BUILDING ENERGY CODES PROGRAM

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ANSI/ASHRAE/IES Standard 90.1-2016: Envelope

March 2017 – PNNL-SA-124574

Prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy

Acknowledgements

PNNL and DOE would like to thank ASHRAE Standing Standard Project Committee 90.1 for their contributions to the development of this presentation and their technical review of the content.

Summary of Changes

- Comprehensive update to the fenestration prescriptive requirements in Tables 5-5-0 through 5-5-8
- Orientation requirements for vertical fenestration were tightened
- SHGC credit for shading by permanent projections was modified to correct how it addressed north-facing fenestration
- Whole building air leakage testing added as an option
- Thresholds for conditioned space were lowered

Compliance Paths
Building Envelope

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Building System

- Envelope
- HVAC
- SWH
- Power
- Lighting
- Other

Mandatory Provisions
(required for all compliance options)

Compliance Options

- Prescriptive Option
- Trade Off Option
- Energy Cost Budget
- Performance Rating Method

Energy Code Compliance

Section 5.1 General
- Scope
- Space-Conditioning Categories
- Envelope Alterations
- Climate

Section 5.2 Definition of Compliance Paths

Section 5.3 Simplified Building *(*Not Used)

Section 5.4 Mandatory Provisions
- Insulation
- Fenestration and Doors
- Air Leakage
- Loading Dock Weatherseals
- Vestibules

Prescriptive Building Envelope Option *(Section 5.5)*

- Opaque Areas
- Fenestration

Building Envelope Trade-Off Option *(Section 5.6)*

Submittals *(Section 5.7)*

Product Information and Installation Requirements *(Section 5.8)*

Inspection and Verification *(Section 5.9)*

Separate envelope component requirements apply to three types of conditioned spaces

- *Nonresidential*
- *Residential*
- *Semiheated*

Semiheated spaces are heated, but not to comfort levels, and not cooled

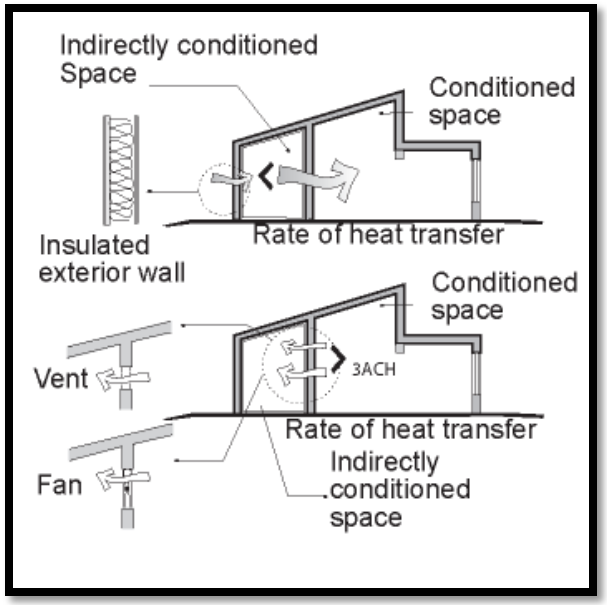
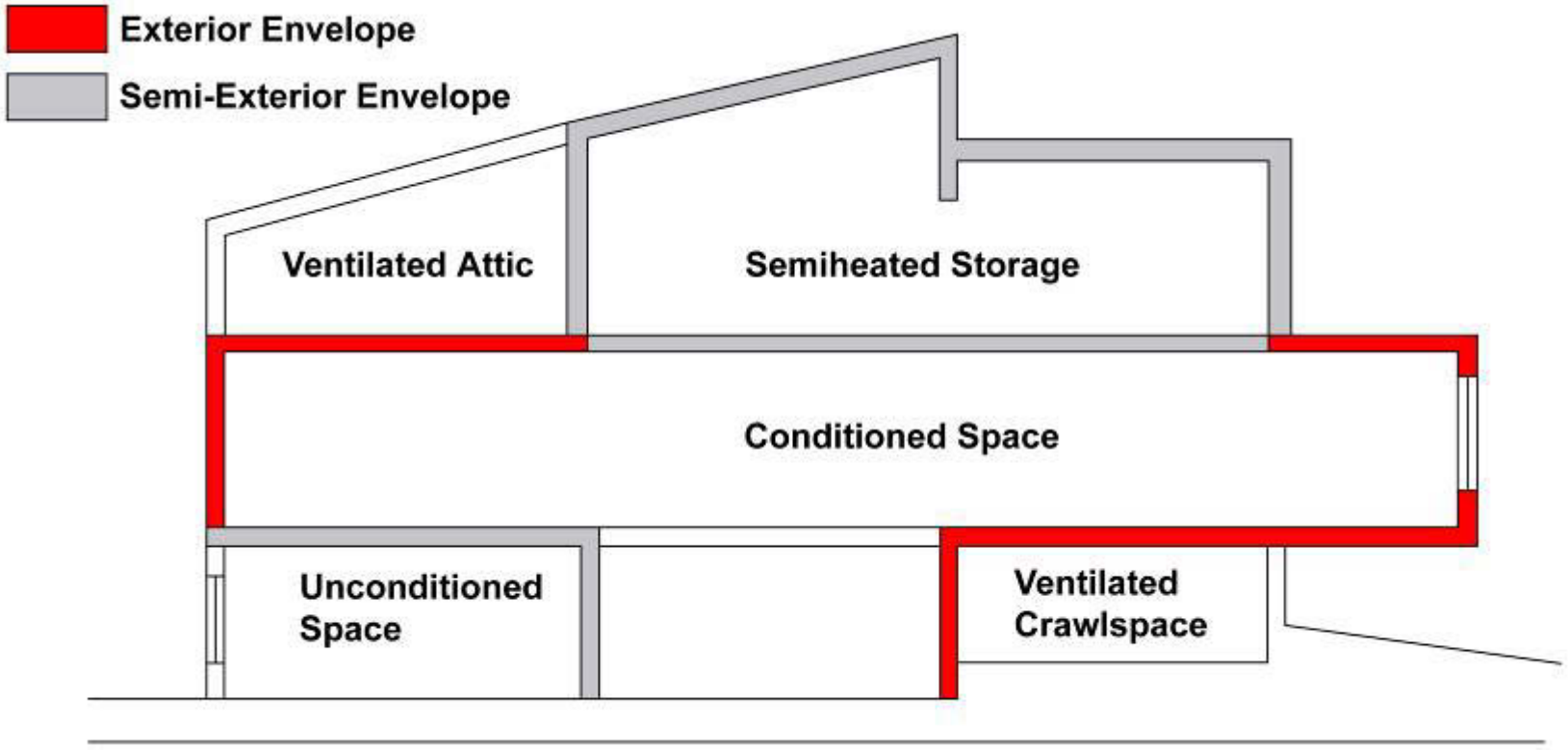


Figure 5-A

Examples of Indirectly Conditioned Spaces

(User's Manual – 90.1.-2013)


Exterior Envelope
Semi-Exterior Envelope
Ventilated Attic
Semiheated Storage
Conditioned Space
Unconditioned Space
Ventilated Crawlspace

Envelope Requirements Are Specified by Space-Conditioning Categories

- Conditioned space must be
  - a *cooled space* with a cooling system sensible cooling output capacity larger than 3.4 Btu/h·ft^2 of floor area
  - a *heated space* with a heating system output capacity larger than that specified in table below
  - Or, an *indirectly conditioned space*

Heating Output, Btu/h·ft^2	Climate Zone
>5	0, 1, 2
>9	3A, 3B
>7	3C
>10	4A, 4B
>8	4C
>12	5
>14	6
>16	7
>19	8

Semiheated space

- has a heating *system* with a capacity ≥ 3.4 Btu/h·ft^2 of *floor* area but is not conditioned space
- *Space* is not cooled at all

Spaces are assumed to be *conditioned space* and comply with requirements of *conditioned space* at time of *construction* regardless of whether the mechanical or electrical *equipment* is included in the building permit application or installed at that time

Exceptions:

- *Space* is designated as *semiheated* or *unconditioned* ***and***
- Approved as such by the building official

Allowed if they don't increase energy usage of building

- ✓ Installation of storm windows or glazing panels with low-emissivity coating
- ✓ Replacement of glazing in existing sash and frame provided *U-factor* and *SHGC* ≤ than previous glass
- ✓ *Alterations* to envelope cavities provided they are insulated to full depth with a nominal R-3.0 per in.
- ✓ *Wall* and *floor alterations* where no new cavities are created
- ✓ *Roof recovering*
- ✓ Removal and replacement of *roof* membranes
- ✓ Replacement of existing *doors* that separate *conditioned space* from exterior do not require a vestibule provided existing vestibule is not removed
- ✓ Replacement of existing fenestration, provided area of replacement is no more than 25% of total fenestration area provided *U-factor* and *SHGC* ≤ than previous fenestration

Section 5 – 5.1.4
Climate – Climate Zone Update

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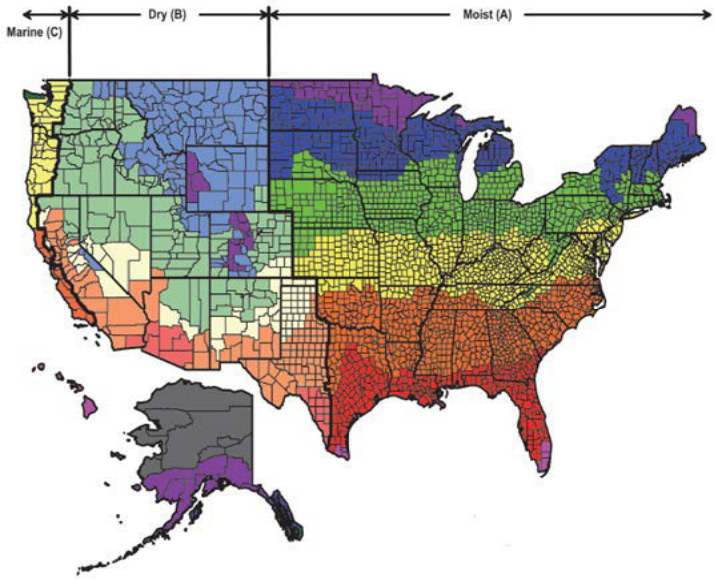
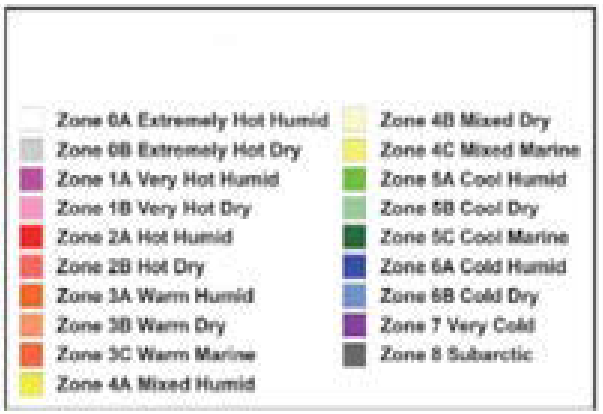
- More accurately represents recent climate, better data
- Aligns with ASHRAE Standard 169-2013
- Retains same climate zone definitions (based on HDDs)
  - Some U.S. counties have shifted zones
- Reflects weather over the most recent 30 years
- Adds new Climate Zone 0 (extremely hot)
- Approximately 10% of U.S. counties reassigned to a different climate zone with a majority reassigned to a warmer climate zone





United States Locations – Use ASHRAE Standard 169 Table Annex 1-1

Annex 1

Table Annex1-1 ASHRAE Standard 169-2013, Table B-1: U.S. Climate Zones by State and County

State/County	Zone	State/County	Zone
Alabama (AL)		Arkansas (AR)	
Zone 3A except...		Zone 3A except...	
Baldwin	2A	Baxter	4A
Coffee	2A	Benton	4A
Covington	2A	Boone	4A
Dale	2A	Carroll	4A
Escambia	2A	Fulton	4A
Geneva	2A	Izard	4A
Henry	2A	Madison	4A
Houston	2A	Marion	4A

Compliance Approach
Building Envelope

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Building System

- Envelope
- HVAC
- SWH
- Power
- Lighting
- Other

Compliance Options

Mandatory Provisions
(required for all compliance options)

- Prescriptive Option
- Trade Off Option
- Energy Cost Budget
- Performance Rating Method

Energy Code Compliance

Insulation *(Section 5.4.1 refers to 5.8.1. through 5.8.1.10)*

- ✓ Labeling *(Section 5.8.1.1)*
- ✓ *Compliance with Manufacturers' Requirements (Section 5.8.1.2)*
- ✓ *Loose-Fill Insulation Limitation (Section 5.8.1.3)*
- ✓ *Baffles (Section 5.8.1.4)*
- ✓ Substantial Contact *(Section 5.8.1.5)*
- ✓ Recessed Equipment *(Section 5.8.1.6)*
- ✓ Insulation Protection *(Section 5.8.1.7)*
- ✓ *Location of roof insulation (Section 5.8.1.8)*
- ✓ *Extent of Insulation (Section 5.8.1.9)*
- ✓ Joints in Rigid Insulation *(Section 5.8.1.10)*

- ✓ Fenestration and *Doors (Section 5.4.2 that refers to 5.8.2)*
- ✓ Air Leakage *(Section 5.4.3)*

Photo courtesy of Ken Baker, K energy

- Continuous air barrier
- Fenestration and doors
- Loading dock weather seals
- Vestibules

- *Continuous air barrier* required except in:
  - *Semiheated spaces* in climate zones 0-6
  - Single wythe concrete masonry *buildings* in climate zone 2B
- Plans
  - *Air barrier* components identified or noted in construction documents
  - Joints, intersections, and penetrations of *air barrier* components (incl. lighting fixtures) detailed
  - To extend over all surfaces of *building envelope* at lowest *floor*, exterior *walls*, and ceiling or *roof*
  - Designed to resist positive and negative pressures from wind, stack effect, and mechanical ventilation

The following areas are to be wrapped, sealed, caulked, gasketed, or taped

- Joints around *fenestration* and *door* frames (both manufactured and site-built)
- Junctions between *walls*
  - And foundations
  - At *building* corners
  - And *roofs* or *ceilings*
- Penetrations for *roofs*, *walls*, and *floors*
- Building assemblies used as ducts or plenums
- Joints, seams, connections between planes, and other changes in *continuous air barrier* materials

New Whole-Building Testing Option

3 Options to Comply (a, b, or c):

- Whole-Building Testing
- Materials Testing
- Assemblies of Materials Testing

Option 1: Whole-Building Testing [5.4.3.1.3(a) Whole-*building* pressurization testing]

Buildings > 50,000 sf

Can comply by testing only (and all) the following portions and area-weighting measured air leakage:

a) Floor areas under roof or with building entrances
b) Representative above-grade wall sections totaling at least 25% of wall area, not including floor area in (a)

Buildings < 50,000 sf

Must comply by testing entire building

1. Building complies if measured air leakage rate is less than 0.40 cfm/ft^2 at 0.30 in. of water
2. If measured air leakage rate is greater than 0.40 cfm/ft^2 but less than 0.60 cfm/ft^2
   - Perform diagnostic evaluation (smoke tracer, infrared imaging, etc.) and seal identified leaks
   - Perform visual inspection of air barrier and seal identified leaks
   - Submit report to code official and building owner identifying corrective actions taken to seal leaks

Option 2: Materials Testing [5.4.3.1 (b)]

Materials with an air permeance of < 0.004 cfm/ft^2 under pressure differential of 0.3 in. of H_2O when tested in accordance with ATM E 2178

These materials meet these requirements

Material	Thickness (minimum)
Plywood	3/8 in.
Oriented strand board	3/8 in.
Extruded polystyrene insulation board	½ in.
Foil-faced urethane insulation board	½ in.
Exterior gypsum sheathing or interior gypsum board	½ in.
Cement board	½ in.
Built up roofing membrane	
Modified bituminous roof membrane	
Single-ply roof membrane	
A Portland cement/sand parge, stucco, or gypsum plaster	½ in.
Cast-in-place and precast concrete	
Sheet metal	
Closed cell 2 lb/ft^3 nominal density spray polyurethane foam	1 in.

Option 3: Assemblies of Materials Testing [5.4.3.1 (c)]

Assemblies of materials and components (sealants, tapes, etc.) that have an average air leakage < 0.04 cfm/ft^2 under a pressure differential of 0.3 in. of H_2O when tested in accordance with ASTM E 2357, 1677, 1680, or 283.

The following assemblies meet these requirements:

Concrete masonry *walls* that are

a. Fully grouted, or
b. Painted to fill the pores.

Section 5 – 5.4.3.2
Air Leakage – Fenestration and Doors

Product	cfm/ft²	Procedure	psf
Glazed *swinging entrance doors*, glazed power-operated sliding *entrance doors*, glazed power-operated folding *entrance doors*, and revolving *doors*	1.0	AAMA/WDMA/CSA 101/I.S.2/A440, NFRC 400, or ASTM E283	1.57
Curtainwall and storefront glazing	0.06	NFRC 400 or ASTM E283	1.57
Unit skylights with condensation weepage openings	0.3	AAMA/WDMA/CSA 101/I.S.2/A440 or NFRC 400	1.57
Unit *skylights* with condensation weepage openings	0.5	AAMA/WDMA/CSA 101/I.S.2/A440	6.24
Nonswinging doors for vehicular access and material transportation (min. opening of 32 in/s)	1.3	ANSI/DASMA 105, NFRC 400, or ASTM E283	1.57
Opaque nonswinging doors, glazed sectional garage doors, and upward acting glazed nonswinging doors	0.4	ANSI/DASMA 105, NFRC 400, or ASTM E283	1.57
All other products	0.2	AAMA/WDMA/CSA 101/I.S.2/A440 or NFRC 400	1.57
All other products	0.3	AAMA/WDMA/CSA 101/I.S/A440	6.24

Exceptions

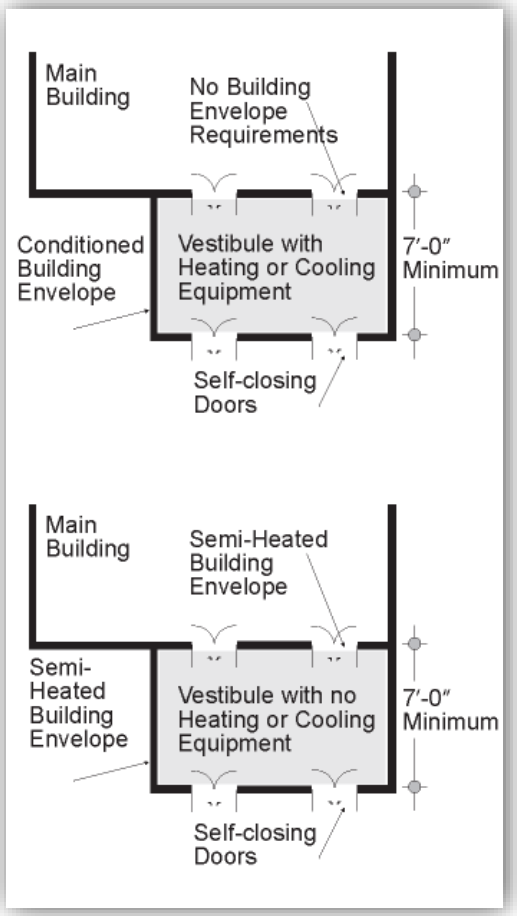
- *Field-fabricated fenestration* and *doors*
- *Metal coiling doors in semiheated spaces* in climate zones 0-6 not to exceed 1.0 cfm/ft² when tested at 1.57 psf in accordance with same procedures as revolving doors
- Products in *buildings* that comply with a whole building air leakage rate of 0.4 cfm/ft² under pressure differential of 0.3 in. H_2O, 1.57 psf per ASTM E779

In climate zones 0 and 4-8

- Cargo doors and loading dock doors equipped with weatherseals
  - To restrict infiltration when vehicles are parked in the loading dock/doorway

Vestibules must have

- Self-closing *doors*
- Interior and exterior *doors* not open at the same time
- Distance between interior and exterior *doors* not < 7 ft when in closed position
- *Floor* area of each vestibule to not exceed the greater of 50 ft^2 or 2% of the gross *conditioned floor area* for that level of the *building*
- Exterior envelope of conditioned vestibule comply with *conditioned space* requirements
- Interior/exterior envelope of unconditioned vestibule comply with *semiheated space* requirements



- Non-entrance *doors* or *doors* opening from *dwelling unit*
- *Building entrances* with revolving *doors*
- All *building entrances* in climate zones 1 and 2 **OR** in *buildings* < 4 stories and < 10,000 ft^2 in gross conditioned floor area in climate zone 3 **OR** in buildings < 1000 ft^2 in *gross conditioned floor area* in climate zones 0 and 4-8
- All *doors* that open from *spaces* < 3000 ft^2 and separate from *building entrance*
- *Semiheated spaces*
- Enclosed elevator lobbies for *building entrances* directly from parking garages

Vestibules opening into large *conditioned spaces* (large retail)

- *spaces* having a *gross conditioned floor area* for that level of the *building* of 40,000 ft^2 and greater,
- and when the *doors* opening into and out of the vestibule are equipped with automatic, electrically driven, self-closing devices, the interior and exterior *doors* shall have a minimum distance between them of not less than 16 ft.

Compliance Approach
Building Envelope

Building System

- Envelope
- HVAC
- SWH
- Power
- Lighting
- Other

Mandatory Provisions
(required for all compliance options)

Compliance Options

- Prescriptive Option
- Trade Off Option
- Energy Cost Budget
- Performance Rating Method

Energy Code Compliance

Each envelope component must separately meet designated space conditioning requirements:

(*Nonresidential, Residential,* and/or *Semiheated)*

Opaque Areas (5.5.3)

Fenestration (5.5.4)

- WWR ≤ 40% of gross *wall* area
- *Skylight*-roof ratio ≤ 3% of *roof* area

Prescriptive requirements for each component specified by climate zone and space conditioning category (Tables 5.5-0 through 5.5-8)

- Insulation levels for *roofs, walls, floors* and *doors*
- Fenestration criteria for windows, glazed *doors* and *skylights*

Compliance

- ✓ Meet or exceed minimum *R-values* in table
  - Only *R-value* of insulation, not to include air films, etc.

OR

- ✓ Meet maximum *U-factor, C-factor,* or *F-factor* for the entire assembly (typical construction assemblies described in Appendix A)

OR

- ✓ Perform area-weighted average *U-factor, C-factor,* or *F-factor*
  - Only if there are multiple assemblies within a single class of construction for a single *space-conditioning* category

Table 5.5-0 *Building Envelope* Requirements for Climate Zone 0 (A,B)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Roofs						
Insulation Entirely above Deck	U-0.039	R-25 c.i.	U-0.032	R-30 c.i.	U-0.218	R-3.8 c.i.
Metal Building	U-0.041	R-10 + 19 FC	U-0.041	R-10 + 19 FC	U-0.115	R-10
Attic and Other	U-0.027	R-38	U-0.027	R-38	U-0.081	R-13
Wall, below-Grade						
Below-grade wall	C-1.140	NR	C-1.140	NR	C-1.140	NR

FC = filled cavity

Reference Table 5.5-0 on page 51 in 90.1-2016

Table 5.5-1 *Building Envelope* Requirements for Climate Zone 1 (A,B)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.048	R-20 c.i.	U-0.039	R-25 c.i.	U-0.218	R-3.8 c.i.
Metal Building	U-0.041	R-10 + 19 FC	U-0.041	R-10 + 19 FC	U-0.115	R-10
Attic and Other	U-0.027	R-38	U-0.027	R-38	U-0.081	R-13
Wood-framed and other	U-0.089	R-13	U-0.089	R-13	U-0.292	NR
Wall, below Grade						
Below-grade wall	C-1.140	NR	C-1.140	NR	C-1.140	NR

FC = filled cavity

Reference Table 5.5-1 on page 52 in 90.1-2016

TABLE 5.5-1 (Cont'd)

Fenestration	Assembly Max. U	Assembly Max. *SHGC*	Assembly Min. *VTISHGC*	Assembly Max. U	Assembly Max. *SHGC*	Assembly Min. *VTISHGC*	Assembly Max. U	Assembly Max. *SHGC*	Assembly Min. *VTISHGC*
Vertical Fenestration, 0% to 40% of *Wall*		(for all frame types)			(for all frame types)			(for all frame types)	
Nonmetal framing, all	0.50	0.25	1.10	0.50	0.25	1.10	0.93	NR	NR
Metal framing, fixed	0.57			0.57			1.20		
Metal framing, operable	0.65			0.65			1.20		
Metal framing, entrance door	1.10			1.10			1.10		
Skylight, 0% to 3% of *Roof*									
All types	0.75	0.35	NR	0.75	0.35	NR	1.80	NR	NR

* The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), FC = filled cavity (see Section A2.3.2.5), NR = no (insulation) requirement.
a. When using the *R-value* compliance method for *metal building roofs*, a thermal spacer block is required (see Section A2.3.2).
b. Exception to Section 5.5.3.2 applies for *mass walls* above *grade*.

Table 5.5-2 *Building Envelope* Requirements for Climate Zone 2 (A,B)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.039	R-25 c.i.	U-0.039	R-25 c.i.	U-0.173	R-5 c.i.
Metal Building	U-0.041	R-10+R-19 FC	U-0.041	R-10+R-19 FC	U-0.096	R-16
Attic and Other	U-0.027	R-38	U-0.027	R-38	U-0.053	R-19
Wood-framed and other	U-0.089	R-13	U-0.089	R-13	U-0.089	R-13
Wall, below Grade						
Below-grade wall	C-1.140	NR	C-1.140	NR	C-1.140	NR

Reference Table 5.5-2 on page 53 in 90.1-2016

Table 5.5-3 *Building Envelope* Requirements for Climate Zone 3 (A,B,C)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.039	R-25 c.i.	U-0.039	R-25 c.i.	U-0.119	R-7.6 c.i.
Metal Building	U-0.041	R-10+R-19 FC	U-0.041	R-10+R-19 FC	U-0.096	R-16
Attic and Other	U-0.027	R-38	U-0.027	R-38	U-0.053	R-19
Steel-framed	U-0.077	R-13 + R-5 c.i.	U-0.064	R-13 + R-7.5 c.i.	U-0.124	R-13
Wood-framed and other	U-0.089	R-13	U-0.064	R-13 + R-3.8 c.i. or R-20	U-0.089	R-13
Wall, below Grade						
Below-grade wall	C-1.140	NR	C-1.140	NR	C-1.140	NR

Reference Table 5.5-3 on page 54 in 90.1-2016

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.093	R-10 c.i.
Metal Building	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls	U-0.082	R-19
Attic and Other	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
Wood-framed and other	U-0.064	R-13 + R-3.8 c.i. or R-20	U-0.064	R-13 + R-3.8 c.i. or R-20	U-0.089	R-13
Wall, below Grade						
Below-grade wall	C-0.119	R-7.5 c.i.	C-0.092	R-10 c.i.	C-1.140	NR

Reference Table 5.5-4 on page 55 in 90.1-2016

Table 5.5-5 *Building Envelope* Requirements for Climate Zone 5 (A,B,C)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.063	R-15 c.i.
Metal Building	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls	U-0.082	R-19
Attic and Other	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
Wood-framed and other	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.089	R-13
Wall, below Grade						
Below-grade wall	C-0.119	R-7.5 c.i.	C-0.092	R-10 c.i.	C-1.140	NR

Reference Table 5.5-5 on page 56 in 90.1-2016

Table 5.5-6 *Building Envelope* Requirements for Climate Zone 6 (A,B)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.063	R-15 c.i.
Metal Building	U-0.031	R-25+R-11 Ls	U-0.029	R-30+R-11 Ls	U-0.060	R-19+R-19
Attic and Other	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
Metal building	U-0.050	R-0 + R-19 c.i.	U-0.050	R-0 + R-19 c.i.	U-0.084	R-0 + R-9.8 c.i.
Steel-framed	U-0.049	R-13 + R-12.5 c.i.	U-0.049	R-13 + R-12.5 c.i.	U-0.084	R-13 + R-3.8 c.i.
Wood-framed and other	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.089	R-13
Wall, below Grade						
Below-grade wall	C-0.092	R-10 c.i.	C-0.063	R-15 c.i.	C-0.119	R-7.5 c.i

Reference Table 5.5-6 on page 57 in 90.1-2016

Table 5.5-7 *Building Envelope* Requirements for Climate Zone 7*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.028	R-35 c.i.	U-0.028	R-35 c.i.	U-0.039	R-25 c.i.
Metal Building	U-0.029	R-30+R-11 Ls	U-0.029	R-30+R-11 Ls	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls
Attic and Other	U-0.017	R-60	U-0.017	R-60	U-0.027	R-38
Steel-framed	U-0.049	R-13 + R-12.5 c.i.	U-0.042	R-13 + R-15.6 c.i.	U-0.064	R-13 + R-7.5 c.i.
Wood-framed and other	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.064	R-13 + R-3.8 c.i.
Wall, below Grade						
Below-grade wall	C-0.063	R-15 c.i.	C-0.063	R-15 c.i.	C-0.119	R-7.5 c.i.

Reference Table 5.5-7 on page 58 in 90.1-2016

Table 5.5-8 *Building Envelope* Requirements for Climate Zone 8*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Roofs						
Insulation Entirely above Deck	U-0.028	R-35 c.i.	U-0.028	R-35 c.i.	U-0.039	R-25 c.i.
Metal Building	U-0.026	R-25+R-11+ R-11 Ls	U-0.026	R-25+R-11+ R-11 Ls	U-0.037	R-19+R-11 Ls or R-25+R-8 Ls
Attic and Other	U-0.017	R-60	U-0.017	R-60	U-0.027	R-38
Steel-framed	U-0.037	R-13 + R-18.8 c.i.	U-0.037	R-13 + R-18.8 c.i.	U-0.064	R-13 + R-7.5 c.i.
Wood-framed and other	U-0.032	R-13 + R-18.8 c.i.	U-0.032	R-13 + R-18.8 c.i.	U-0.051	R-13 + R-7.5 c.i.
Wall, below Grade						
Below-grade wall	C-0.063	R-15 c.i.	C-0.063	R-15 c.i.	C-0.119	R-7.5 c.i.

Reference Table 5.5-8 on page 59 in 90.1-2016

Table A5.3.3.1 Assembly *U-Factors* for *Steel-Joist Floors*

Framing Type and Spacing Width (Actual Depth)	Cavity Insulation *R-Value*: Rated (Effective	Overall *U-Factor* for Entire Base	Overall *U-Factor* for Assembly of Base *Floor* Plus *Continuous Insulation* (Uninterrupted by Framing)																			
			Rated *R-Value* of *Continuous Insulation*																			
Framing Type and Spacing Width (Actual Depth)	Cavity Insulation R-Value: Rated (Effective Installed [See Table A9.2A])	Overall U-Factor For Entire Base Floor Assembly	Overall U-Factor for Assembly of Base Floor Plus Continuous Insulation (Uninterrupted by Framing) Rated R-Value of Continuous Insulation																			
			R-1.00	R-2.00	R-3.00	R-4:00	R-5.00	R-6.00	R-7.00	R-8.00	R-9.00	R-10.00	R-11.00	R-12.00	R-13.00	R-14.00	R-15.00	R-20.00	R-25.00	R-30.00	R-35.00	R-40.00
Steel Joist Floor with Rigid Foam																						
	None (0.0)	**0.350**	0.259	0.206	0.171	0.146	0.127	0.113	0.101	0.092	0.084	0.078	0.072	0.067	0.063	0.059	0.056	0.044	0.036	0.030	0.026	0.023
2 in.	R-8 (7.52)	0.096	0.088	0.081	0.075	0.070	0.065	0.061	0.058	0.054	0.052	0.049	0.047	0.045	0.043	0.041	0.039	0.033	0.028	0.025	0.022	0.020
3 in.	R-12 (10.80)	0.073	0.068	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.041	0.039	0.038	0.036	0.035	0.030	0.026	0.023	0.021	0.019
4 in.	R-16 (13.92)	0.060	0.056	0.053	0.051	0.048	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.034	0.032	0.031	0.027	0.024	0.021	0.019	0.018
5 in.	R-20 (17.00)	0.050	0.048	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.033	0.032	0.031	0.030	0.030	0.029	0.025	0.022	0.020	0.018	0.017
6 in.	R-24 (19.68)	0.044	0.042	0.041	0.039	0.038	0.036	0.035	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.027	0.027	0.024	0.021	0.019	0.017	0.016
Steel-Joist Floor with Batt Insulation																						

Meet or exceed minimum R-value in table for climate zone

Skylight curbs insulated to level of *roofs* with insulation entirely above deck or R-5, whichever is less

Three types of *roofs* are defined

- ✓ *Roofs* with insulation entirely above deck
  - *R-value* is for continuous insulation
  - Exception: Interruptions for framing and pads for mechanical equipment ≤ 1% of surface of the total roof area
- ✓ *Metal building roofs*
  - First value is for insulation
    - draped over purlins and then compressed when metal spanning members attached or
    - hung between purlins provided there's a min. of 1" thermal break between purlins and metal spanning members
  - Second value is for double-layer installations with insulation installed parallel to the purlins
- ✓ *Attics* and other *roofs*
  - *R-value* is for insulation installed both inside and outside the roof or entirely inside the roof cavity

- ✓ Rated *R-value* clearly identified by an identification mark applied by manufacturer to each piece of *building envelope* insulation
  - ✓ Exception- provide documentation
- ✓ Per manufacturer's instructions
- ✓ Achieve rated *R-value*
- ✓ No open-blown or poured loose-fill insulation when ceiling slope is > 3/12
- ✓ If eave vents installed
  - Provide baffling of air vents to deflect incoming air above the surface of the insulation
  - Metal buildings **Exception**
    - if roof and *wall* insulation is compressed between *roof* or wall skin and the structure

Photos courtesy of MBMA

Required in climate zones 0-3

Minimum three-year aged solar *reflectance* of 0.55 and minimum three-year aged thermal *emittance* of 0.75 (tested in accordance with CRRC-1 Standard)

OR

Minimum Solar Reflectance Index of 64, based on

- Three-year aged solar *reflectance*
- Three-year aged thermal *emittance*
  - Tested in accordance with CRRC-1 Standard

OR

Increase *roof* insulation levels in Table 5.5.3.1.1

- Ballasted *roofs* with minimum stone *ballast* of 17 lb/ft^2 or 23 lb/ft^2 pavers
- *Vegetated roof systems* containing minimum thickness of 2.5 in. of growing medium that covers minimum of 75% of roof area with durable plantings
- *Roofs*, where a minimum of 75% of the *roof* area is:
  1. shaded during peak sun angle on June 21 by permanent components or features of the *building*
  2. covered by off-set PV arrays, *building*-integrated PV arrays, or solar air or water collectors **OR**
  3. permitted to be interpolated using a combination of 1 and 2 above
- Steep-sloped *roofs*
- Low-sloped *metal building roofs* in climate zones 2-3
- *Roofs* over: ventilated attics, *semiheated spaces*, or *conditioned spaces* that aren't *cooled spaces*
- Asphaltic membranes in climate zones 2-3

Meet or exceed *R-value* specified for climate zone in appropriate table

When *wall* consists of both above-grade and below-grade portion, entire *wall* to be insulated on either exterior or interior or be integral

If insulated on interior

- *above-grade wall* insulation requirements apply

If insulated on exterior or integral

- below-grade wall portion to be insulated to the below-grade wall requirements and
- above-grade to above-grade *wall* requirements

- *Above-grade wall* in Climate Zone 0 to meet one of the following:

  A. East and west *walls*, minimum of 75% of the opaque wall area to have a minimum SRI 29
  - glass sprandrel areas a minimum solar reflectance of 29% determined in accordance with NFRC 300 or ISO 9050 is permitted
  - Each *wall* is allowed to be considered separately

  B. East and west *walls*, minimum of 30% of the *above-grade wall* area be shaded through the use of shade-providing plants, manmade structures, *existing buildings*, hillsides, permanent *building* projections, *on-site renewable energy systems*, or combination
  - Shade coverage calculated at 10 a.m. for east walls and 3 p.m. for west *walls* on summer solstice

The building is allowed to be rotated up to 45 degrees to the nearest cardinal orientation for compliance calculation purposes

Four types of walls are defined

- Mass walls
  - *heat capacity (HC)* determined from Table A3.1-2 or A3.1-3
  - *Rated R-value* is for *continuous insulation* or when uninterrupted by framing other than metal clips no closer than 24 in. o.c. horizontally and 16 in. o.c. vertically

Exception

- Requirement of U-0.151

Four types of *walls* are defined (cont'd)

- Metal building wall *R-value*
  - for insulation compressed between metal wall panels and the steel structure
- Steel-framed wall *R-value*
  - for uncompressed insulation installed in the cavity between steel studs; also acceptable to be continuous insulation uninterrupted by studs
- Wood-framed and other *R-value*
  - for uncompressed insulation installed in the cavity between wood studs; also acceptable to be continuous insulation uninterrupted by studs

Meet or exceed values in appropriate table for climate zone

R-value is for continuous insulation

Exception

- If framing is used, compliance is based on maximum assembly *C-factor*

Photo courtesy of Dow Building Solutions

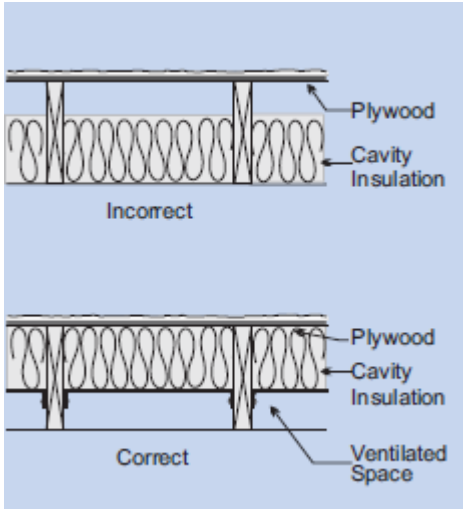
Table A4.2.1 Assembly *C-Factors* for *Below-Grade Walls*

Framing Type and Depth	*Rated R-Value of Insulation* Alone	Specified *C-Factors* (*Wall* Only, without Soil and Air Films)
No Framing	R-0	C-1.140
Exterior Insulation, Continuous and Uninterrupted by Framing		
No Framing	R-5.0	C-0.170
No Framing	R-7.5	C-0.119
No Framing	R-10.0	C-0.092
No framing	R-45.0	C-0.022
No framing	R-50.0	C-0.020
Continuous *Metal Framing* at 24 in. on Center Horizontally		

Meet or exceed values in appropriate table for climate zone

3 classes of floors over *unconditioned space* are defined:

- *Mass floors*
  - *R-value* is for continuous insulation
  - If framing is used, compliance is based on maximum assembly *U-factor*
- *Steel-joist floors*
  - *R-value* is for uncompressed insulation or spray-on insulation, but is also acceptable for continuous insulation
- *Wood-framed a*nd others
  - *R-value* is for uncompressed insulation, but is also acceptable for continuous insulation



For the *rated R-value* of insulation to be installed around the perimeter of the slab-on-grade floor to the distance specified or exceed the values in the appropriate table for climate zone.

Be installed around the perimeter to the distance specified

- **Inside foundation *wall*** – extend downward from top of slab a minimum distance specified or to the top of the footing, whichever is less
- **Outside foundation *wall*** – extend from top of the slab or downward to at least the bottom of the slab and then horizontally to a minimum distance specified
- In all climate zones, the horizontal insulation extending outside of the foundation to be covered by pavement or by soil a minimum of 10 in. thick

Exception: monolithic *slab-on-grade floor*, insulation to extend from the top of the *slab-on-grade* to the bottom of the footing.

U-factor not greater than specified for climate zone in appropriate table

Table 5.5-4 *Building Envelope* Requirements for Climate Zone 4 (A,B,C)*

Opaque Elements	*Nonresidential*		*Residential*		Semiheated	
	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*	Assembly Maximum	Insulation Min. *R-Value*
Opaque Doors						
Swinging	U-0.370		U-0.370		U-0.370	
Nonswinging	U-0.310		U-0.310		U-0.360	

Criteria apply to *fenestration*, including windows, glass *doors*, glass block, plastic panels, and *skylights*

- specified by fenestration type, *space-conditioning category* and by climate zone

Compliance with values in Tables 5.5-0 through 5.5-8

- *U-factor* not greater than specified
- *SHGC* not greater than specified
- Meet or exceed minimum *VT/SHGC*
- Use NFRC ratings or default values in Appendix A

- Exceptions:
  - Area weighting allowed within same *class of construction* and *space-conditioning category*
  - Area weighting for *vertical fenestration* allowed across multiple *classes of construction* for a single *space-conditioning category*, but not across multiple *space-conditioning categories*

Total *vertical fenestration area* to be smaller than specified values in Tables 5.5-0 through 5.5-8 (40% for all climate zones)

- Including both fixed and operable *vertical fenestration*
- Exception: street-level *vertical fenestration* (5.5.4.4.1)

Total *skylight* area smaller than specified in Tables 5.5-0 through 5.5-8 (3% of roof area for all climate zones)

- Permitted to be no greater than 6% of *gross roof area* provided criteria in exception 1 to *skylight SHGC* requirements are met (5.5.4.4.2) and *daylight area under skylights* is more than or equal to half the *floor* area of the *space*

Minimum *skylight* area must be provided in *enclosed spaces* that are

- ≥ 2,500 ft^2
- In spaces with ceiling height > 15 ft and
- Space types

- Office
- Lobby
- Atrium
- Concourse
- Corridor
- Storage (incl. nonrefrigerated warehouse)
- Gymnasium/fitness /exercise area
- Playing area
- Gymnasium seating area
- Convention exhibit/event space
- Courtroom
- Automotive service
- Fire station engine room
- Manufacturing
- Corridor/transition and bay areas
- Retail
- Library reading and stack areas
- Distribution/sorting area
- Transportation
- Baggage and seating areas
- Workshop

Section 5 – 5.5.4.2.3
Minimum *Skylight* Fenestration Area

The *skylight* area must *daylight* a minimum of half the floor area and provided

- Minimum ratio of 3% of *skylight* area to *daylight area* with a *skylight VLT* at least 0.40

  OR

- a minimum *skylight effective aperture* of at least 1%

Exceptions

- *Enclosed spaces* in Climate Zones 6-8
- *Enclosed spaces* under shaded *roofs* (beam sunlight blocked for more than 1500 daytime hours between 8 a.m. and 4 p.m.)
- *Daylight area* under rooftop monitors is > 50% of floor area
- Documented that 90% of *skylight* area is shaded on June 21 (Northern Hemisphere)/December 21 (Southern Hemisphere) at noon by permanent features
- Where total *space* area minus the *primary and secondary sidelighted area*(s) is < 2,500 ft and where lighting is controlled according to sidelighting requirements of Section 9.4.1

U-factor not greater than specified in Tables 5.5-0 through 5.5-8

- **Exception**: *U-factor* for *skylights* allowed to be increased no greater than
  - 0.90 Btu/h•ft^2 °F in Climate Zone 0-3
  - 0.75 Btu/h•ft^2 °F in Climate Zone 4-8

  Provided they have a glazing material or diffuser with a measured haze value greater than 90% when tested in accordance with ASTM D1003

  Have a skylight VT greater than 0.40 and

  All general lighting in the daylight area under *skylights* controlled by multi-level photocontrols in accordance with Section 9.4.1.1 (f)

Determined in accordance with NFRC 100

Skylights – determine for a slope of 20° above the horizontal

Exceptions

- A8.1 acceptable for skylights, A8.2 acceptable for other vertical fenestration, and A7 acceptable for opaque doors
- ANSI/DASMA 105 acceptable for sectional garage doors and metal coiling doors

Vertical fenestration (5.5.4.4.1)

- *SHGC* values < Table value for appropriate total *vertical fenestration area*

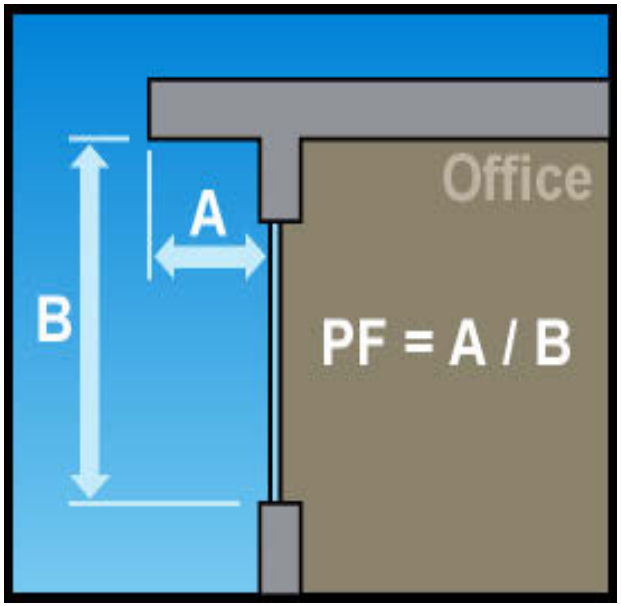
Exceptions

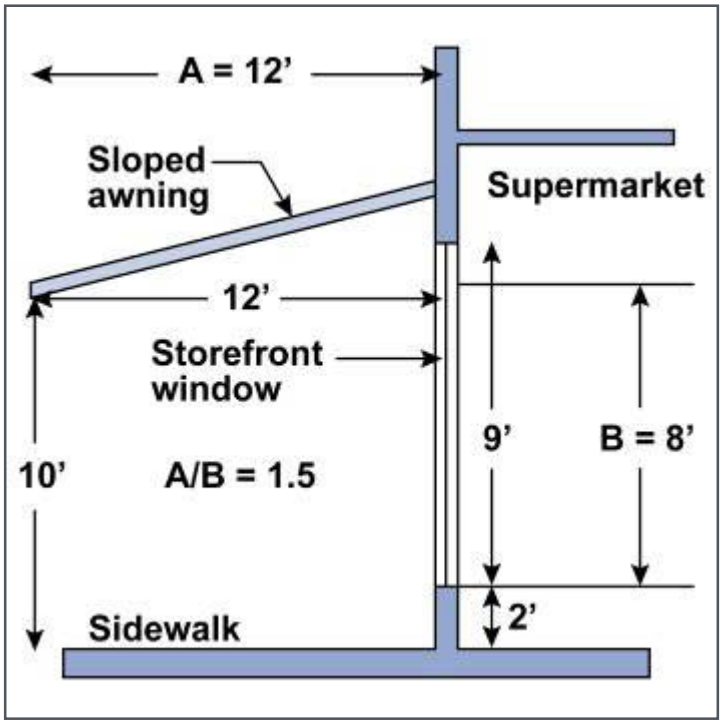
- For south, east, or west-oriented *vertical fenestration* only, the *SHGC* in the proposed *building* can be reduced by using the multipliers in Table 5.5.4.4.1 for *fenestration* shaded by permanent projections that will last as long as the building itself
- For south, east, or west-oriented *vertical fenestration* shaded by partially *opaque* permanent projections that will last as long as the *building* itself, can reduce the PF by multiplying by values in Table 5.5.4.4.1
- Street-level exception only applies when using the prescriptive compliance option
- *Dynamic glazing* cannot be area-weighted with other fenestration and minimum *SHGC* of *dynamic glazing* shall be used to show compliance for *dynamic glazing*
- North-oriented *vertical fenestration* allowed to have *SHGC* equal to or less than the area-weighted average *SHGC* of the south, east, and west-oriented *vertical fenestration* before any reductions made for permanent projections in Exception 1 and 2 of Section 5.5.4.4.1

Information – Overhangs

Standard credits permanent overhangs by adjustment to *SHGC*

Size of overhang is determined by projection factor





Determined in accordance with NFRC 200

Exceptions

- *Shading Coefficient (SC)* x 0.86 is acceptable for overall *fenestration* area (NFRC 300)
- *SHGC* of center-of-glass is acceptable (NFRC 300) for overall fenestration area
- *SHGC* from A8.1 for *skylights* is an acceptable alternative for determining compliance
- *SHGC* from A8.2 for *vertical fenestration* is an acceptable alternative for determining compliance

Skylights

- *SHGC* values < Table value for appropriate total *skylight* area

Exceptions:

1. If *skylights*
   - Have a glazing material or diffuser with measured haze value > 90% when tested according to ASTM D1003, **and**
   - Have a *skylight* VT > 0.40, **and**
   - Have all general lighting in daylight area under *skylights* controlled by multilevel photocontrols per Section 9.4.1.1 (f)

2. Dynamic Glazing

- Minimum *SHGC* is used to demonstrate compliance
- Considered separately from other *vertical fenestration*
- Area-weighted averaging with other *vertical fenestration* that isn't *dynamic glazing* isn't allowed

Two options to comply for *vertical fenestration*:

(a) For Climate Zones 0 - 8

$A_W \leq (A_T)/4$ *and* $A_E \leq (A_t)/4$

OR

(b) For Climate Zones 0 – 3

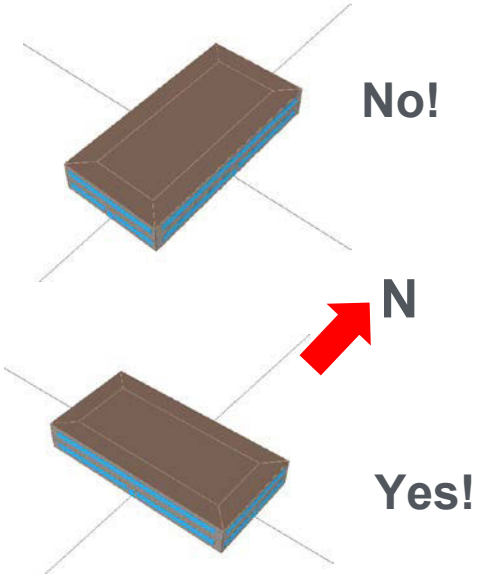
$A_W \times SHGC_W \leq (A_T \times SHGC_C)/4$ *and*

$A_E \times SHGC_E \leq (A_T \times SHGC_C)/4$

For Climate Zones 4 – 8

$A_W \times SHGC_W \leq (A_T \times SHGC_C)/5$ *and*

$A_E \times SHGC_E \leq (A_T \times SHGC_C)/5$



Where,

A_W and $SHGC_W$ = west-oriented *vertical fenestration area* and SHGC

A_E and $SHGC_E$ = east-oriented *vertical fenestration area* and SHGC

A_T = total *vertical fenestration area*

$SHGC_C$ = SHGC criteria in Tables 5.5-0 through 5.5-8

Exceptions

- Complies with Exception 3 of Section 5.5.4.4.1
- *Buildings* with shade on 75% of the west and east
- *Alterations* and additions that don't increase *vertical fenestration area*
- *Buildings* where west- and east-oriented *vertical fenestration area* < 20% of *gross wall area* for each of those facades and SHGC on those facades < 90% of $SHGC_c$
- *Buildings* in Climate Zone 8

When *automatic daylighting controls* are required per 9.4.1.1 (e) or (f)

- *fenestration* to have a ratio of *VT/SHGC* not less than listed in Tables 5.5-0 through 5.5-8 (>1.1 for all climate zones)

Exceptions

- Can have a *light-to-solar-gain ratio (LSG)* of not less than 1.25
  - center-of-glass *SHGC* and *VT* determined per NFRC 300 and NFRC 301 by independent lab or included in a database published by a government agency and certified by a manufacturer
- *Fenestration* not covered in scope of NFRC 200
- *Enclosed spaces*
  - where *daylight area under rooftop monitors* is > 50% of *enclosed space floor area*
  - with *skylights* complying with 5.5.4.2.3
  - where *sidelighting effective aperture* is ≥ 0.15
- *Dynamic glazing*
  - *VT/SHGC* ratio and *LSG* determined using maximum *VT* and maximum *SHGC*
  - Considered separately from other *fenestration;* cannot include *dynamic glazing* with other fenestration for area-weighted averaging

Compliance Approaches

Building System

- Envelope
- HVAC
- SWH
- Power
- Lighting
- Other

Mandatory Provisions
(required for all compliance options)

Compliance Options

- Prescriptive Option
- Trade Off Option
- Energy Cost Budget
- Performance Rating Method

Energy Code Compliance

Proposed design must comply with Sections 5.1, 5.4, 5.7, 5.8, and 5.9

Proposed envelope performance factor (EPF) of *proposed design* is less than or equal to the *proposed envelope performance factor* of the *base design*

- All *building envelope* components shown on drawings or installed in *existing buildings* to be included in proposed building design
- Fenestration and *opaque* envelope types and area used in simulation model to be consistent with design documents
- Don't need to separately describe any envelope assembly covering < 5% of total area of that assembly
  - as long as it's similar to an assembly being modeled
  - if not separately described, add the area of that assembly to an assembly with same orientation and thermal properties

- If building permit will apply to less than the whole building
  - Parameters relating to unmodified existing conditions or future building components to be identical for both proposed EPF and base EPF
- Future components meet prescriptive requirements of Section 5.5

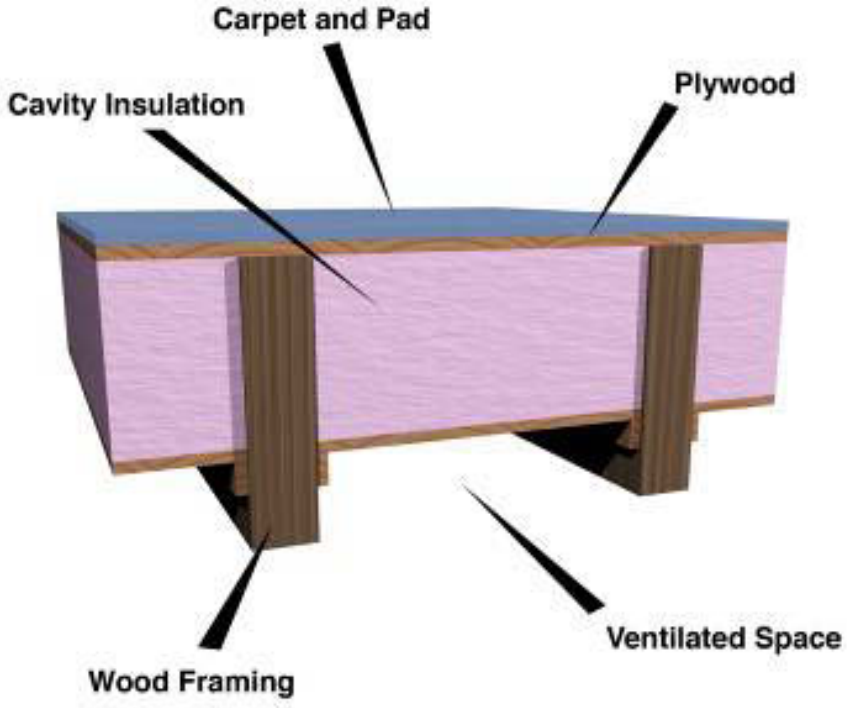
- General – AHJ can require compliance documentation and supplemental information per 4.2.2
- Space Conditioning Categories – if building has *semiheated* or *unconditioned spaces* and compliance is sought using *semiheated* criteria, *spaces* to be clearly indicated on *floor plans*
- Visible Transmittance – include test results for *skylight* glazing or diffusers (per 5.8.2.5)
- ***Daylight Areas*** – documentation to identify *daylight* areas on *floor plans*, including
  - *Primary sidelighted areas*
  - *Secondary sidelighted areas*
  - *Daylight area under skylights*
  - *Daylight areas under roof monitor*

- ✓ Labeling of Building Envelope Insulation *(Section 5.8.1.1)*
- ✓ Compliance with Manufacturers' Requirements *(Section 5.8.1.2)*
- ✓ Loose-Fill Insulation Limitation *(Section 5.8.1.3)*
- ✓ Baffles *(Section 5.8.1.4)*
- ✓ Substantial Contact *(Section 5.8.1.5)*
- ✓ Recessed Equipment *(Section 5.8.1.6)*
- ✓ Insulation Protection *(Section 5.8.1.7)*
- ✓ Location of Roof Insulation *(Section 5.8.1.8)*
- ✓ Extent of Insulation *(Section 5.8.1.9)*
- ✓ Joints in Rigid Insulation *(Section 5.8.1.10)*

Install insulation in a permanent manner in substantial contact with inside surface

Flexible batt insulation in *floor* cavities

- Supported in a permanent manner by supports no more than 24 in. on center (o.c.)



Recessed *equipment* should not affect insulation thickness

- Lighting fixtures
- HVAC *equipment* (includes *wall* heaters, ducts, and plenums)
- Other

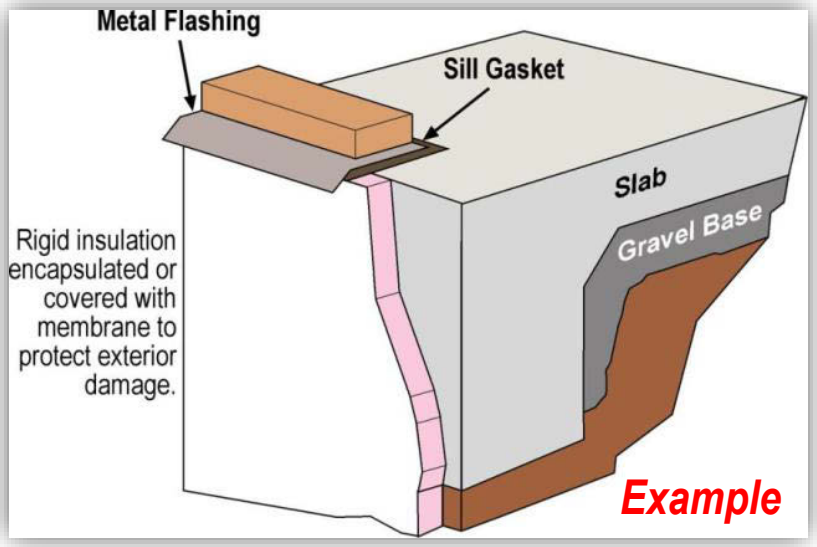
Except when

- Total combined area affected (include necessary clearances) is < 1% of *opaque* area of the assembly, **OR**
- Entire *roof, wall,* or *floor* is covered with insulation to the full depth required, **OR**
- Effects of reduced insulation are included in area-weighted calculations and compressed insulation values from Table A9.4.3

In all cases, air leakage to be limited through or around recessed *equipment* to the *conditioned space* in accordance with Section 5.4.3 (Air leakage)

Insulation Protection

- Cover exterior insulation with protective material
  - Sunlight
  - Moisture
  - Landscaping operations
  - *Equipment* maintenance
  - Wind
- Access to attics and mechanical rooms without damaging or compressing insulation
- Insulation materials in ground contact to have a water absorption rate ≤ 0.3% *(ASTM C272)*



Roof Insulation

- Not installed on a suspended ceiling with removable ceiling panels
- Non-compliant

- Insulation should extend over the full component area to the required *rated R-value of insulation*
  - *U-factor*
  - *C-factor* OR
  - *F-factor*

  Unless otherwise allowed in Section 5.8.1

Where 2 or more layers of rigid insulation board are used in a *construction* assembly

- the edge joints between each layer of boards to be staggered

Required Inspections:

- *Fenestration* and *doors*
  - Air leakage testing where applicable conducted by independent third party
  - Operation of *door* and closer or operating mechanism inspected for conformance with the *manufacturer's* instructions
  - Seals or gaskets installed per *manufacturer's* instructions
- Loading dock weatherseals
  - Ensure that the seals are in good condition

- Opaque building envelope air tightness
  - *Opaque roof, above-grade walls*, and *below-grade walls*, and *floors* subject to the following inspections:
    - Use of compliant materials and assemblies per Section 5.4.3.1.3
    - Integration with adjoining *fenestration* and *continuous air barrier* elements
- Fenestration
  - Skylights size and location in relation to designed *primary sidelighted area* and *secondary lighted area* below
  - *Roof monitor* size and location in relation to designed *primary sidelighted area* and *secondary lighted area* below
  - *Dynamic glazing* with *SHGC* and *U-factor* per Section 5.5.4.4.1 and 5.5.4.4.2 and testing of the operation of conformance per *manufacturer's* instructions.
  - Permanent *fenestration* projections installation and performance per Section 5.5.4.4.1 and *construction documents*.

- Building Envelope Performance
  - Verified per Section 4.2.5
- Air Leakage
  - In accordance with one of the following methods:
    a. An air barrier design and installation program implemented to include:
       1. Design review conducted to assess compliance with requirements in Sections 5.4.3.1.1, 5.4.3.1.2 and applicable portions of 5.4.3.1.3
       2. Periodic field inspection of *continuous air barrier* components and assemblies conducted during *construction* while the air barrier is still accessible for inspection and *repair* to verify compliance with Sections 5.4.3.1.1, 5.4.3.1.2 and applicable portions of 5.4.3.1.3
       3. Reporting in compliance with Section 4.2.5

- Air Leakage cont'd

  b. A *whole-building* air leakage verification program implemented to include the following elements:

  1. whole-building pressurization testing performed in accordance with Section 5.4.3.1.3(a) and use of any exceptions documented

  2. Reporting in compliance with Section 4.2.5