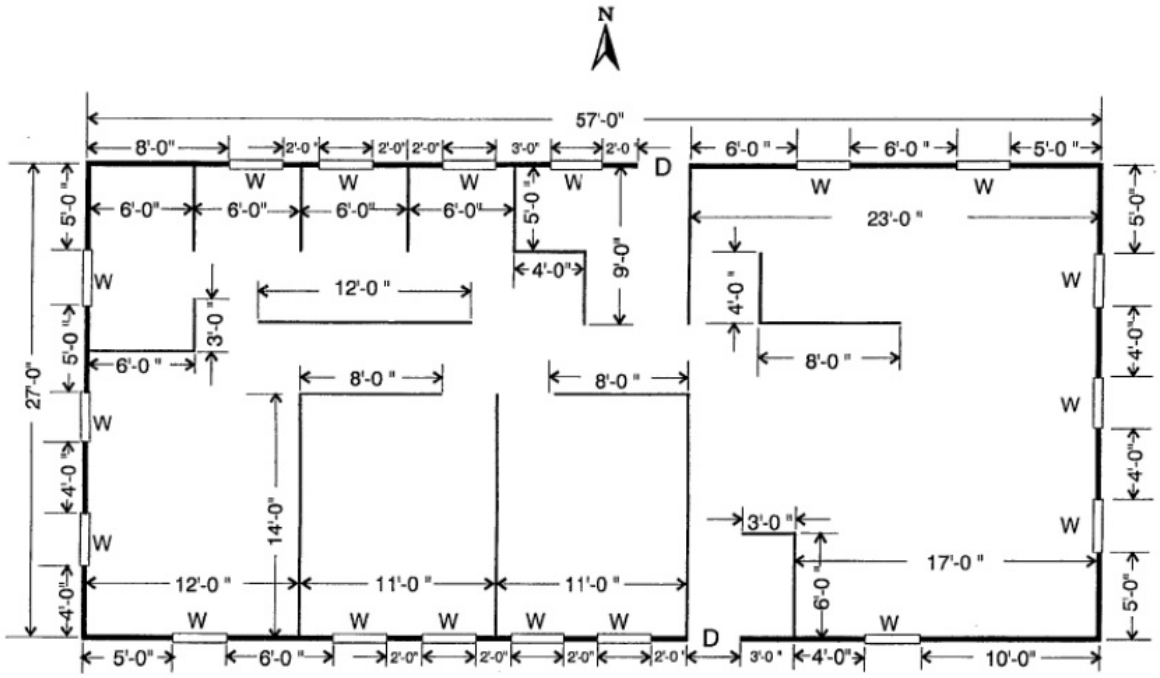


Figure 1 Base Building (Case L100A) - Isometric View of Southeast Corner (ANSI/ASHRAE 2011, Figure 7-1)



Legend:
W = Window (3′ wide x 5′ high), see Figure 2-8
D = Solid-core wood door (3′ wide x 6′8″ high)

Figure 2 Base Building (Case L100A) – Main Floor Plan (ANSI/ASHRAE 2011, Figure 7-2)

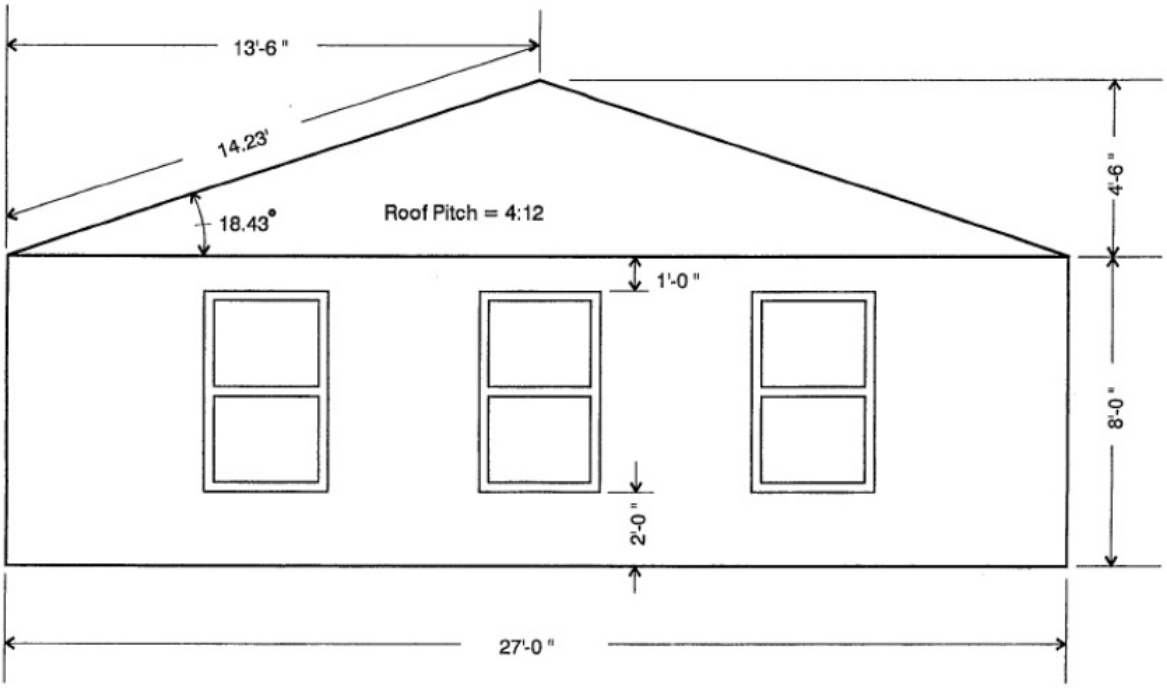


Figure 3 Base Building (Case L100A) – East Wall Elevation View (ANSI/ASHRAE 2011, Figure 7-3)

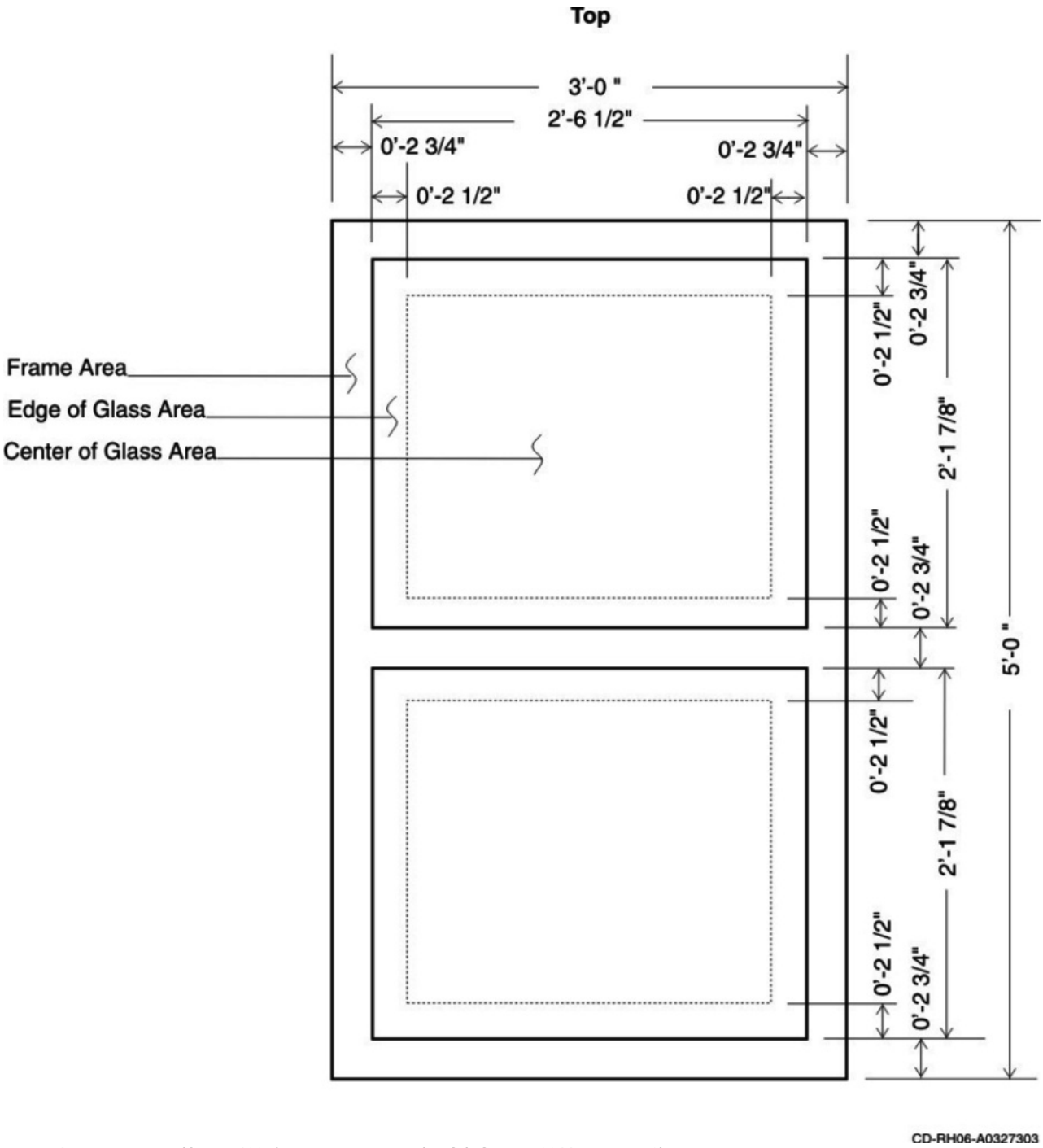


Figure 4 Base Building (Case L100A) – Window Details (ANSI/ASHRAE 2011, Figure 7-8)

Table 2 Base Building (Case L100A) Window Characteristics

	Area (ft^2)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	SHGC (dir. Nor.)	Trans (dir Nor.)	SC
Glass Pane	10.96	1.064	0.857	0.857	1.0
Alum. Sash w/ thermal break	4.04	0.971			

Other characteristics of the base building included:

Infiltration:

- Conditioned zone 0.67 air change/hour
- Attic 2.4 air changes/hour

Internal Load:

Angle	Properties (Notes 1, 2) Trans	Refl	Abs	SHGC
0	0.837	0.075	0.088	0.857
10	0.836	0.075	0.089	0.857
20	0.835	0.075	0.090	0.856
30	0.830	0.077	0.093	0.852
40	0.821	0.083	0.097	0.843
50	0.800	0.099	0.101	0.823
60	0.752	0.143	0.105	0.776
70	0.639	0.253	0.108	0.664
80	0.390	0.505	0.105	0.414
90	0.000	1.000	0.000	0.000
Hemis	0.756	0.136	0.098	0.779

Note1: Trans = Transmittance, Refl = Reflectance, Abs = Absorptance, SHGC = Solar Heat Gain Coefficient, Hemis = Hemispherically integrated property.
Note 2: Output is from WINDOW 4.1 for the following properties at direct normal incidence: transmittance = 0.837, reflectance = 0.075. SHGC accounts for surface coefficients, and is based on wind speed = 10.7 mph.

Mechanical System: 100% convective air system, heating capacity 3,413 million Btu/h, cooling capacity 3,413 million Btu/h, 100% efficient with no duct losses, no latent heat extraction, non-proportional-type dual setpoint thermostat with deadband, heating on <68°F, cooling on >78°F, and no fan heat added to supply air.

1.3.1.2 Case L110A – High Infiltration

Case L110A uses the Base Building modeled in Case L100A but changes the conditioned zone infiltration rate from 0.67 air changes/hr to 1.5 air changes/hr.

1.3.1.3 Case L120A – Well Insulated Walls and Roof

Case L120A uses the Base Building modeled in Case L100A with the following changes:

- Exterior walls have 2” x 6” 24” O.C. framing and R-18 batt insulation with R-7.2 polyisocyanurate exterior board insulation (Figure 5)
- An extra layer of R-38 batt insulation is added to the ceiling (Figure 6)

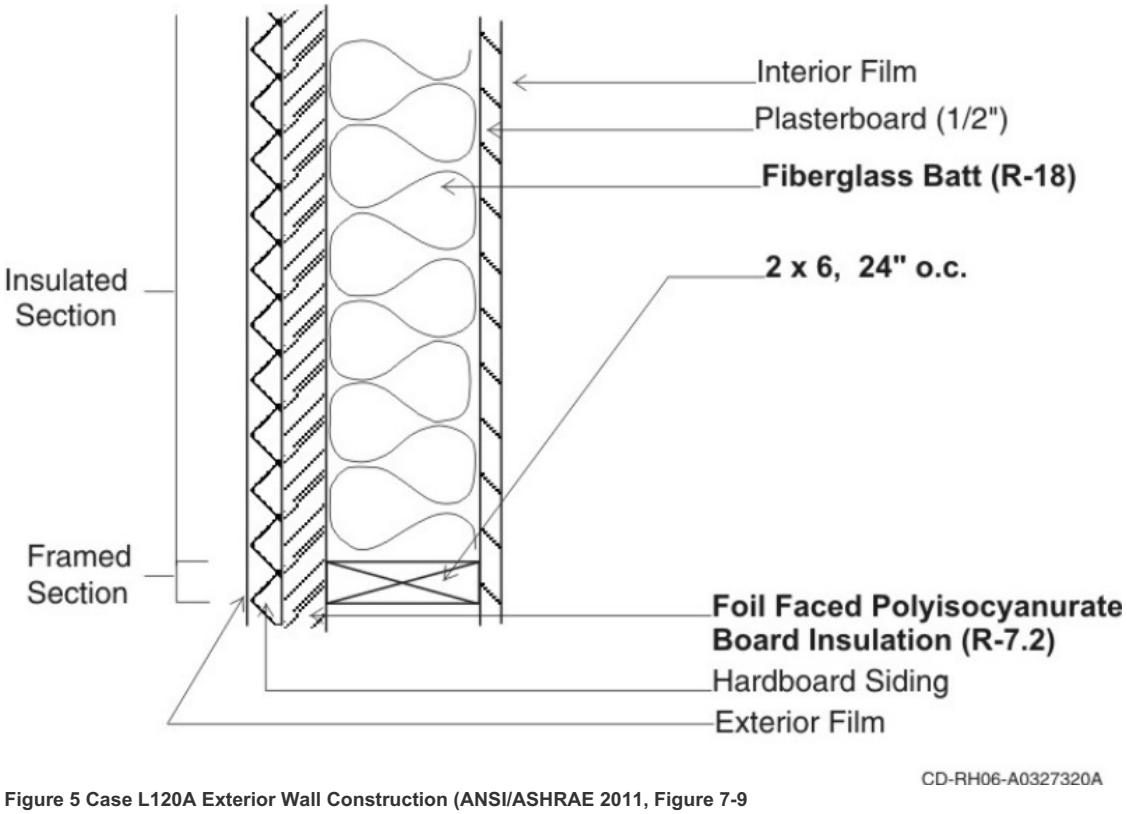


Figure 5 Case L120A Exterior Wall Construction (ANSI/ASHRAE 2011, Figure 7-9

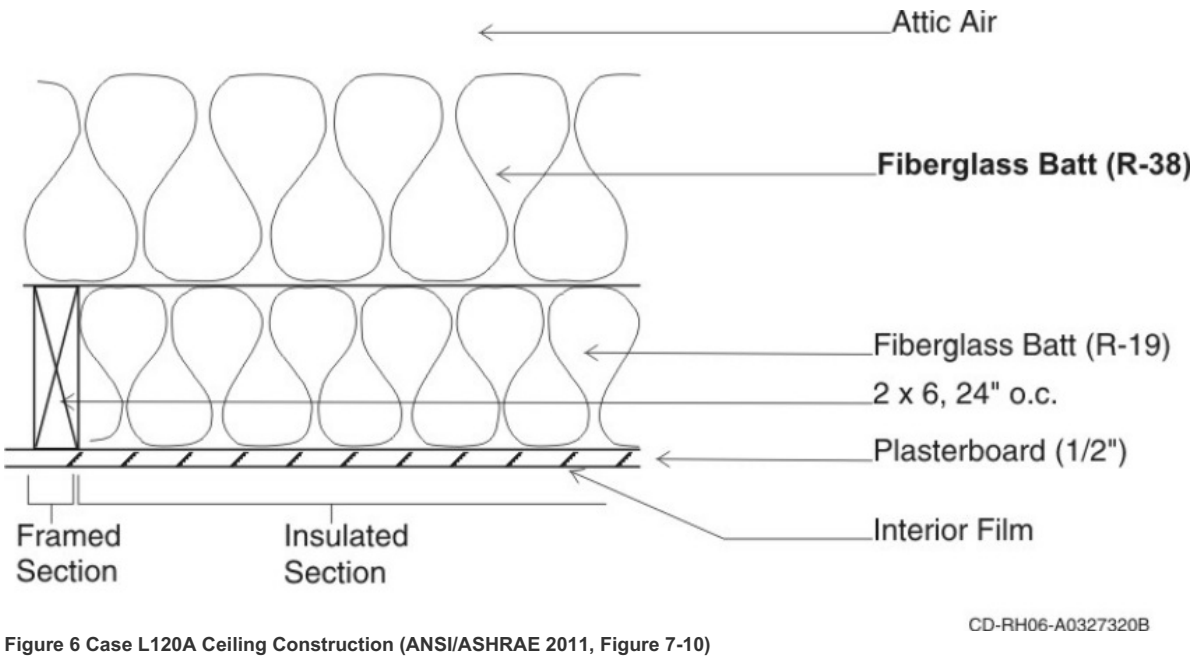


Figure 6 Case L120A Ceiling Construction (ANSI/ASHRAE 2011, Figure 7-10)

1.3.1.4 Case L130A – Double-Pane Low-Emissivity Windows with Wood Frame

Case L130A is exactly the same as Case L100A except all single-pane windows are replaced with double-pane low-emissivity windows with wood frame spacers. The basic properties of the window are shown below.

Table 3 Case L130A Window Characteristics

	Area (${ft}^2})	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	SHGC (dir. Nor.)	Trans (dir Nor.)	SC
Dbl-pane, low-e, argon	10.96	0.247	0.432	0.387	0.504
Wood frame w/inuslated spacer	4.04	0.446			
Window composite air-air	15.00	0.300	0.335	0.283	0.391

1.3.1.5 Case L140A – Zero Window Area

Case L140A is the same as Case L100A except the gross window area (glass and frame) is replaced with the Case L100A solid exterior wall construction.

1.3.1.6 Case L150A – South-Oriented Windows

Case L150A is identical to the Base Case building of Case L100A except that all windows are moved to the south wall as shown in Figure 7. The east, west and north walls have no windows. The door in the north wall remains. Window details are the same as those indicated in Figure 4 and Table 2.

1.3.1.7 Case L155A – South-Oriented Windows with Overhang

Case L155A is identical to Case L150A except that an opaque overhang is included at the top of the south exterior wall (see Figure 8). The overhang traverses the entire length of the south wall extends outward from the wall by 2.5 ft.

1.3.1.8 Case L160A – East- and West-Oriented Windows

Case L160A uses the Base Building modeled in Case L100A except that all windows are moved to the east and west walls as shown in Figure 9. The north and south walls have no windows but the doors remain.

1.3.1.9 Case L170A – No Internal Loads

Case L170A is identical to Case L100A except the internal sensible and latent loads in the conditioned zone are set to zero for all hours of the year.

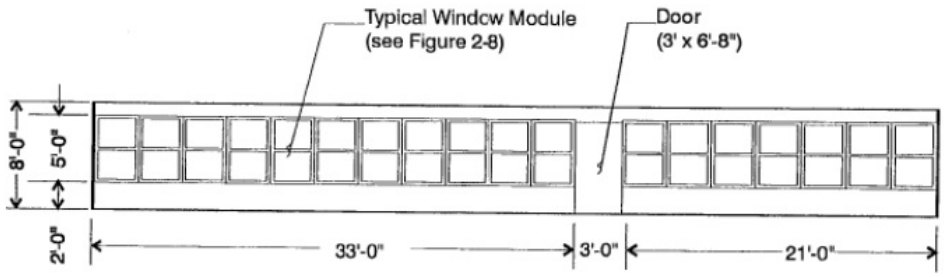


Figure 7 Case L150A South Wall Elevation Showing Windows (ANSI/ASHRAE 2011, Figure 7-12)

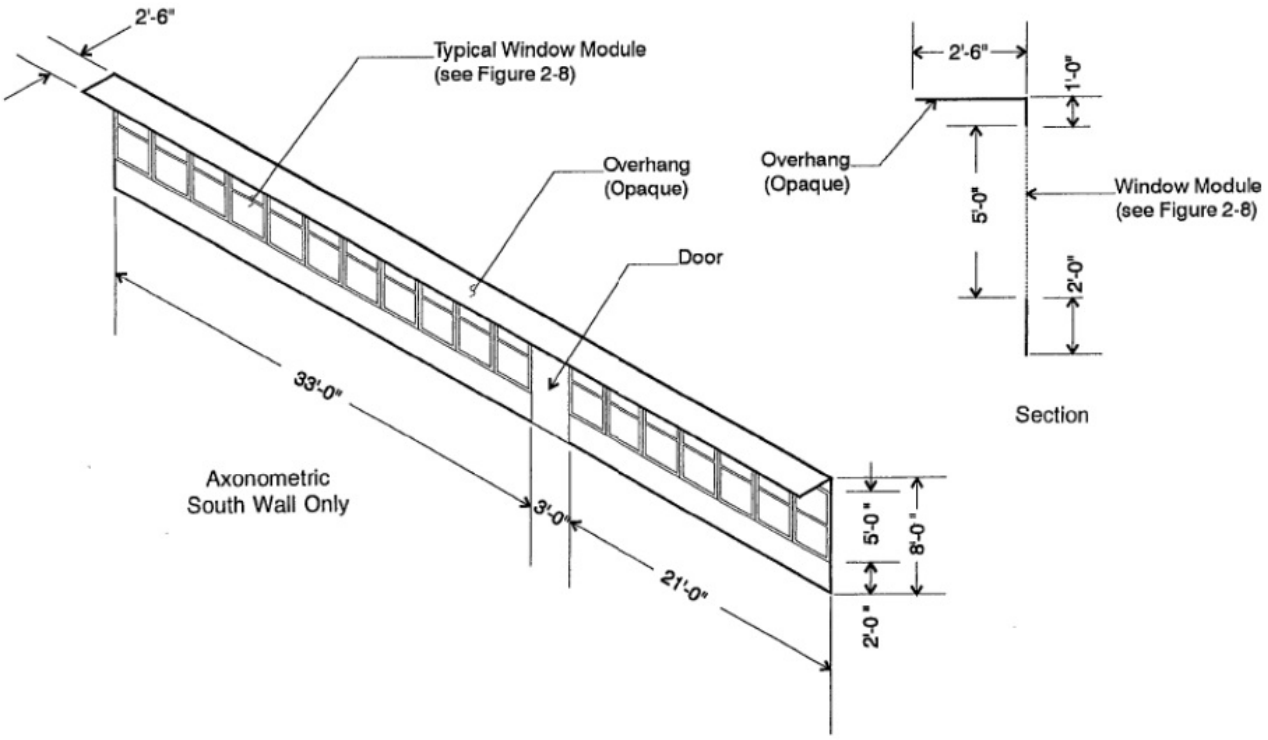


Figure 8 Case L155A South Wall with Overhang (ANSI/ASHRAE 2011, Figure 7-13)

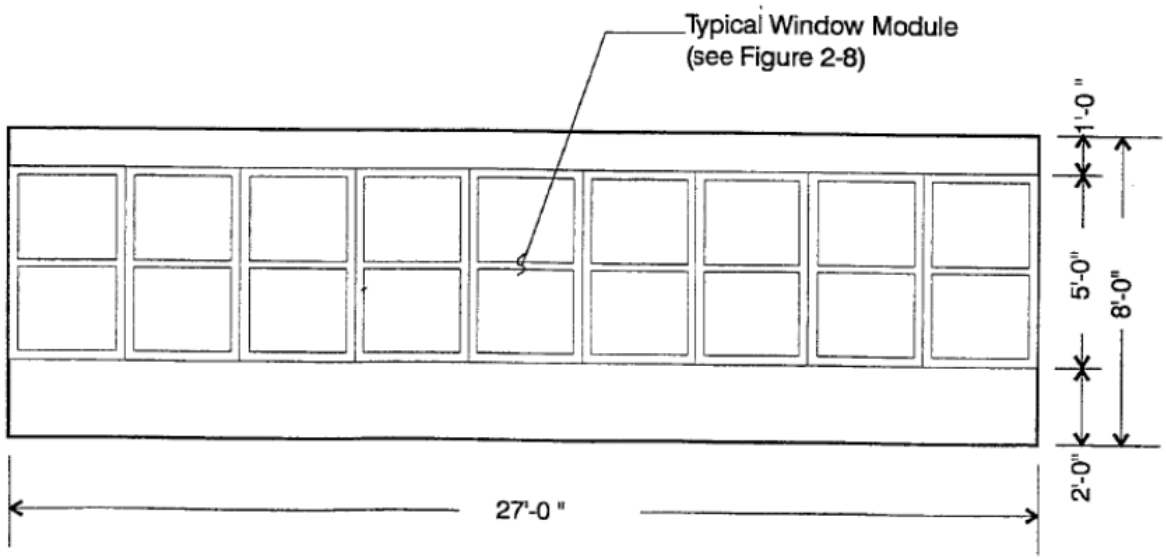


Figure 9 Case L160A East and West Wall Elevation Showing Windows (ANSI/ASHRAE 2011, Figure 7-16)

1.3.1.10 Case L200A – Energy Efficient

Case L200A is the same as the Base Building Case L100A except for the following changes:

- Infiltration for the conditioned zone is set to 1.5 air changes/hr
- Exterior wall fiberglass insulation is replaced with an air gap
- Floor fiberglass insulation is eliminated
- Ceiling fiberglass insulation is reduced from 5.5” to 3.5”

1.3.1.11 Case202A – Low Exterior Solar Absorptance Associated with Light Exterior Surface Color

Case L202A is the same as Case L200A except that the exterior shortwave absorptance is set to 0.2 for exterior walls, roof, end gables and doors. Window frame absorptance remains at 0.6.

1.3.1.12 Case302A – Slab-on-Grade, Uninsulated ASHRAE Slab

Case L302A is the same as Base Building Case L100A except that the raised floor exposed to air is changed to an uninsulated slab-on-grade construction as shown in Figure 10 with properties as shown in Table 4.

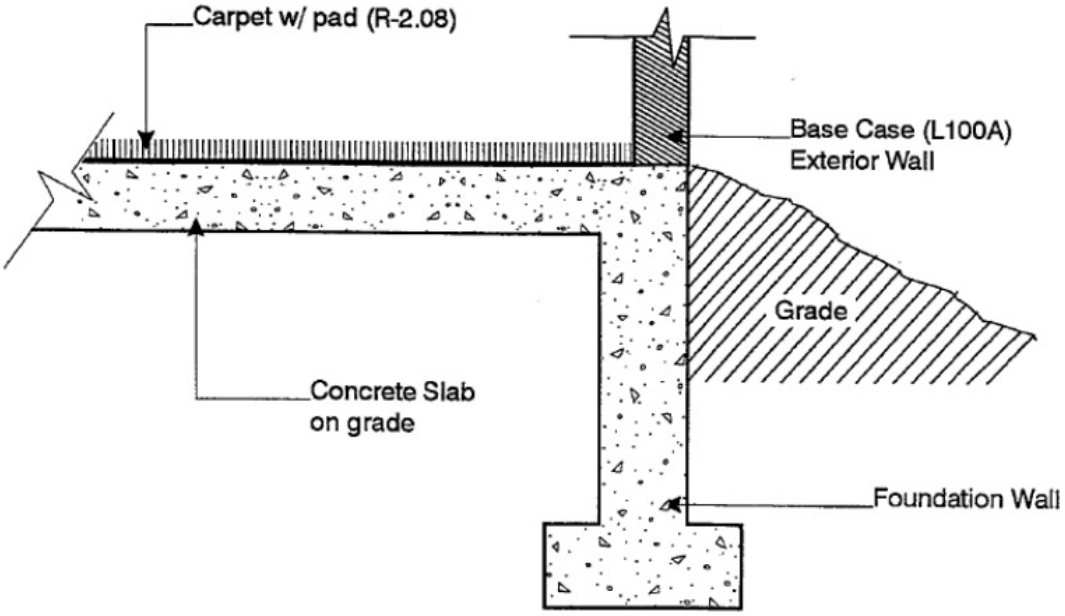


Figure 10 Case L302A Uninsulated Slab-on-Grade Section (ANSI/ASHRAE 2011, Figure 7-20)

Table 4 Case L302A Slab-on-Grade Construction

	R ($\frac{h \cdot ft^2 \cdot F}{Btu}$)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)
Interior Surface Coeff.	0.765	1.307
Carpet w/ fibrous pad	2.08	0.481
Slab Loss Coeff.	6.564	0.152
Total air-air	9.409	0.106

1.3.1.13 Case304A – Slab-on-Grade, Insulated ASHRAE Slab

Case L304A is the same as Case L302A except that the slab is insulated with R-5.4 perimeter insulation.

1.3.1.14 Case 322A – Uninsulated ASHRAE Conditioned Basement

Case L322A is the same as Base Building Case L100A but with the following changes:

- Add a separate basement conditioned zone (Figure 11) with basement walls, concrete basement floor slab and basement ceiling (Figure 12)
- Basement zone is to be controlled by the same thermostat used to control the main floor.

For further details regarding basement walls, ceiling and floor constructions refer to ANSI/ASHRAE Standard 140-2011, Section 7.2.2.12.

1.3.1.15 Case 324A – Insulated ASHRAE Conditioned Basement

Case L324A is the same as Case L322A except that insulation has been added to the interior side of the basement wall and rim joist (Figures 13 and 14).

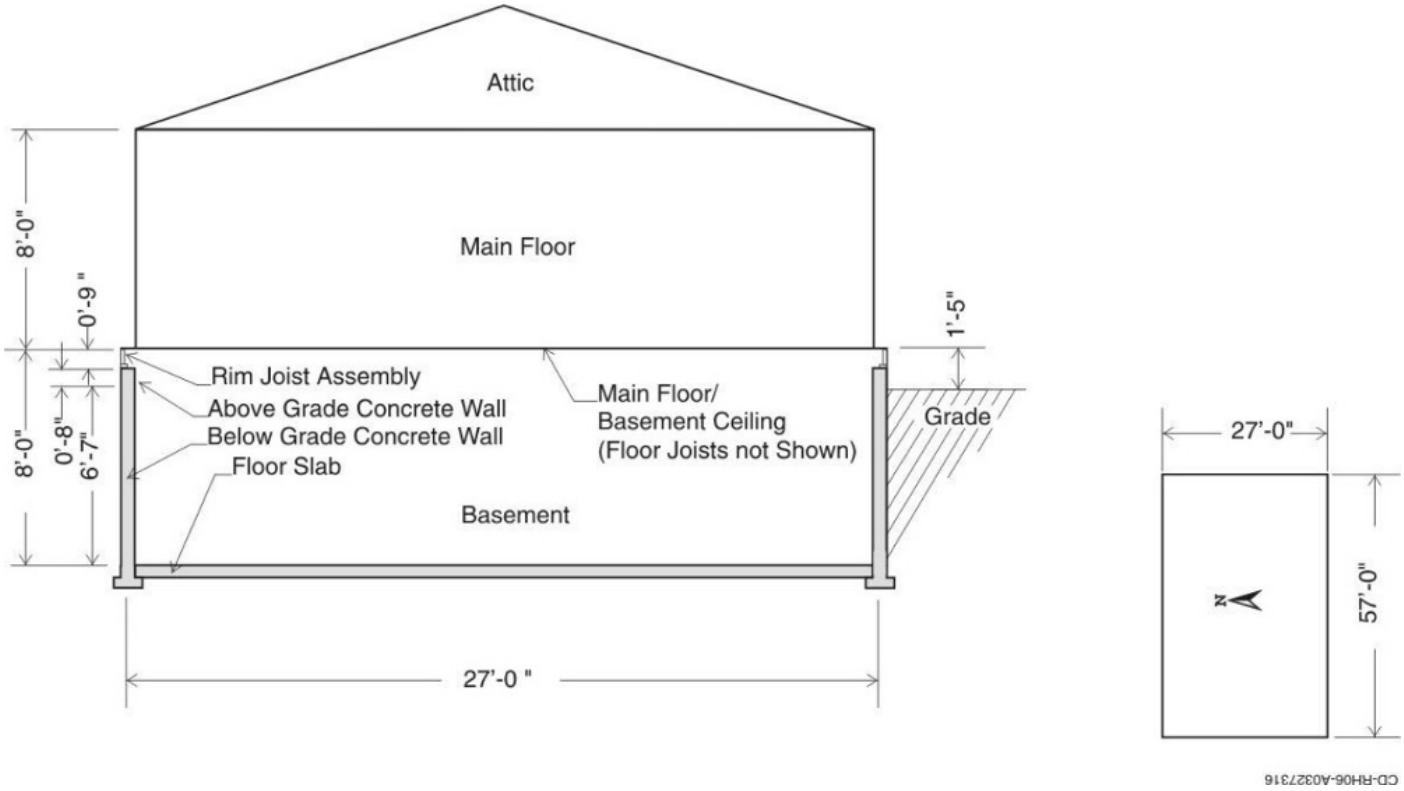


Figure 11 Case L322A Uninsulated Basement Section (ANSI/ASHRAE 2011, Figure 7-22)

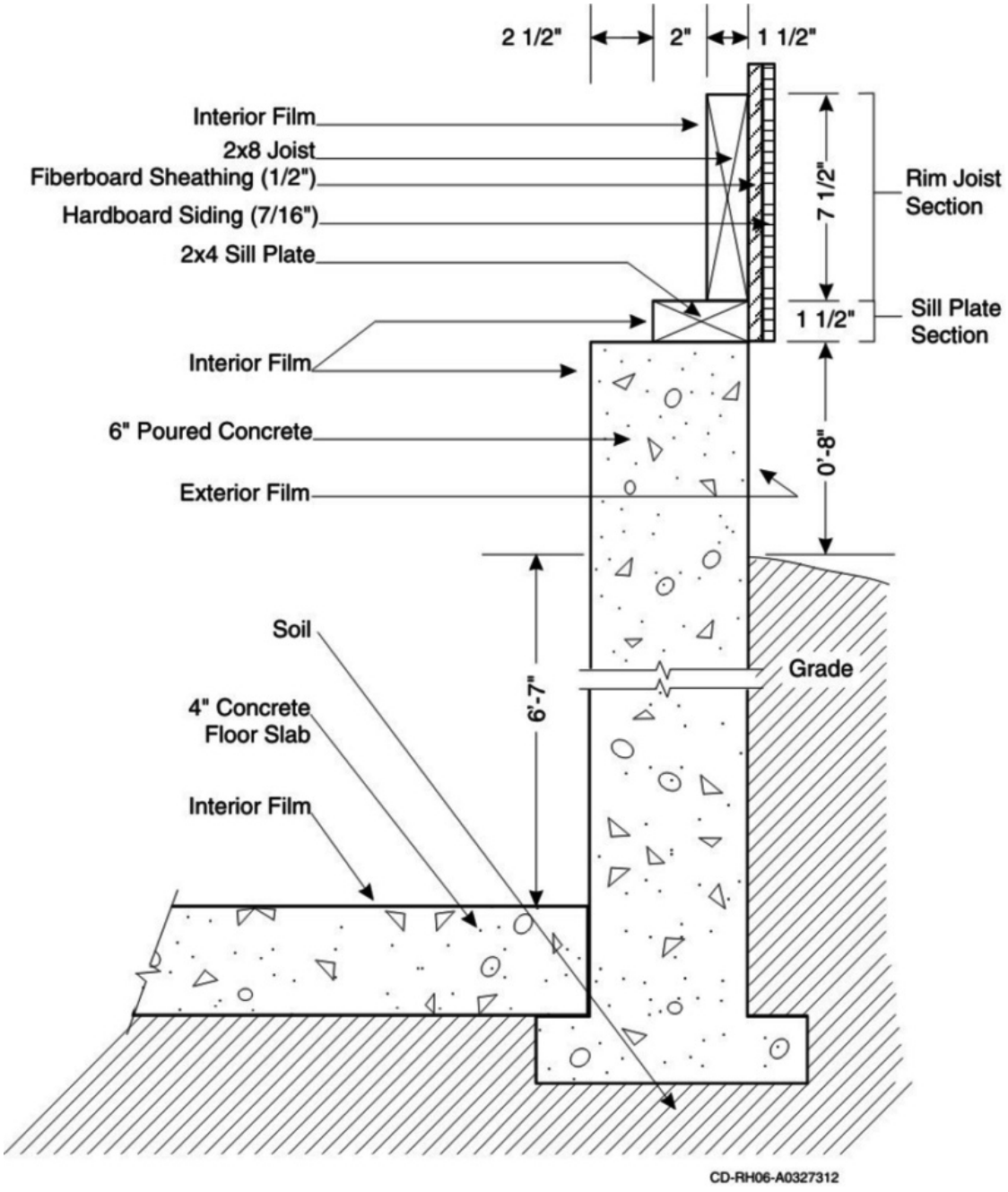


Figure 12 Case L322A Basement and Floor Section (ANSI/ASHRAE 2011, Figure 7-23)

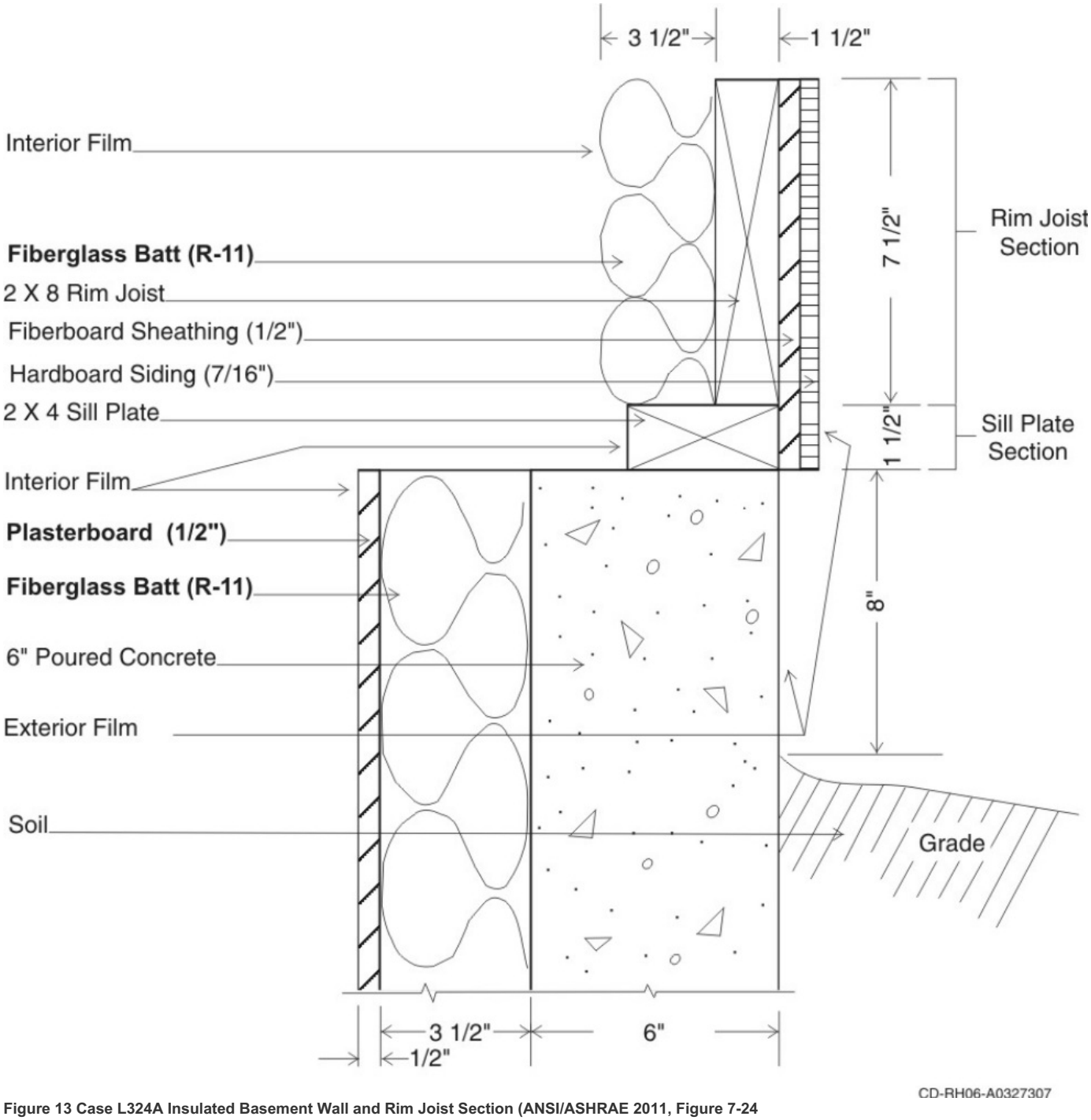


Figure 13 Case L324A Insulated Basement Wall and Rim Joist Section (ANSI/ASHRAE 2011, Figure 7-24

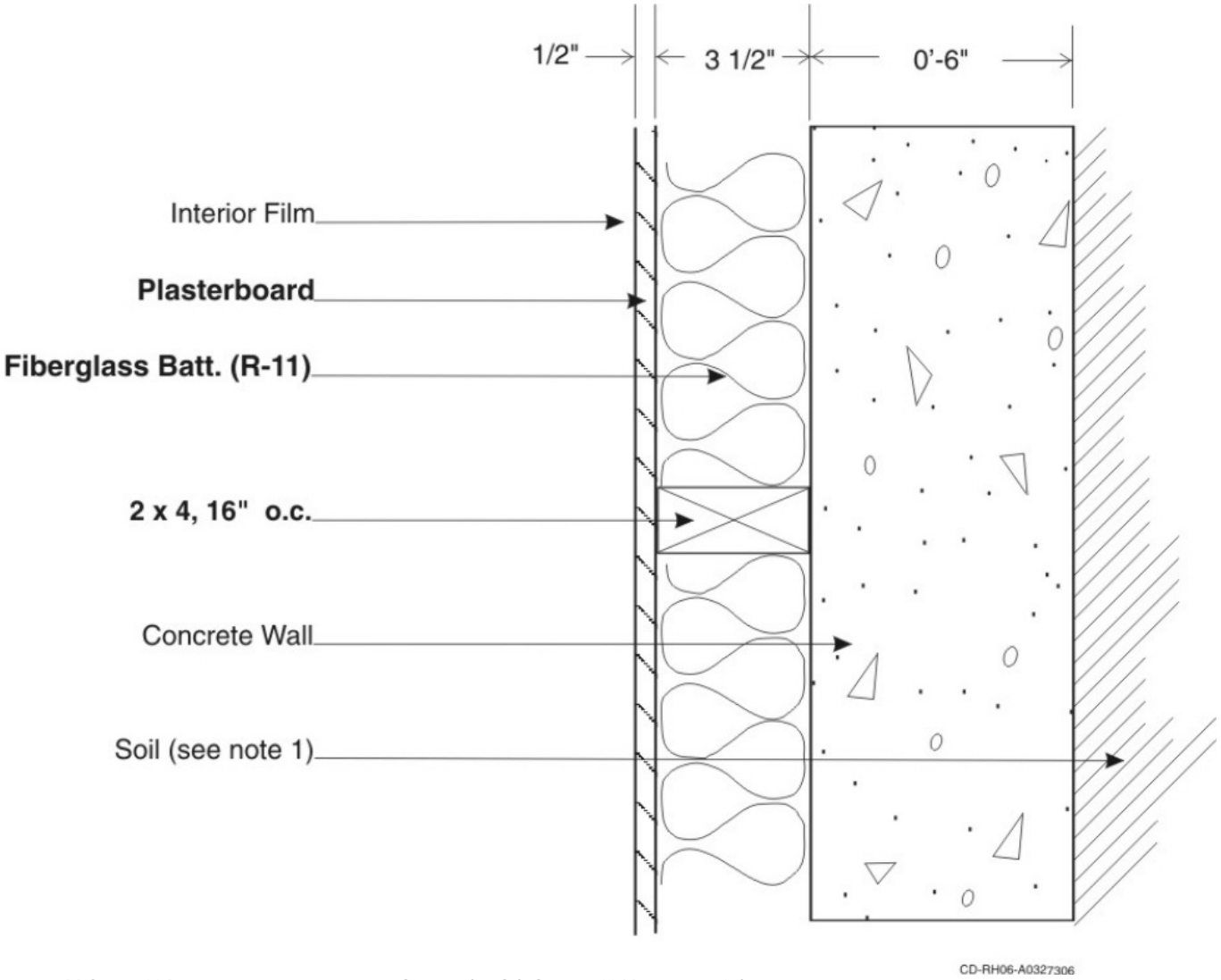


Figure 14 Case L324A Insulated Basement Wall Section (ANSI/ASHRAE 2011, Figure 7-25)

1.3.2 Tier II Test Cases

1.3.2.1 Case L165A – East/West Shaded Windows

Case L165A is exactly the same as Case L160A except that an opaque overhang and ten opaque fins are added to the east and west walls as shown in Figure 15.

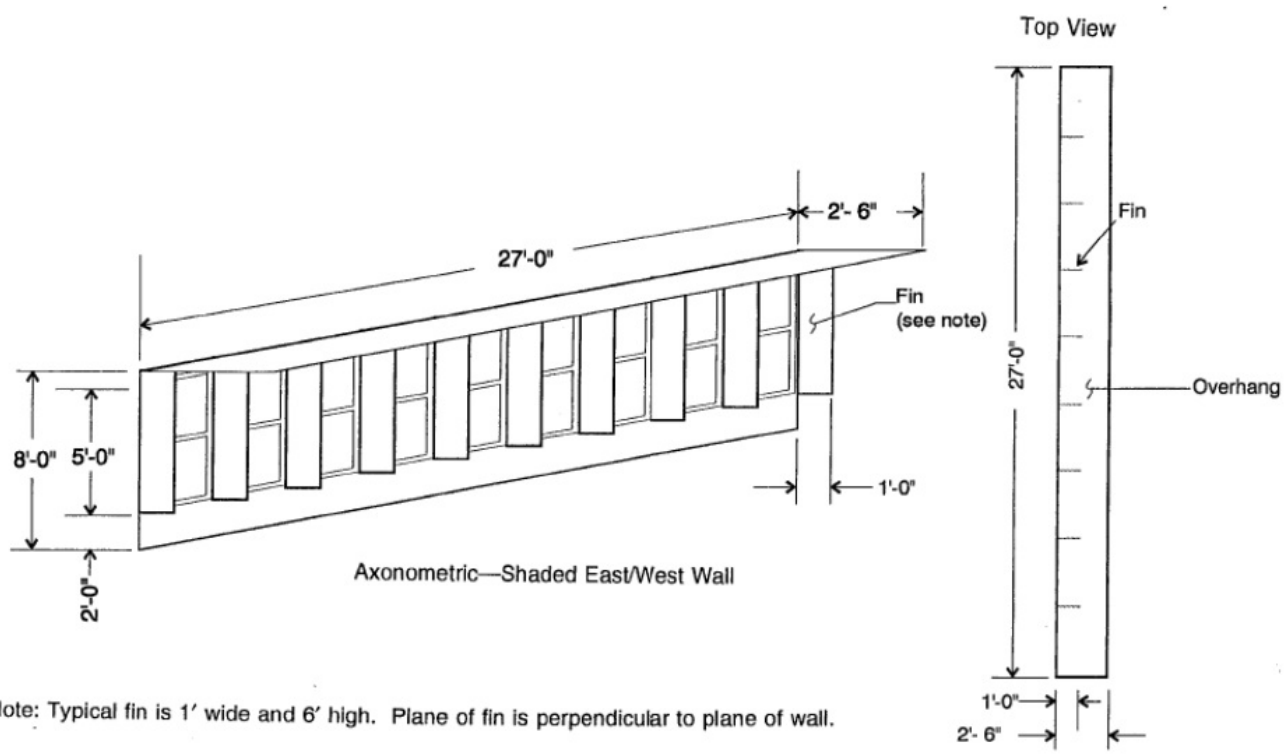


Figure 15 Case L165A Overhang and Fin configuration for East and West Windows (ANSI/ASHRAE 2011, Figure 7-26)

1.3.2.2 Case P100A – Passive Solar Base Case

Case P100A is based on Case L120A with the following changes:

- All windows are located on south wall and have increased glass area (Figure 16)
- Windows are clear double-pane with wood frame and modified geometry (Figure 17 and Table 5)
- Floor is R-23 composite floor with brick pavers for thermal mass (Table 6)
- Three of the 14’ lightweight interior walls are replaced with 14’ double brick walls for thermal mass (Figure 16 and Table 7)

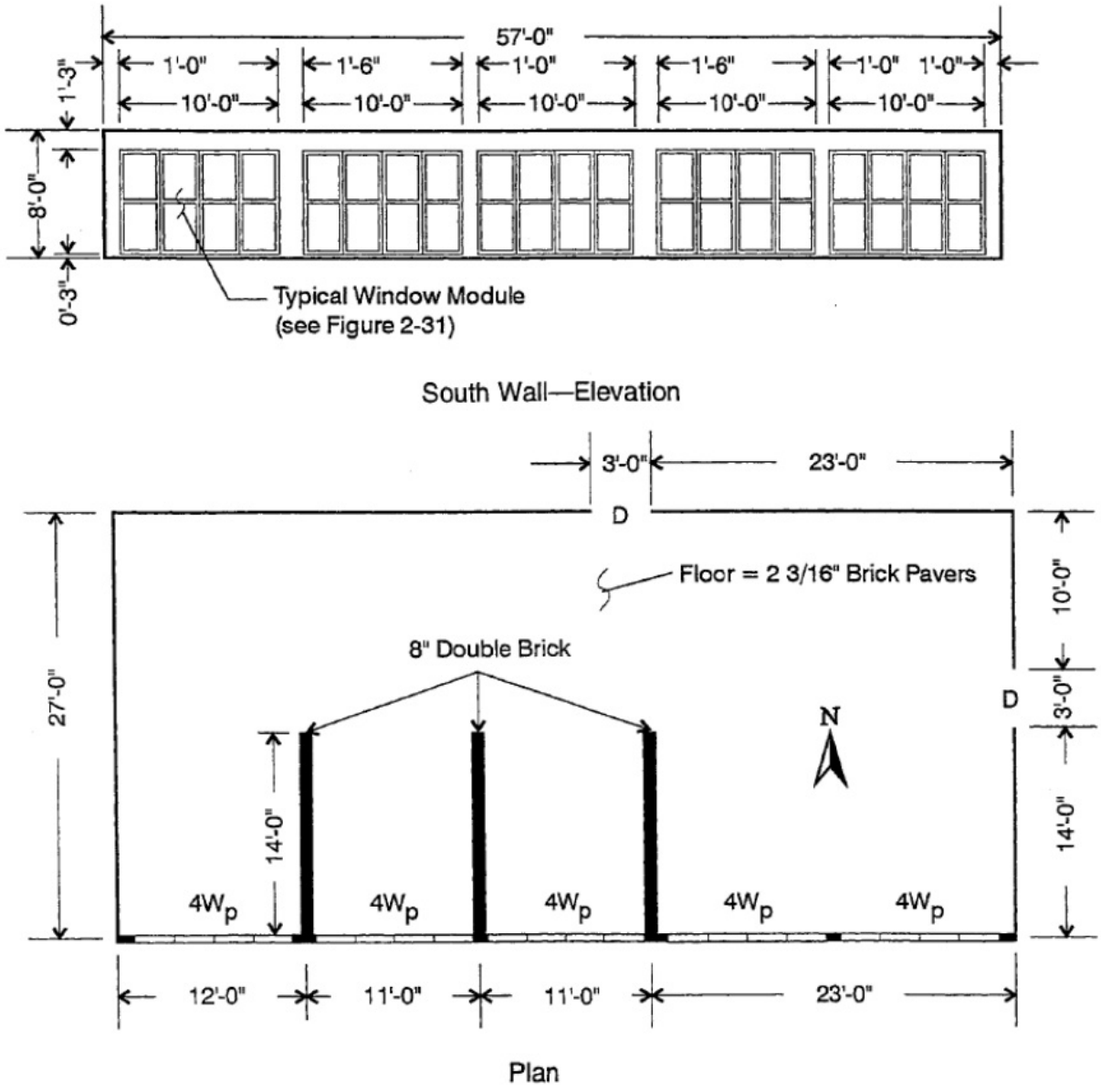


Figure 16 Case P100A South Wall Window Configuration and Location of mass Walls(ANSI/ASHRAE 2011, Figure 7-28)

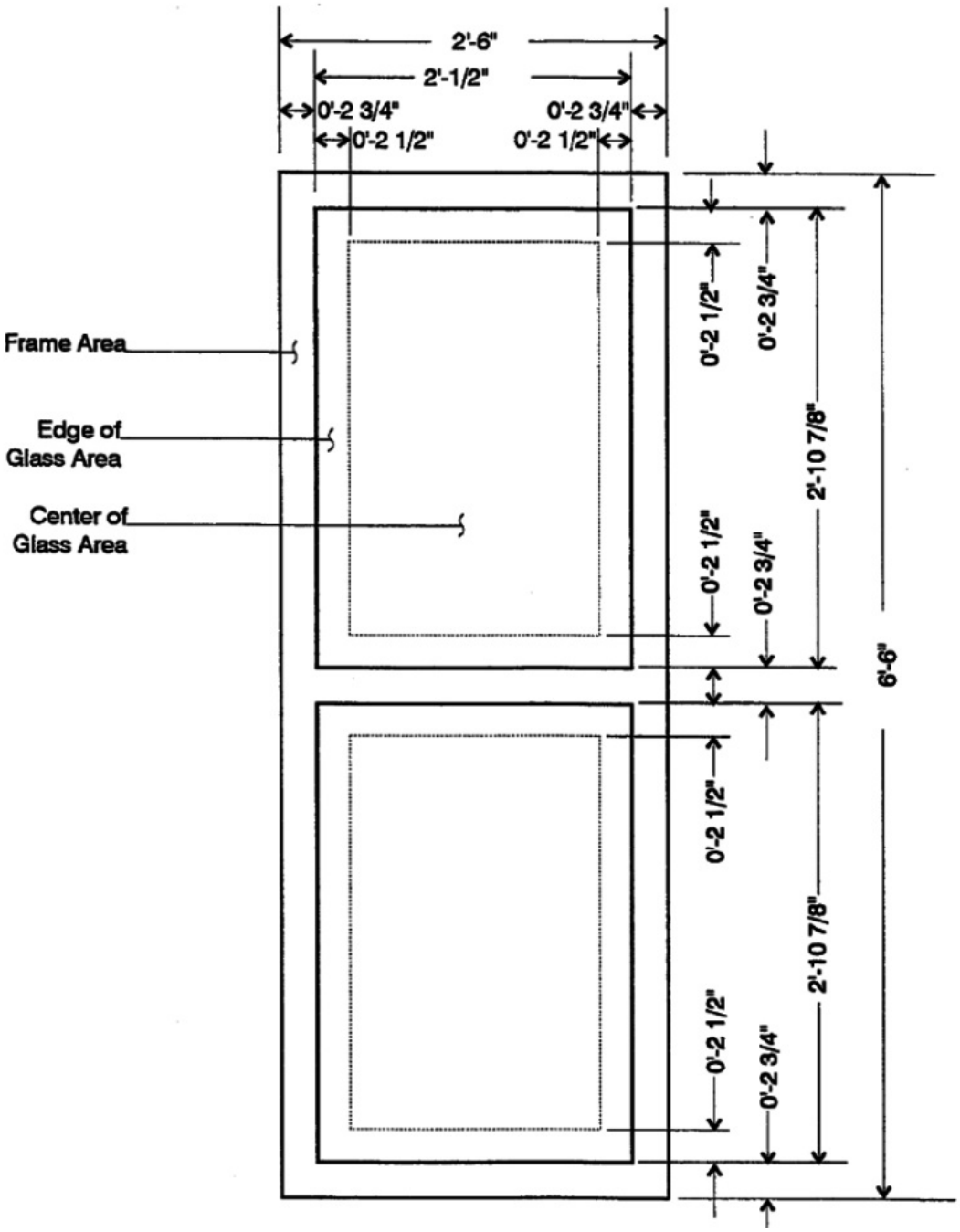


Figure 17 Case P100A Window Details (ANSI/ASHRAE 2011, Figure 7-31)

Table 5 Case P100A Window Characteristics

	Area (ft^2)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	SHGC (dir. Nor.)	Trans (dir. Nor.)	SC
Glass Pane	11.87	05167	0.760	0.705	0.887
Wood frame w/metal spacer	4.38	0.492			
Window composite air-air	16.25	0.510	0.557	0.515	0.672

Table 6 Case P100A Floor Construction

	Thickness (in)	R ($\frac{h \cdot ft^2 \cdot F}{Btu}$)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	k ($\frac{h \cdot ft \cdot F}{Btu}$)	Density ($\frac{lb}{ft^3}$)	Cp ($\frac{Btu}{lb \cdot ft}$)
Int. Surf. Coeff.		0.765	1.307			
Brick pavers	2.19	0.243	4.114	0.7500	135.0	0.24
Plywood ¾”	0.75	0.937	1.067	0.0667	34.0	0.29
Fiberglass batt	7.25	24.00	0.042	00252	0.66	0.20
Joists 2” x 8” 16” O.C.	7.25	9.058	0.110	0.0667	32.0	0.33
Ext. Surf. Coeff.		0.455	2.200			
Total air-air		23.354	0.043			

Table 7 Case P100A Interior Mass Wall Construction

	Thickness (in)	R ($\frac{h \cdot ft^2 \cdot F}{Btu}$)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	k ($\frac{h \cdot ft \cdot F}{Btu}$)	Density ($\frac{lb}{ft^3}$)	Cp ($\frac{Btu}{lb \cdot ft}$)
Int. Surf. Coeff.		0.685	1.460			
Face brick	4.0	0.444	2.250	0.7500	130.0	0.24
Int. Surf. Coeff.		0.685	1.460			

1.3.2.3 Case P105A – Passive Solar with Overhang

Case P105A is exactly the same as case P100A except that a south wall opaque overhang is included that extends outward horizontally 3.47 ft with a vertical offset of 2.08 ft. from the top of the window (Figure 18). The overhang extends the entire length of the south wall.

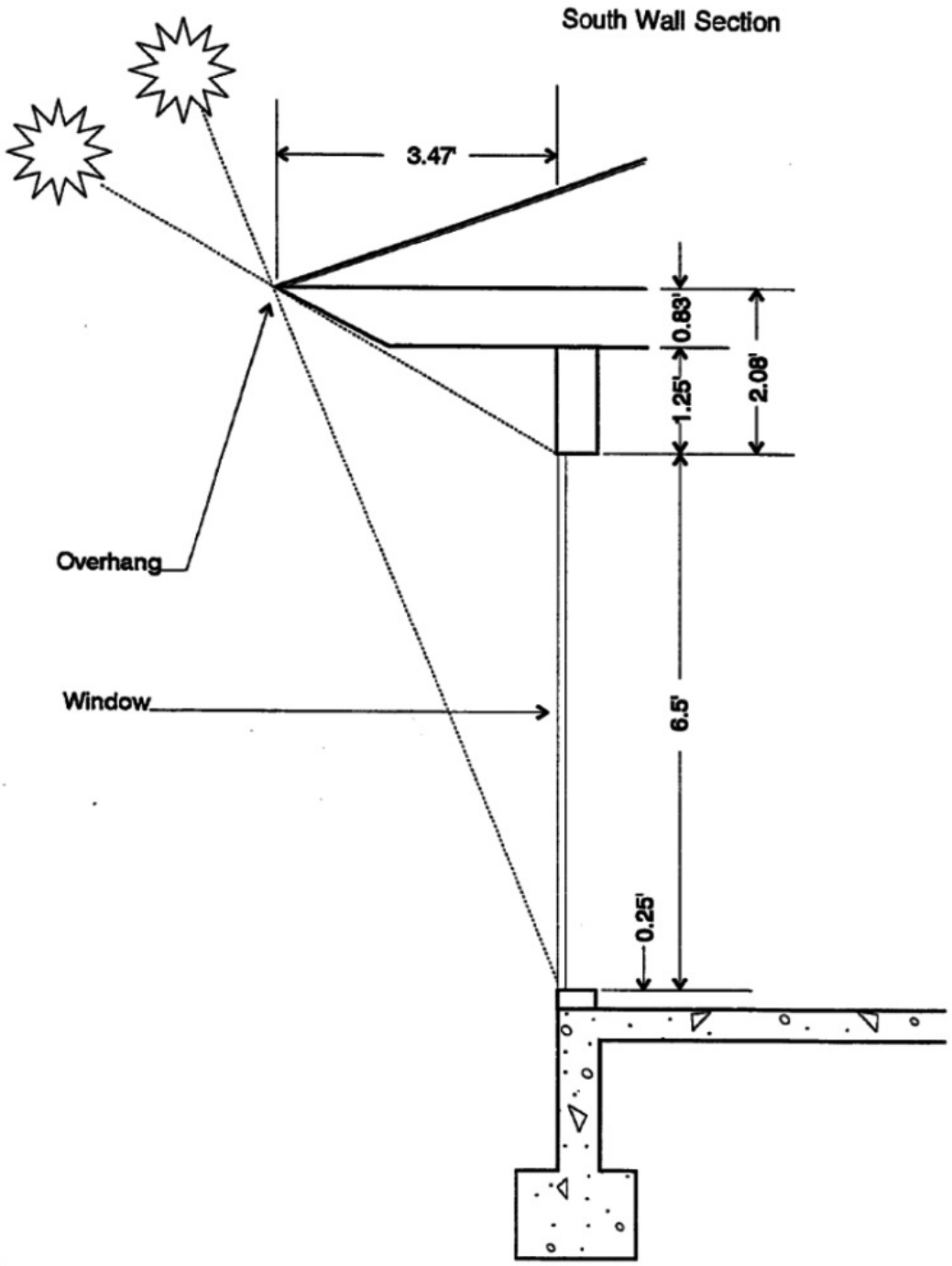


Figure 18 Case P105A South Wall with Overhang (ANSI/ASHRAE 2011, Figure 7-32)

1.3.2.4 Case P110A – Low mass Version of Case P100A

Case P110A is the same as Case P100A except for the following:

- The brick pavers have been removed from the floor and replaced with an equivalent resistance mass-less floor covering (Table 8)
- The three massive internal walls are configurated as in Case L100A

Table 8 Case P110A Floor Construction

	Thickness (in)	R ($\frac{h \cdot ft^2 \cdot F}{Btu}$)	U ($\frac{Btu}{h \cdot ft^2 \cdot F}$)	k ($\frac{h \cdot ft \cdot F}{Btu}$)	Density ($\frac{lb}{ft^3}$)	Cp ($\frac{Btu}{lb \cdot ft}$)
Int. Surf. Coeff.		0.765	1.307			
Floor covering		0.243	4.114			
Plywood ¾”	0.75	0.937	1.067	0.0667	34.0	0.29
Fiberglass batt	7.25	24.00	0.042	00252	0.66	0.20
Joists 2” x 8” 16” O.C.	7.25	9.058	0.110	0.0667	32.0	0.33
Ext. Surf. Coeff.		0.455	2.200			
Total air-air		23.354	0.043			

1.3.2.5 Case P140A – Zero Window Area Version of Case P100A

Case P140A is the same as Case P100A except the glazing is removed from the south wall such that the entire south wall is opaque with the same construction as used in Case L120A (Figure 5).

1.3.2.6 Case P150A – Even Window Distribution Version of Case P100A

Case P150A is the same as Case P100A except that all windows are evenly distributed among the walls (Figure 19). The interior wall locations are the same as in Case P100A.

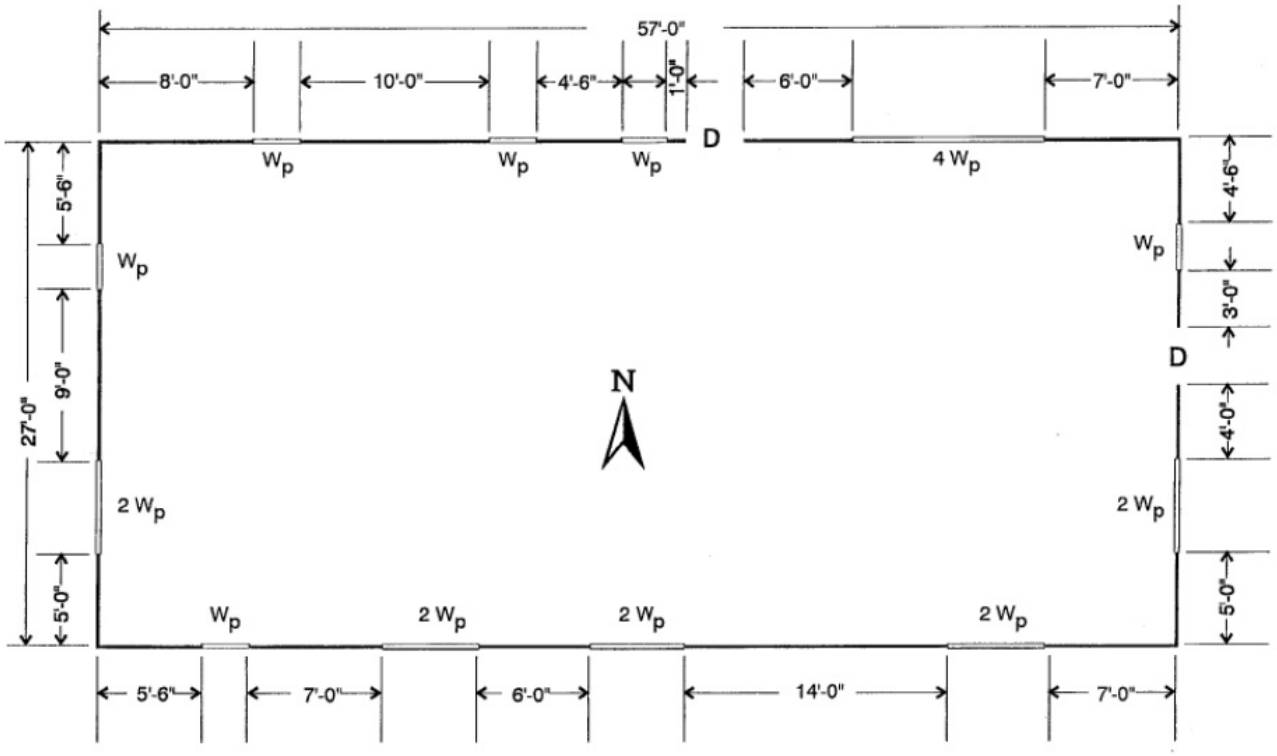


Figure 19 Case P150A Window Locations (ANSI/ASHRAE 2011, Figure 7-35)

1.3.3 Weather Data

Weather files were provided as part of the standard for Colorad.TMY and Lasvega.TMY. Colorad.TMY is a clear, cold climate and is used to simulate heating loads. Lasvega.TMY is a hot, dry climate and is used to simulate cooling loads. Both weather files were used for all test cases except for the ground-coupling cases (L302A, L304A, L322A and L324A) and passive solar cases (P100A, P105A, P110A, P140A and P150A) which did not require the use of the Lasvega.TMY weather file.

1.4 Modeling Notes

The specifications as presented in Section 5 - Test Procedures of ANSI/ASHRAE Standard 140-2011 and Section 7.2 – Input Specifications were followed to prepare the EnergyPlus models for the test cases described above. In some cases the specification provided redundant input values for a particular element of the building due to the fact different programs require different inputs. The following notes are presented regarding preparation of EnergyPlus IDF files:

- Although the Standard spelled out in detail the exterior and interior radiative and convective surface properties, these were not used. The Standard indicated that if your program automatically calculates the exterior and interior film coefficients, then these radiative and convective input values were to be disregarded. For inside surface coefficients, the EnergyPlus SurfaceConvectionAlgorithm:Inside was set to TARP. For outside surface coefficients, the EnergyPlus SurfaceConvectionAlgorithm:Outside was set to DOE-2.
- The material layers for walls, floors and roofs were specified using the Material object except for the window aluminum frame which was described using the Material:NoMass object. The opaque surface radiative properties listed in the Material object were defined in the Standard and were set as follows:
    - Thermal Emissivity 0.90

    - Solar Absorptance 0.60
    - Visible Absorptance 0.60
- The convergence variables in the Building object were set as follows:
    - Loads Convergence Tolerance Value 0.04
    - Temperature Convergence Tolerance Value 0.004
- To get the shade calculations to work for the window overhang test cases, the following variables in the Building object had to be set:
    - Solar Distribution = FullInteriorAnd Exterior
    - Same was true for cases with window fins.
- The ZoneHVAC:IdealLoadsAirSystem object was used to model the mechanical system.
- All simulations were done using a Timestep = 4; output results were reported hourly.
- Internal walls were modeled using the Energyplus InternalMass object.
- For all cases individual windows were modeled with the window frame and divider specified using the EnergyPlus WindowProperty:FrameAndDivider object. Overhangs and fins were modeled as shown in Figures 20 and 21.
- For the slab-on-grade test cases, L302A and L304A, the EnergyPlus F-factor method for simulating ground-coupled heat transfer for a slab-on-grade floor was utilized. The F-factor for the floor was set to 1.33 W/m-K for the uninsulated floor of case L302AC and 0.9326 W/m-K for the insulated floor of case L304AC.

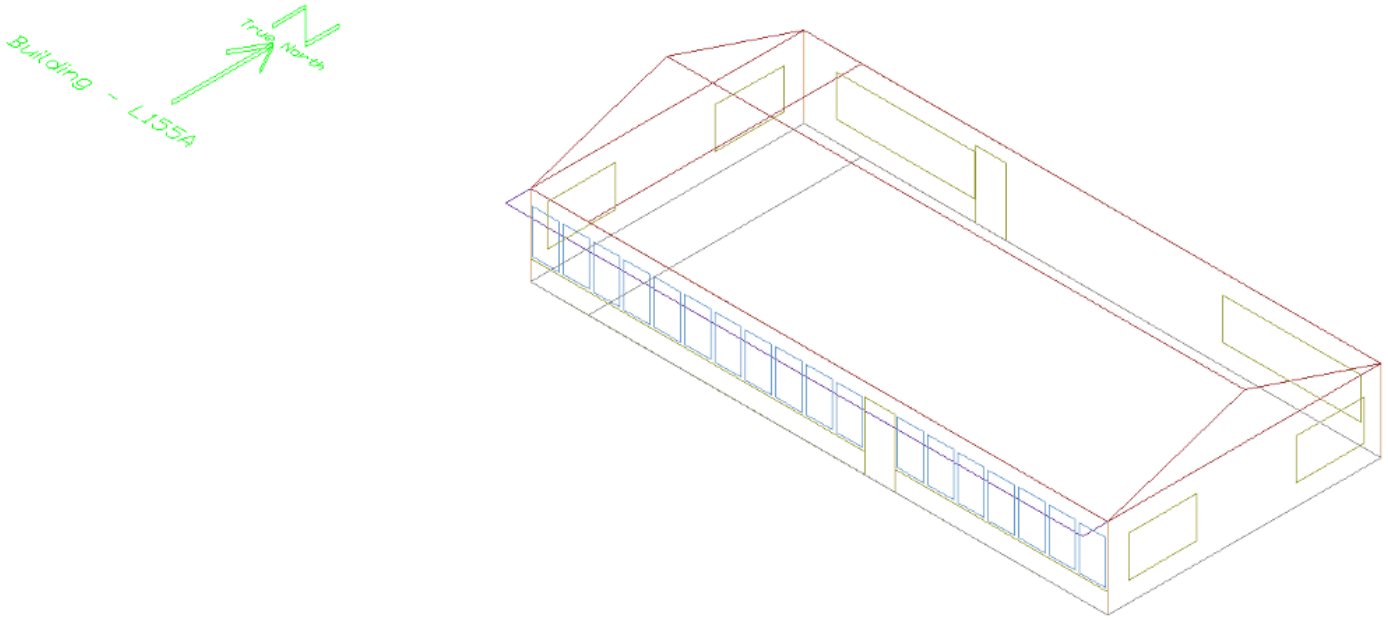


Figure 20 Case L155A Building as Modeled with EnergyPlus with Individual Windows and Overhang on South Wall

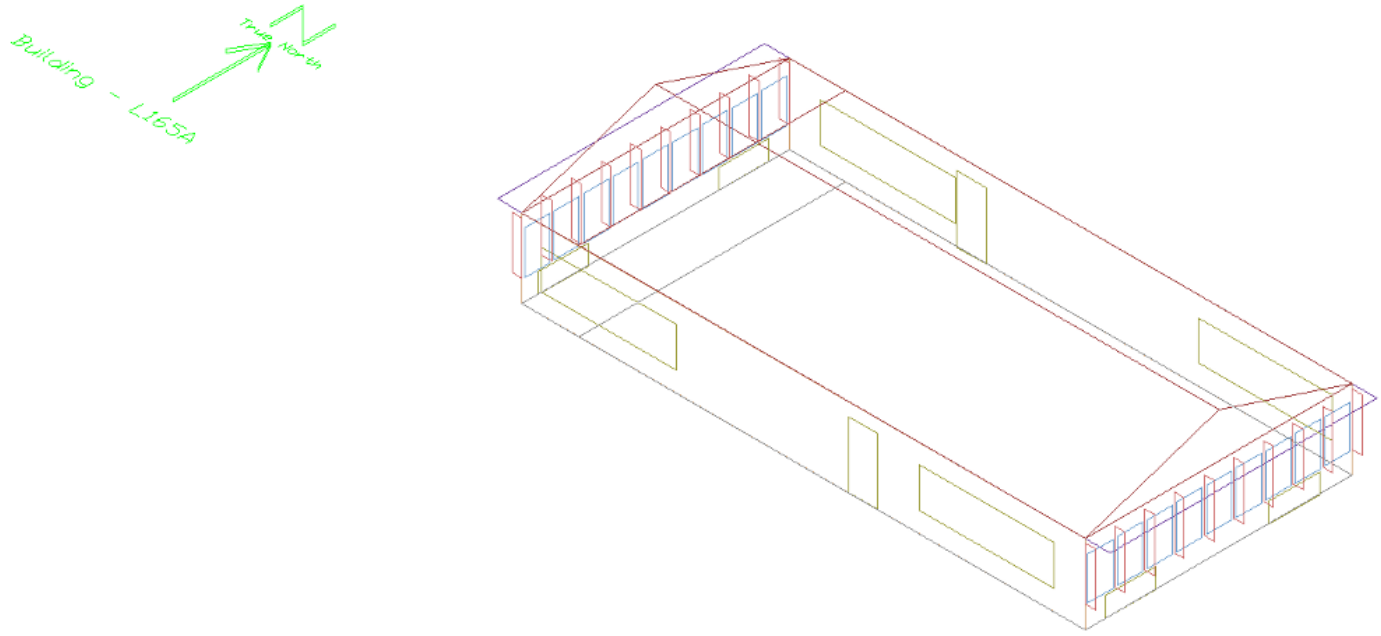


Figure 21 Case L165A Building as Modeled with EnergyPlus with Overhang and Individual Windows with Fins on South Wall

2 Results and Discussion

The results of the EnergyPlus simulations along with other whole building energy analysis programs that participated in the comparison are summarized in a set of charts presented in Appendix A. The nomenclature for the various programs referred to in these charts along with the program author and modeler responsible for using the program as part of the BESTEST project are presented in the table below.

Code Name	Computer Program	Developer	Implemented by
BLAST	BLAST-3.0 level 215	CERL, U.S.	
DOE2.1E	DOE2.1E	LANL/LBL, U.S.	
SUNCODE	SERIRES/SUNCODE 5.7	NREL, U.S	
ENERGYPLUS	EnergyPlus ver. 8.3.0-b45b06b780	U.S. Dept. of Energy	GARD Analytics, U.S.

Tables 9 and 12 show a comparison of EnergyPlus results to the results of other programs as presented in ANSI/ASHRAE Standard 140. In these tables, the column titled “Within Bounds” indicated whether the EnergyPlus results are within the simple range of results from the reference programs.

Annex B22 of ANSI/ASHRAE Standard 140-2011 Titled *Example Procedures for Developing Acceptance Range Criteria for Section 7 Test Cases* presents a procedure which can be used to determine if a program’s results fall within acceptable ranges compared to the standard results which are from much earlier HERS testing done with BLAST 3.0, DOE-2.1E and SERIRES back in 1995. This procedure uses standard deviations and 90% confidence limits to determine an acceptable range which has limits of 90% max confidence limit + 4 million BTU and 90% min confidence limit – 4 million BTU. The results of applying this procedure and comparing EnergyPlus results are shown in Tables 13 through 16.

2.1 EnergyPlus Issues Which Arose Due to Testing

When simulating Test Cases L322A and L324A which had basements with underground walls which had uninsulated and insulated walls using the EnergyPlus F-factor method, EnergyPlus results with EnergyPlus versions 7.2 and earlier showed only a small decrease in heating loads when the underground walls were insulated versus uninsulated. As expected, other programs showed much larger changes in heating loads. This issue was looked into in EnergyPlus 8.0.0.008 and code changes made to improve results (see Section 2.2).

2.2 Summary of Changes that were Implemented During Testing

This section documents the changes that took place in results as modifications were made to the EnergyPlus code or changes were made in the modeling approach. The table below summarizes pertinent input file and code changes that were made as the testing progressed.

Summary of Pertinent EnergyPlus Changes that were Implemented During Testing

Version	Input-File-Changes	Code-Changes
7.2.0.006		The model coefficients for the DOE-2 outside face convection correlations were changed
8.0.0.008		Corrected thermal resistance of the soil which affected cases using F-factor method(CR8886)
8.2.0		EnergyPlus code was converted to C++

In version 7.2.0.006 the model coefficients for the DOE-2 outside face convection correlations were changed which resulted in annual heating loads increasing by as much as 4.0% which brought the EnergyPlus results closer to the range of results for other programs. The annual cooling load decreased by as much as 3.7% which moved the EnergyPlus results farther away from the range of results of other programs.

In EnergyPlus v8.0 code changes were made to correct the thermal resistance of the soil. This changed the results for Cases L322AC (uninsulated underground wall) L324AC (insulated underground wall) and increased the difference between these two cases which use the F-factor method. Where previously the annual heating load for Case L324AC was only 1.2% less than that for Case L322AC, now with EnergyPlus 8.0.0.008 and later releases that difference increased to 6.3% less.

For EnergyPlus version 8.2.0, the source code was converted from FORTRAN to C++. This produced negligible differences in results.

Table 9 EnergyPlus HERS Tier-1 Colorado Springs Annual Heating Test Results Compared to ANSI/ASHRAE Standard 140-2011 Results

Tier-1 Test	Description	EnergyPlus Annual Heating Load (x106 Btu)	Std. 140 Annual Heating Load (x106 Btu) Min Value	Std. 140 Annual Heating Load (x106 Btu) Max Value	Std. 140 Annual Heating Load (x106 Btu) Mean Value	Within Bounds	%Diff from Min
Case L100AC	Base Case	49.80	58.00	72.39	64.11	NO	-14.1%
Case L110AC	Base Case with High Infiltration 1.5 ACH	75.17	81.39	96.53	87.96	NO	-7.6%
Case L120AC	Base Case with Well Insulated Walls & Roof	40.79	45.10	57.82	51.06	NO	-9.6%
Case L130AC	Base Case with Double-Pane Low-E Window w/Wood Frame	40.55	45.84	49.98	47.39	NO	-11.6%
Case L140AC	Base Case with Zero Window Area	46.80	47.25	52.48	49.63	NO	-0.9%
Case L150AC	Base Case with All Windows on South Wall	43.60	49.48	64.03	56.15	NO	-11.9%
Case L155AC	Case L150AC with Overhang Along Entire Wall	45.35	52.30	66.90	58.86	NO	-13.3%
Case L160AC	Base Case with East/West Windows Along Entire Wall	50.73	58.29	73.51	64.90	NO	-13.0%
Case L170AC	Base Case with No Internal Loads	60.54	71.65	85.46	76.72	NO	-15.5%
Case L200AC	Base Case but Energy Efficient Walls, Floor, Ceiling	122.16	133.97	168.34	146.14	NO	-8.8%
Case L202AC	Case L200AC but Low Exterior Solar Absorptance	129.20	137.47	172.55	150.69	NO	-6.0%
Case L302AC	Base Case with Slab-on-Grade Floor w/no perimeter insulation	47.30	67.44	82.92	73.62	NO	-29.9%
Case L304AC	Base Case with Slab-on-Grade Floor w/perimeter insulation	39.41	56.64	69.16	61.95	NO	-30.4%
Case L322AC	Base Case with Uninsulated ASHRAE Conditioned Basement	94.25	88.26	105.94	95.28	YES	6.8%
Case L324AC	Case L324A with Interior Insulation Applied to Basement Walls	88.32	61.11	72.58	66.20	NO	44.5%

Table 10 EnergyPlus HERS Tier-2 Colorado Springs Annual Heating Test Results Compared to ANSI/ASHRAE Standard 140-2011 Results

Tier-2 Test	Description	EnergyPlus Annual Heating Load (x106 Btu)	Std. 140 Annual Heating Load (x106 Btu) Min Value	Std. 140 Annual Heating Load (x106 Btu) Max Value	Std. 140 Annual Heating Load (x106 Btu) Mean Value	Within Bounds	%Diff from Min	%Diff from Max
Case L165AC	Case L160AC with Shaded East/West Windows	54.11	64.73	78.05	69.87	NO	-16.4%	
Case P100AC	Base Case for Passive Solar Tests	11.29	10.020000	14.400000	12.240000	YES	12.7%	
Case P105AC	Base Case P100AC with Overhang	13.50	12.100000	16.960000	14.550000	YES	11.6%	
Case P110AC	Base Caes P100AC with Lt.Wt. Floor and Lt.Wt. Interior Walls	25.67	20.170000	23.780000	22.110000	NO		8.0%
Case P140AC	Base Case P100AC with No South Windows and Case L120 Floor	32.65	25.820000	29.420000	28.220000	NO		11.0%
Case P150AC	Base Case P100AC with Even Window Distribution	23.08	22.580000	28.010000	25.230000	YES	2.2%	

Table 11 EnergyPlus HERS Tier-1 Las Vegas Annual Cooling Test Results Compared to ANSI/ASHRAE Standard 140-2011 Results

Tier-1 Test	Description	EnergyPlus Annual Cooling Load (x106 Btu)	Std. 140 Annual Cooling Load (x106 Btu) Min Value	Std. 140 Annual Cooling Load (x106 Btu) Max Value	Std. 140 Annual Cooling Load (x106 Btu) Mean Value	Within Bounds	%Diff from Min
Case L100AL	Base Case	48.85	54.660000	60.80	58.26	NO	-10.6%
Case L110AL	Base Case with High Infiltration 1.5 ACH	51.89	57.710000	63.82	61.57	NO	-10.1%
Case L120AL	Base Case with Well Insulated Walls & Roof	47.96	51.360000	56.14	54.17	NO	-6.6%
Case L130AL	Base Case with Double-Pane Low-E Window w/Wood Frame	35.93	36.960000	41.25	39.05	NO	-2.8%
Case L140AL	Base Case with Zero Window Area	22.86	23.520000	26.54	24.90	NO	-2.8%
Case L150AL	Base Case with All Windows on South Wall	64.33	67.730000	77.35	72.37	NO	-5.0%
Case L155AL	Case L150AC with Overhang Along Entire Wall	48.84	54.090000	59.06	56.89	NO	-9.7%
Case L160AL	Base Case with East/West Windows Along Entire Wall	57.90	62.620000	68.69	66.31	NO	-7.5%
Case L170AL	Base Case with No Internal Loads	39.71	45.830000	49.30	48.07	NO	-13.3%
Case L200AL	Base Case but Energy Efficient Walls, Floor, Ceiling	60.57	65.710000	76.71	71.84	NO	-7.8%
Case L202AL	Case L200AC but Low Exterior Solar Absorptance	49.42	59.610000	70.57	64.14	NO	-17.1%

Table 12 EnergyPlus HERS Tier-2 Las Vegas and Colorado Springs Annual Cooling Test Results Compared to ANSI/ASHRAE Standard 140-2011 Results

Tier-2 Test	Description	EnergyPlus Annual Cooling Load (x106 Btu)	Std. 140 Annual Cooling Load (x106 Btu) Min Value	Std. 140 Annual Cooling Load (x106 Btu) Max Value	Std. 140 Annual Cooling Load (x106 Btu) Mean Value	Within Bounds	%Diff from Min
Case L165AL	Case L160AC with Shaded East/West Windows	48.32	52.87	59.58	55.74	NO	-8.6%
Case P100AC	Base Case for Passive Solar Tests	17.71	18.11	23.01	20.40	NO	-2.2%
Case P105AC	Base Case P100AC with Overhang	11.19	11.94	13.61	13.00	NO	-6.3%
Case P110AC	Base Caes P100AC with Lt.Wt. Floor and Lt.Wt. Interior Walls	25.45	30.19	36.48	32.51	NO	-15.7%
Case P140AC	Base Case P100AC with No South Windows and Case L120 Floor	1.61	1.68	2.84	2.09	NO	-4.2%
Case P150AC	Base Case P100AC with Even Window Distribution	11.52	12.43	15.03	13.83	NO	-7.3%

Suffix AL refers to Las Vegas
Suffix AC refers to Colorado Springs

Table 13 EnergyPlus Acceptance Test Results - HERS Tier-1 Colorado Springs Annual Heating

	Base case		Delta			Delta			Delta			Delta
	L100AC	L110AC	L110AC - L100AC	L100AC	L120AC	L120AC - L100AC	L100AC	L130AC	L130AC - L100AC	L100AC	L140AC	L140AC - L100AC
BLAST	61.94	85.95	24.01	61.94	50.27	-11.67	61.94	46.35	-15.59	61.94	49.15	-12.79
DOE 2.1E	58.00	81.39	23.39	58.00	45.10	-12.90	58.00	45.84	-12.16	58.00	47.25	-10.75
SERIRES	72.39	96.53	24.14	72.39	57.82	-14.57	72.39	49.98	-22.41	72.39	52.48	-19.91
Ref Max	72.39	96.53	24.14	72.39	57.82	-11.67	72.39	49.98	-12.16	72.39	52.48	-10.75
Ref Min	58.00	81.39	23.39	58.00	45.10	-14.57	58.00	45.84	-22.41	58.00	47.25	-19.91
Ref Mean	64.11	87.96	23.85	64.11	51.06	-13.05	64.11	47.39	-16.72	64.11	49.63	-14.48
Ref StdDev	7.44	7.77	0.40	7.44	6.40	1.46	7.44	2.26	5.22	7.44	2.65	4.81
Ref 90% Conf Max	79.46	103.99	24.67	79.46	64.27	-10.04	79.46	52.05	-5.95	79.46	55.09	-4.55
Ref 90% Conf Min	48.76	71.92	23.02	48.76	37.86	-16.05	48.76	42.73	-27.49	48.76	44.16	-24.41
Ref Max + 4 mil BTU	76.39	100.53	28.14	76.39	61.82	-7.67	76.39	53.98	-8.16	76.39	56.48	-6.75
Ref Min - 4mil BTU	54.00	77.39	19.39	54.00	41.10	-18.57	54.00	41.84	-26.41	54.00	43.25	-23.91
Range Max	79.46	103.99	28.14	79.46	64.27	-7.67	79.46	53.98	-5.95	79.46	56.48	-4.55
Range Min	48.76	71.92	19.39	48.76	37.86	-18.57	48.76	41.84	-27.49	48.76	43.25	-24.41
EnergyPlus	49.80	75.17	25.38	48.59	40.79	-7.80	48.59	40.55	-8.04	48.59	46.80	-1.79
Passes	YES	YES	YES		YES	YES		NO	YES		YES	NO

			Delta			Delta			Delta
	L100AC	L150AC	L150AC -L100AC	L100AC	L160AC	L160AC -L100AC	L100AC	L170AC	L170AC -L100AC
BLAST	61.94	54.93	-7.01	61.94	62.90	0.96	61.94	73.06	11.12
DOE 2.1E	58.00	49.48	-8.52	58.00	58.29	0.29	58.00	71.65	13.65
SERIRES	72.39	64.03	-8.36	72.39	73.51	1.12	72.39	85.46	13.07
Ref Max	72.39	64.03	-7.01	72.39	73.51	1.12	72.39	85.46	13.65
Ref Min	58.00	49.48	-8.52	58.00	58.29	0.29	58.00	71.65	11.12
Ref Mean	64.11	56.15	-7.96	64.11	64.90	0.79	64.11	76.72	12.61
Ref StdDev	7.44	7.35	0.83	7.44	7.80	0.44	7.44	7.60	1.33
Ref 90% Conf Max	79.46	71.32	-6.25	79.46	81.01	1.70	79.46	92.41	15.35
Ref 90% Conf Min	48.76	40.97	-9.68	48.76	48.79	-0.12	48.76	61.03	9.88
Ref Max + 4 mil BTU	76.39	68.03	-3.01	76.39	77.51	5.12	76.39	89.46	17.65
Ref Min - 4mil BTU	54.00	45.48	-12.52	54.00	54.29	-3.71	54.00	67.65	7.12
Range Max	79.46	71.32	-3.01	79.46	81.01	5.12	79.46	92.41	17.65
Range Min	48.76	40.97	-12.52	48.76	48.79	-3.71	48.76	61.03	7.12
EnergyPlus	48.59	43.60	-4.99	48.59	50.73	2.14	48.59	60.54	11.95
Passes		YES	YES		YES	YES		NO	YES

Table 13 EnergyPlus Acceptance Test Results - HERS Tier-1 Colorado Springs Annual Heating (Cont'd)

	Base Case		Delta	Base Case		Delta	Base Case		Delta	Base Case		Delta
	L150AC	L155AC	L155AC - L150AC	L100AC	L200AC	L200AC - L100AC	L200AC	L202AC	L202AC - L200AC	L100AC	L302AC	L302AC - L100AC
BLAST	54.93	57.39	2.46	61.94	133.97	72.03	133.97	137.47	3.50	61.94	70.50	8.56
DOE 2.1E	49.48	52.30	2.82	58.00	136.12	78.12	136.12	142.06	5.94	58.00	67.44	9.44
SERIRES	64.03	66.90	2.87	72.39	168.34	95.95	168.34	172.55	4.21	72.39	82.92	10.53
Ref Max	64.03	66.90	2.87	72.39	168.34	95.95	168.34	172.55	5.94	72.39	82.92	10.53
Ref Min	49.48	52.30	2.46	58.00	133.97	72.03	133.97	137.47	3.50	58.00	67.44	8.56
Ref Mean	56.15	58.86	2.72	64.11	146.14	82.03	146.14	150.69	4.55	64.11	73.62	9.51
Ref StdDev	7.35	7.41	0.22	7.44	19.25	12.43	19.25	19.07	1.26	7.44	8.20	0.99
Ref 90% Conf Max	71.32	74.16	3.18	79.46	185.90	107.70	185.90	190.06	7.14	79.46	90.55	11.55
Ref 90% Conf Min	40.97	43.56	2.25	48.76	106.39	56.37	106.39	111.32	1.96	48.76	56.69	7.47
Ref Max + 4 mil BTU	68.03	70.90	6.87	76.39	172.34	99.95	172.34	176.55	9.94	76.39	86.92	14.53
Ref Min - 4mil BTU	45.48	48.30	-1.54	54.00	129.97	68.03	129.97	133.47	-0.50	54.00	63.44	4.56
Range Max	71.32	74.16	6.87	79.46	185.90	107.70	185.90	190.06	9.94	79.46	90.55	14.53
Range Min	40.97	43.56	-1.54	48.76	106.39	56.37	106.39	111.32	-0.50	48.76	56.69	4.56
EnergyPlus	43.60	45.35	1.75	49.80	122.16	72.36	122.16	129.20	7.05	49.80	47.30	-2.50
Passes	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO

	Base Case		Delta	Base Case		Delta	Base Case		Delta
	L304AC	L302AC	L302AC -L304AC	L100AC	L322AC	L322AC -L100AC	L324AC	L322AC	L322AC -L324AC
BLAST	60.05	70.50	10.45	61.94	91.65	29.71	64.91	91.65	26.74
DOE 2.1E	56.64	67.44	10.80	58.00	88.26	30.26	61.11	88.26	27.15
SERIRES	69.16	82.92	13.76	72.39	105.94	33.55	72.58	105.94	33.36
Ref Max	69.16	82.92	13.76	72.39	105.94	33.55	72.58	105.94	33.36
Ref Min	56.64	67.44	10.45	58.00	88.26	29.71	61.11	88.26	26.74
Ref Mean	61.95	73.62	11.67	64.11	95.28	31.17	66.20	95.28	29.08
Ref StdDev	6.47	8.20	1.82	7.44	9.38	2.08	5.84	9.38	3.71
Ref 90% Conf Max	75.31	90.55	15.42	79.46	114.66	35.46	78.26	114.66	36.74
Ref 90% Conf Min	48.59	56.69	7.92	48.76	75.91	26.89	54.14	75.91	21.42
Ref Max + 4 mil BTU	73.16	86.92	17.76	76.39	109.94	37.55	76.58	109.94	37.36
Ref Min - 4mil BTU	52.64	63.44	6.45	54.00	84.26	25.71	57.11	84.26	22.74
Range Max	75.31	90.55	17.76	79.46	114.66	37.55	78.26	114.66	37.36
Range Min	48.59	56.69	6.45	48.76	75.91	25.71	54.14	75.91	21.42
EnergyPlus	39.41	47.30	7.88	49.80	94.25	44.45	88.32	94.25	5.93
Passes	NO	NO	YES	YES	YES	NO	NO	YES	NO

Table 14 EnergyPlus Acceptance Test Results - HERS Tier-2 Colorado Springs Annual Heating

	Base Case		Delta	Base Case		Delta	Base Case		Delta
	L160AC	L165AC	L165AC -L160AC	P100AC	P105AC	P105AC -P100AC	P100AC	P110AC	P110AC -P100AC
BLAST	62.90	66.84	3.94	12.31	14.60	2.29	12.31	22.37	10.06
DOE 2.1E	58.29	64.73	6.44	10.02	12.10	2.08	10.02	20.17	10.15
SERIRES	73.51	78.05	4.54	14.40	16.96	2.56	14.40	23.78	9.38
Ref Max	73.51	78.05	6.44	14.40	16.96	2.56	14.40	23.78	10.15
Ref Min	58.29	64.73	3.94	10.02	12.10	2.08	10.02	20.17	9.38
Ref Mean	64.90	69.87	4.97	12.24	14.55	2.31	12.24	22.11	9.86
Ref StdDev	7.80	7.16	1.31	2.19	2.43	0.24	2.19	1.82	0.42
Ref 90% Conf Max	81.01	84.66	7.67	16.77	19.57	2.81	16.77	25.86	10.73
Ref 90% Conf Min	48.79	55.09	2.28	7.72	9.54	1.81	7.72	18.35	8.99
Ref Max + 4 mil BTU	77.51	82.05	10.44	18.40	20.96	6.56	18.40	27.78	14.15
Ref Min - 4mil BTU	54.29	60.73	-0.06	6.02	8.10	-1.92	6.02	16.17	5.38
Range Max	81.01	84.66	10.44	18.40	20.96	6.56	18.40	27.78	14.15
Range Min	48.79	55.09	-0.06	6.02	8.10	-1.92	6.02	16.17	5.38
EnergyPlus	50.73	54.11	3.37	11.29	13.50	2.21	11.29	25.67	14.38
Passes	YES	NO	YES	YES	YES	YES	YES	YES	NO

	Base Case		Delta	Base Case		Delta
	P100AC	P140AC	P140AC -P100AC	P100AC	P150AC	P150AC -P100AC
BLAST	12.31	29.42	17.11	12.31	25.10	12.79
DOE 2.1E	10.02	25.82	15.80	10.02	22.58	12.56
SERIRES	14.40	29.42	15.02	14.40	28.01	13.61
Ref Max	14.40	25.82	-11.42	14.40	22.58	-8.18
Ref Min	10.02	29.42	-19.40	10.02	25.10	-15.08
Ref Mean	12.24	28.22	-15.98	12.24	25.23	-12.99
Ref StdDev	2.19	2.08	0.11	2.19	2.72	-0.53
Ref 90% Conf Max	16.77	32.51	-15.74	16.77	30.84	-14.07
Ref 90% Conf Min	7.72	23.93	-16.21	7.72	19.62	-11.90
Ref Max + 4 mil BTU	18.40	29.82	-7.42	18.40	26.58	-4.18
Ref Min - 4mil BTU	6.02	25.42	-23.40	6.02	21.10	-19.08
Range Max	18.40	32.51	-7.42	18.40	30.84	-4.18
Range Min	6.02	23.93	-16.21	6.02	19.62	-11.90
EnergyPlus	11.29	32.65	21.35	11.29	23.08	11.78
Passes	YES	NO	NO	YES	YES	NO

Table 15 EnergyPlus Acceptance Test Results - HERS Tier-1 Las Vegas Annual Cooling

	Base Case		Delta			Delta			Delta			Delta
	L100AL	L110AL	L110AL - L100AL	L100AL	L120AL	L110AL - L100AL	L100AL	L130AL	L110AL - L100AL	L100AL	L140AL	L110AL - L100AL
BLAST	54.66	57.71	3.05	54.66	51.36	-3.30	54.66	36.96	-17.70	54.66	23.52	-31.14
DOE 2.1E	60.08	63.82	3.74	60.08	56.14	-3.94	60.08	41.25	-18.83	60.08	26.54	-33.54
SERIRES	59.32	63.18	3.86	59.32	55.01	-4.31	59.32	38.93	-20.39	59.32	24.64	-34.68
Ref Max	60.08	63.82	3.86	60.08	56.14	-3.30	60.08	41.25	-17.70	60.08	26.54	-31.14
Ref Min	54.66	57.71	3.05	54.66	51.36	-4.31	54.66	36.96	-20.39	54.66	23.52	-34.68
Ref Mean	58.02	61.57	3.55	58.02	54.17	-3.85	58.02	39.05	-18.97	58.02	24.90	-33.12
Ref StdDev	2.93	3.36	0.44	2.93	2.50	0.51	2.93	2.15	1.35	2.93	1.53	1.81
Ref 90% Conf Max	64.08	68.50	4.45	64.08	59.33	-2.79	64.08	43.48	-16.18	64.08	28.05	-29.39
Ref 90% Conf Min	51.96	54.64	2.65	51.96	49.01	-4.91	51.96	34.61	-21.76	51.96	21.75	-36.85
Ref Max + 4 mil BTU	64.08	67.82	7.86	64.08	60.14	0.70	64.08	45.25	-13.70	64.08	30.54	-27.14
Ref Min - 4mil BTU	50.66	53.71	-0.95	50.66	47.36	-8.31	50.66	32.96	-24.39	50.66	19.52	-38.68
Range Max	64.08	68.50	7.86	64.08	60.14	0.70	64.08	45.25	-13.70	64.08	30.54	-27.14
Range Min	50.66	53.71	-0.95	50.66	47.36	-8.31	50.66	32.96	-24.39	50.66	19.52	-38.68
EnergyPlus	48.85	51.89	3.03	49.40	47.96	-1.44	49.40	35.93	-13.47	49.40	22.86	-26.54
Passes	NO	NO	YES		YES	YES		YES	NO		YES	NO

			Delta			Delta			Delta
	L100AL	L150AL	L110AL -L100AL	L100AL	L160AL	L110AL -L100AL	L100AL	L170AL	L110AL -L100AL
BLAST	54.66	67.73	13.07	54.66	62.62	7.96	54.66	45.83	-8.83
DOE 2.1E	60.08	77.35	17.27	60.08	68.69	8.61	60.08	49.08	-11.00
SERIRES	59.32	72.03	12.71	59.32	67.62	8.30	59.32	49.30	-10.02
Ref Max	60.08	77.35	17.27	60.08	68.69	8.61	60.08	49.30	-8.83
Ref Min	54.66	67.73	12.71	54.66	62.62	7.96	54.66	45.83	-11.00
Ref Mean	58.02	72.37	14.35	58.02	66.31	8.29	58.02	48.07	-9.95
Ref StdDev	2.93	4.82	2.54	2.93	3.24	0.33	2.93	1.94	1.09
Ref 90% Conf Max	64.08	82.32	19.58	64.08	73.00	8.96	64.08	52.08	-7.71
Ref 90% Conf Min	51.96	62.42	9.12	51.96	59.62	7.62	51.96	44.06	-12.19
Ref Max + 4 mil BTU	64.08	81.35	21.27	64.08	72.69	12.61	64.08	53.30	-4.83
Ref Min - 4mil BTU	50.66	63.73	8.71	50.66	58.62	3.96	50.66	41.83	-15.00
Range Max	64.08	82.32	21.27	64.08	73.00	12.61	64.08	53.30	-4.83
Range Min	50.66	62.42	8.71	50.66	58.62	3.96	50.66	41.83	-15.00
EnergyPlus	49.40	64.33	14.93	49.40	57.90	8.50	49.40	39.71	-9.69
Passes		YES	YES		NO	YES		NO	YES

			Delta			Delta			Delta
	L150AL	L155AL	L155AL -L150AL	L100AL	L200AL	L200AL -L100AL	L200AL	L202AL	L202AL -L100AL
BLAST	67.73	54.09	-13.64	54.66	65.71	11.05	65.71	59.61	-6.10
DOE 2.1E	77.35	59.06	-18.29	60.08	73.10	13.02	73.10	62.24	-10.86
SERIRES	72.03	57.51	-14.52	59.32	76.71	17.39	76.71	70.57	-6.14
Ref Max	77.35	59.06	-13.64	60.08	76.71	17.39	76.71	70.57	-6.10
Ref Min	67.73	54.09	-18.29	54.66	65.71	11.05	65.71	59.61	-10.86
Ref Mean	72.37	56.89	-15.48	58.02	71.84	13.82	71.84	64.14	-7.70
Ref StdDev	4.82	2.54	2.47	2.93	5.61	3.24	5.61	5.72	2.74
Ref 90% Conf Max	82.32	62.14	-10.38	64.08	83.42	20.52	83.42	75.95	-2.05
Ref 90% Conf Min	62.42	51.64	-20.58	51.96	60.26	7.12	60.26	52.33	-13.35
Ref Max + 4 mil BTU	81.35	63.06	-9.64	64.08	80.71	21.39	80.71	74.57	-2.10
Ref Min - 4mil BTU	63.73	50.09	-22.29	50.66	61.71	7.05	61.71	55.61	-14.86
Range Max	82.32	63.06	-9.64	64.08	83.42	21.39	83.42	75.95	-2.05
Range Min	62.42	50.09	-22.29	50.66	60.26	7.05	60.26	52.33	-14.86
EnergyPlus	64.33	48.84	-15.49	48.85	60.57	11.72	60.57	49.42	-11.15
Passes		NO	YES		YES	YES		NO	YES

Table 16 EnergyPlus Acceptance Test Results - HERS Tier-2 Las Vegas and Colorado Springs Annual Cooling

	Base Case		L165AL - L160AL	Base Case		L105AC - L100AC	Base Case		L110AC - L100AC	Base Case		L140AC - L100AC	Base Case		L150AC - L100AC
	L160AL	L165AL	Delta	P100AC	P105AC	Delta	P100AC	P110AC	Delta	P100AC	P140AC	Delta	P100AC	P150AC	Delta
BLAST	62.62	54.77	-7.85	18.11	11.94	-6.17	18.11	30.19	12.08	18.11	1.68	-16.43	18.11	12.43	-5.68
DOE 2.1E	68.69	52.87	-15.82	23.01	13.61	-9.40	23.01	36.48	13.47	23.01	2.84	-20.17	23.01	15.03	-7.98
SERIRES	67.62	59.58	-8.04	20.07	13.46	-6.61	20.07	30.86	10.79	20.07	1.74	-18.33	20.07	14.03	-6.04
Ref Max	68.69	59.58	-7.85	23.01	13.61	-6.17	23.01	36.48	13.47	23.01	2.84	-16.43	23.01	15.03	-5.68
Ref Min	62.62	52.87	-15.82	18.11	11.94	-9.40	18.11	30.19	10.79	18.11	1.68	-20.17	18.11	12.43	-7.98
Ref Mean	66.31	55.74	-10.57	20.40	13.00	-7.39	20.40	32.51	12.11	20.40	2.09	-18.31	20.40	13.83	-6.57
Ref StdDev	3.24	3.46	4.55	2.47	0.92	1.75	2.47	3.45	1.34	2.47	0.65	1.87	2.47	1.31	1.24
Ref 90% Conf Max	73.00	62.88	-1.18	25.49	14.91	-3.78	25.49	39.64	14.88	25.49	3.44	-14.45	25.49	16.54	-4.01
Ref 90% Conf Min	59.62	48.60	-19.96	15.30	11.10	-11.01	15.30	25.38	9.35	15.30	0.74	-22.17	15.30	11.12	-9.12
Ref Max + 4 mil BTU	72.69	63.58	-3.85	27.01	17.61	-2.17	27.01	40.48	17.47	27.01	6.84	-12.43	27.01	19.03	-1.68
Ref Min - 4mil BTU	58.62	48.87	-19.82	14.11	7.94	-13.40	14.11	26.19	6.79	14.11	-2.32	-24.17	14.11	8.43	-11.98
Range Max	73.00	63.58	-1.18	27.01	17.61	-2.17	27.01	40.48	17.47	27.01	6.84	-12.43	27.01	19.03	-1.68
Range Min	58.62	48.60	-19.96	14.11	7.94	-13.40	14.11	25.38	6.79	14.11	-2.32	-24.17	14.11	8.43	-11.98
EnergyPlus	57.90	48.32	-9.58	17.71	11.19	-6.52	17.71	25.45	7.74	17.71	1.61	-16.10	17.71	11.52	-6.19
Passes	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Suffix AL refers to Las Vegas
Suffix AC refers to Colorado Springs

3 Conclusions

EnergyPlus Version 8.3.0-b45b06b780 was used to model a range of building specifications as specified in Section 7 of the ANSI/ASHRAE Standard 140-2011 - *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.*

The ability of EnergyPlus to predict thermal loads was tested using a test suite of 34 test cases which included a single-story house with various design options including with and without a basement. The annual heating and cooling loads predicted by EnergyPlus were compared to results from 3 other whole building energy simulation programs that participated in an International Energy Agency (IEA) project which concluded in November 1995. When using the acceptance procedure described in ANSI/ASHRAE Standard 140-2011 Annex B22, for the 19 heating tests modeled by EnergyPlus which compare to a base case, EnergyPlus was within acceptable delta range for 12 comparisons. For the 15 cooling tests modeled by EnergyPlus which compare to a base case, EnergyPlus was within acceptable delta range for 13 comparisons.

4 References

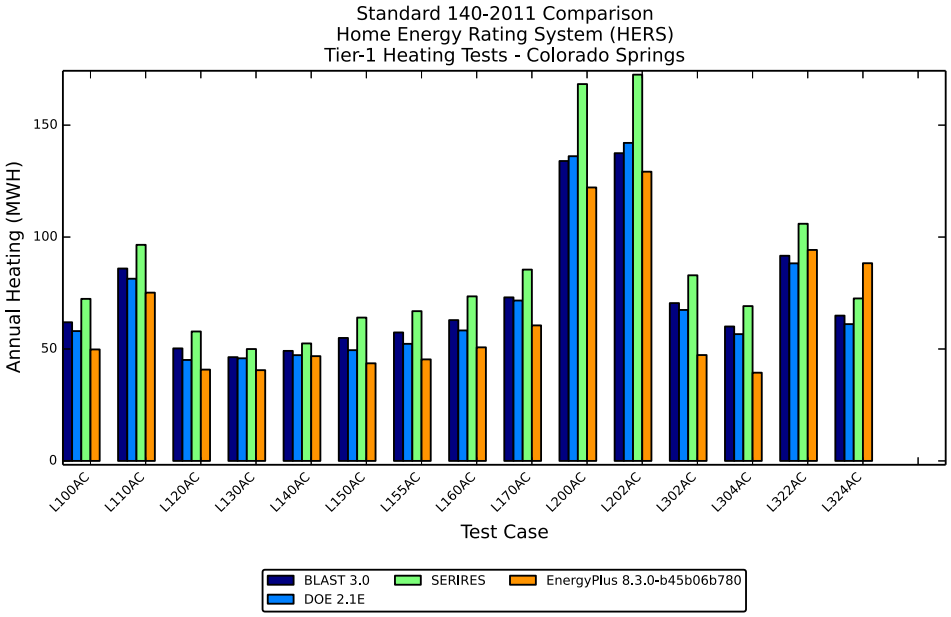
ANSI/ASHRAE 2011. Standard 140-2011, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

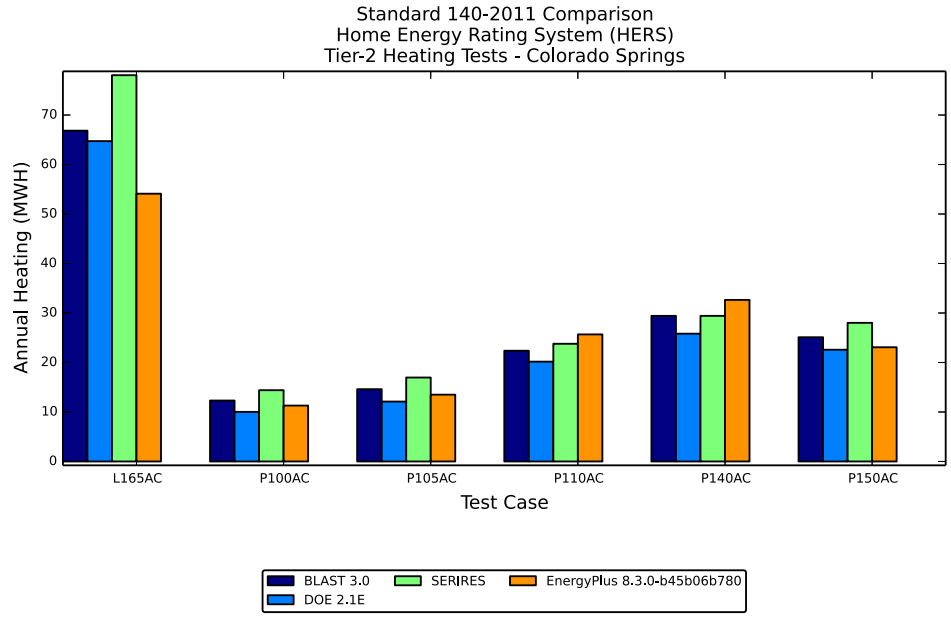
EnergyPlus 2014. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies. www.energyplus.gov

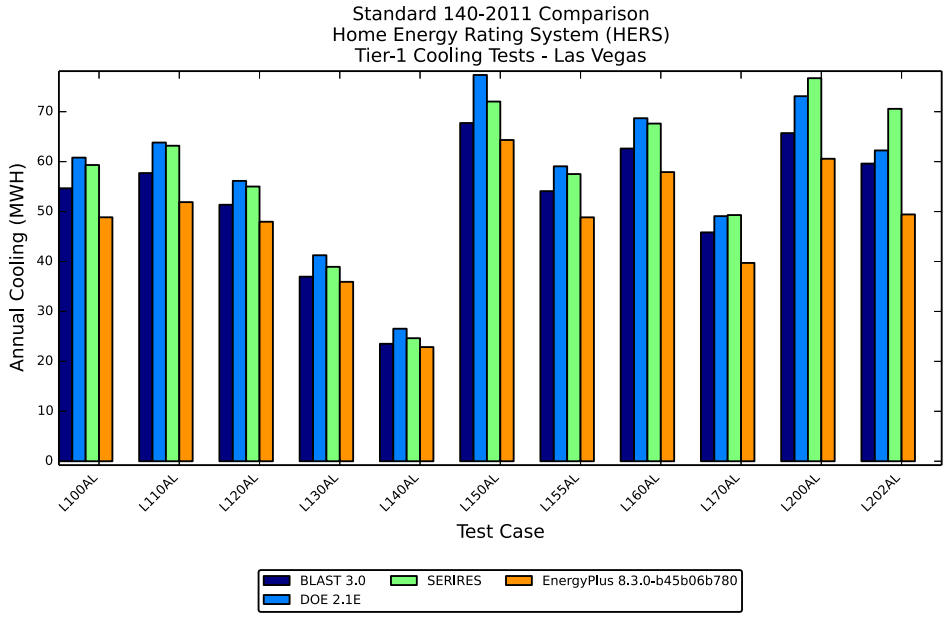
NREL 1995. Judkoff, R. and J. Neymark. Home Energy Rating System Building Energy Simulation Test (HERS BESTEST), National Renewable Energy Laboratory, November 1995, NREL/TP-472-7332a.

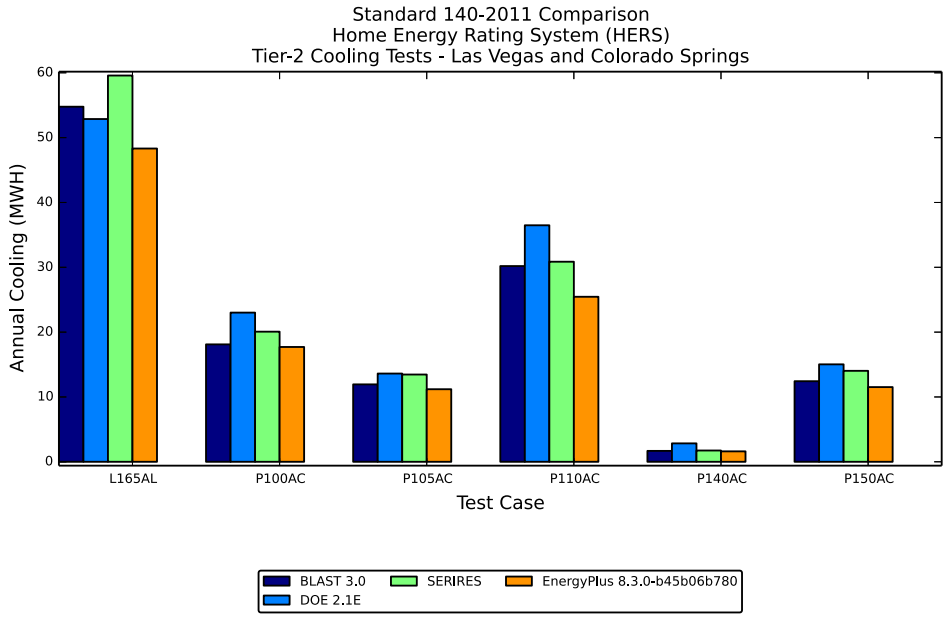
5 Appendix A

Charts Comparing EnergyPlus Results with Other Whole Building Energy Simulation Programs






Standard 140-2011 Comparison
Home Energy Rating System (HERS)
Tier-1 Cooling Tests - Las Vegas
Annual Cooling (MWH)
0
10
20
30
40
50
60
70
L100AL
L110AL
L120AL
L130AL
L140AL
L150AL
L155AL
L160AL
L170AL
L200AL
L202AL
Test Case
BLAST 3.0
DOE 2.1E
SERIRES
EnergyPlus 8.3.0-b45b06b780


Standard 140-2011 Comparison
Home Energy Rating System (HERS)
Tier-2 Cooling Tests - Las Vegas and Colorado Springs
Annual Cooling (MWH)
0
10
20
30
40
50
60
L165AL
P100AC
P105AC
P110AC
P140AC
P150AC
Test Case
BLAST 3.0
DOE 2.1E
SERIRES
EnergyPlus 8.3.0-b45b06b780

6 Appendix B

ANSI/ASHRAE Standard 140-2011 Output Form – Modeling Notes

STANDARD 140 OUTPUT FORM – MODELING NOTES

SOFTWARE: EnergyPlus
VERSION: 8.3.0-b45b06b780

Simulated Effect:
Inside and outside convection algorithm

Optional Settings or Modeling Capabilities:

```
SurfaceConvectionAlgorithm:Inside = Simple
SurfaceConvectionAlgorithm:Inside = TARP
SurfaceConvectionAlgorithm:Inside = Ceiling Diffuser
SurfaceConvectionAlgorithm:Inside = AdaptiveConvectionAlgorithm*

*SurfaceConvectionAlgorithm:Outside = SimpleCombined
SurfaceConvectionAlgorithm:Outside = TARP
SurfaceConvectionAlgorithm:Outside = MoWitt
SurfaceConvectionAlgorithm:Outside = DOE-2
SurfaceConvectionAlgorithm:Outside = AdaptiveConvectionAlgorithm*
```

Setting or Capability Used:

```
SurfaceConvectionAlgorithm:Inside = TARP
SurfaceConvectionAlgorithm:Outside = DOE-2
```

Physical Meaning of Option Used:
TARP uses variable natural convection based on temperature difference.DOE-2 is based on correlations from measurements for rough surfaces.

Simulated Effect:
Solar distribution effects for shade surfaces

Optional Settings or Modeling Capabilities:

```
SOLAR DISTRIBUTION = MinimalShadowing
SOLAR DISTRIBUTION = FullExterior
SOLAR DISTRIBUTION = FullInteriorAndExterior
SOLAR DISTRIBUTION = FullExteriorWithReflections
SOLAR DISTRIBUTION = FullInteriorAndExteriorWithReflections*
```

Setting or Capability Used:

```
SOLAR DISTRIBUTION = FullInteriorAndExterior
```

Physical Meaning of Option Used:
Full interior and exterior shadow calculations are performed each hour.

Simulated Effect:
Calculating resulting zone temperature.

Optional Settings or Modeling Capabilities:

```
ZoneCapacitanceMultiplier:ResearchSpecial,
Temperature capacity Multiplier > 0,
Humidity Capacity Multiplier > 0,
Carbon Dioxide Capacity Multiplier >0
```

Setting or Capability Used:
Let default to

```
ZoneCapacitanceMultiplier:ResearchSpecial
Temperature capacity Multiplier =1,
Humidity Capacity Multiplier =1,
Carbon Dioxide Capacity Multiplier =1
```

Physical Meaning of Option Used:
Used for stability in predictor corrector step by increasing reactive capacity of zone

---

Simulated Effect:
Various variables used to describe properties of surfaces.

Optional Settings or Modeling Capabilities:

```
Visible Absorptance = 0.0 to 1.0
```

Setting or Capability Used:

```
*Visible Absorptance = Solar Absorptance = 0.6
```

Physical Meaning of Option Used:
Solar Absorptance – property of surface describing ability to absorb incident solar radiation

---

Simulated Effect:
Simulation time increment.

Optional Settings or Modeling Capabilities:

```
*TimeStep = whole number between 1 and 60 evenly divisible into 60
```

Setting or Capability Used:

```
TimeStep = 4
```

Physical Meaning of Option Used:
The simulation time increment is 15 minutes. Outputs were set to report hourly.

Simulated Effect:
Frequency of solar and shadow calculations.

Optional Settings or Modeling Capabilities:

```
ShadowCalculation >= 1 (default = 20, every 20 days)
```

Setting or Capability Used:

```
ShadowCalculation = 1
```

Physical Meaning of Option Used:
Solar and shadow calculations frequency done based on value set.

Simulated Effect:
Window properties for double pane glazing made of standard 1/8”(3mm) clear glass with ½” (13mm) air gap.

Optional Settings or Modeling Capabilities:
EnergyPlus requires window properties for front and back of window surface.

Setting or Capability Used:
Window properties were described as follows:

```
WindowMaterial:Glazing,
 Glass Type 1, !- Name
 SpectralAverage, !- Optical Data Type
 , !- Window Glass Spectral Data Set Name
 0.003175, !- Thickness {m}
 0.86156, !- Solar Transmittance at Normal Incidence
 0.07846, !- Front Side Solar Reflectance at Normal Incidence
 0.07846, !- Back Side Solar Reflectance at Normal Incidence
 0.91325, !- Visible Transmittance at Normal Incidence
 0.08200, !- Front Side Visible Reflectance at Normal Incidence
 0.08200, !- Back Side Visible Reflectance at Normal Incidence
 0.0, !- Infrared Transmittance at Normal Incidence
 0.84, !- Front Side Infrared Hemispherical Emissivity
 0.84, !- Back Side Infrared Hemispherical Emissivity
 1.06; !- Conductivity {W/m-K}


WindowMaterial:Gas,
 Air Space Resistance, !- Name
 AIR, !- Gas Type
 0.013; !- Thickness {m}

Construction,
 Double Pane Window, !- Name
 Glass Type 1, !- Outside Layer
 Air Space Resistance, !- Layer 2
 Glass Type 1; !- Layer 3
```

Physical Meaning of Option Used:
Description of window properties for double pane clear glass window for determining solar and conduction heat gain.

Simulated Effect:
Ground Reflectance.

Optional Settings or Modeling Capabilities:

```
Site:GroundReflectance = 0.0 to 1.0*
```

Setting or Capability Used:

```
Site:GroundReflectance = 0.20
```

Physical Meaning of Option Used:
Property of ground surface describing amount of incident solar that is reflected.