



The Building Envelope

And the Building Science that Makes it Work!

Instructor: Matt Belcher

9/30/21



Housekeeping

- Attendees are muted upon entry
- Questions? Enter them in the chat box
- Webinar is being recorded – slides and recording will be sent to attendees
- CEUs will be available upon request (ICC)
 - Information at end of presentation
- Email nwestfall@mwalliance.org with questions

Overview

- Defining the Building Envelope
- Applied Building Science to Envelope Performance
- Energy Code Requirements
 - Fenestration
 - Insulation
 - Air Barrier
- Compliance Paths
- ASHRAE 90.1 as Referenced by IECC
- Testing/Compliance
- Existing Buildings



Defining The Building Envelope





Building Envelope

The building envelope is what ***separates the inside from the outside***

It is defined as any building element assembly that encloses conditioned space or ***provides a boundary*** between conditioned space and exempt or non-conditioned space

The building envelope includes: below grade (basement) walls, exterior walls, windows, doors, floors, ceilings, roofs, etc.



Building Envelope

The building envelope must serve four functions:

1. Keep bulk moisture out.
2. Handle moisture as vapor.
3. Contain air movement.
4. Contain heat.

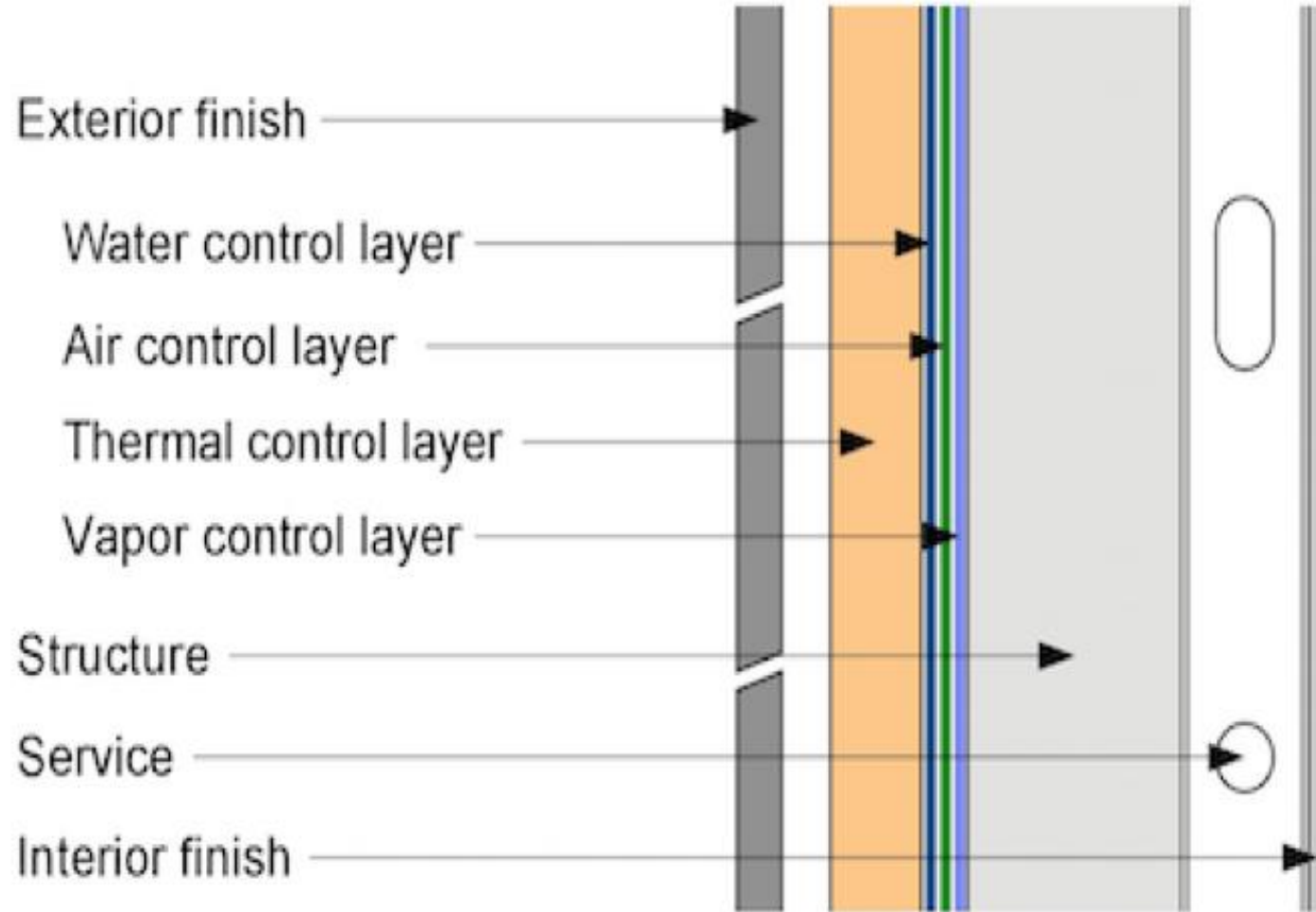
Building Envelope

- All of the elements of the envelope and the assembly methods (and details) determine how well the building envelope performs.
- The building envelope must be an unbroken boundary surrounding the structure.
- All elements must be in close alignment with each other.

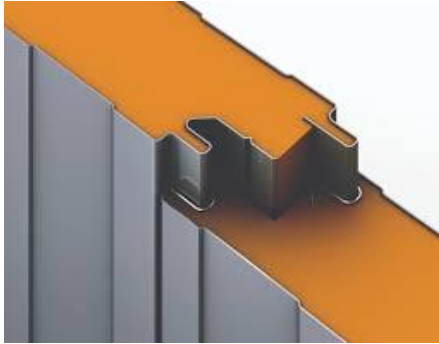


Image: U.S. Gypsum

Building Envelope: Control Layers



Building Envelope: Many Wall Types



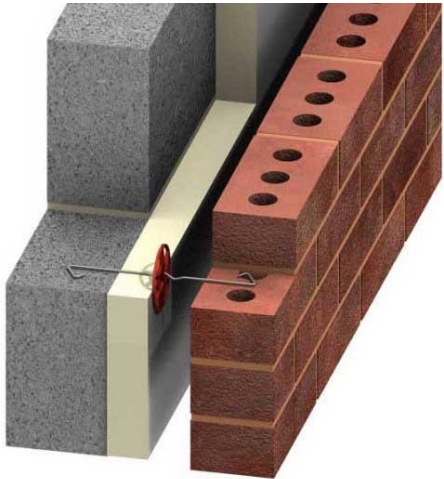
Insulated Panel



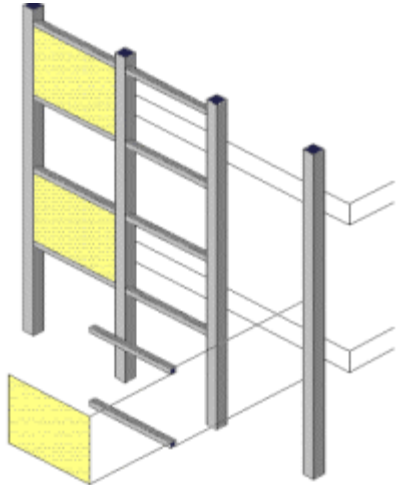
Steel Stud / Exterior Sheathing



Mass Timber



Cavity Wall



Stick-Built Curtain Wall

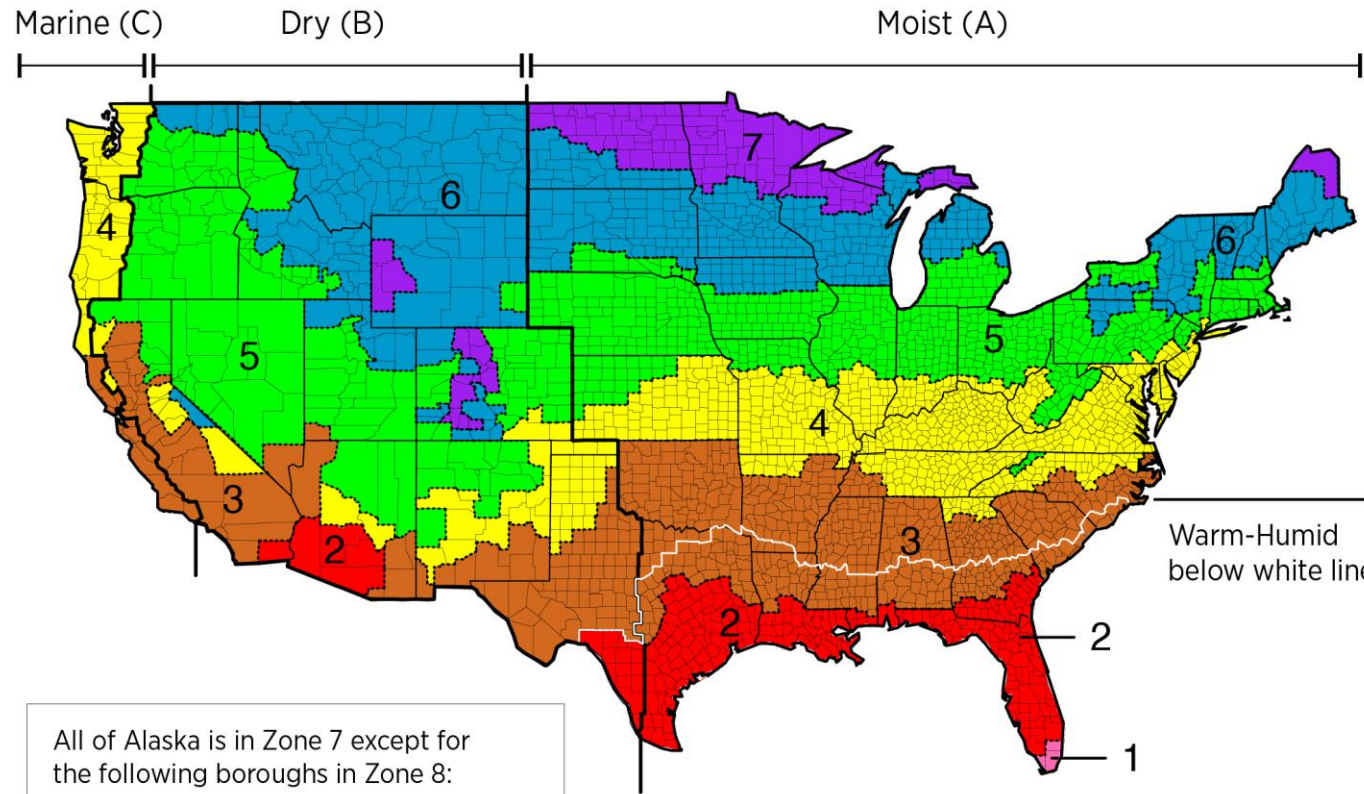




Applied Building Science To The Building Envelope



2018 IECC Climate Zones



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:
Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Warm-Humid below white line

Image: Building America Solution Center



(Not so) Advanced Physics in Building Science:

Heat

Hot



Cold

Moisture

Wet



Dry



Moisture Flows Four Ways

#1 – Bulk water

#2 – Capillary water

#3 – Air-transported moisture

#4 – Diffusive moisture movement

Moisture Flows Four Ways

Bulk Water – Priority #1



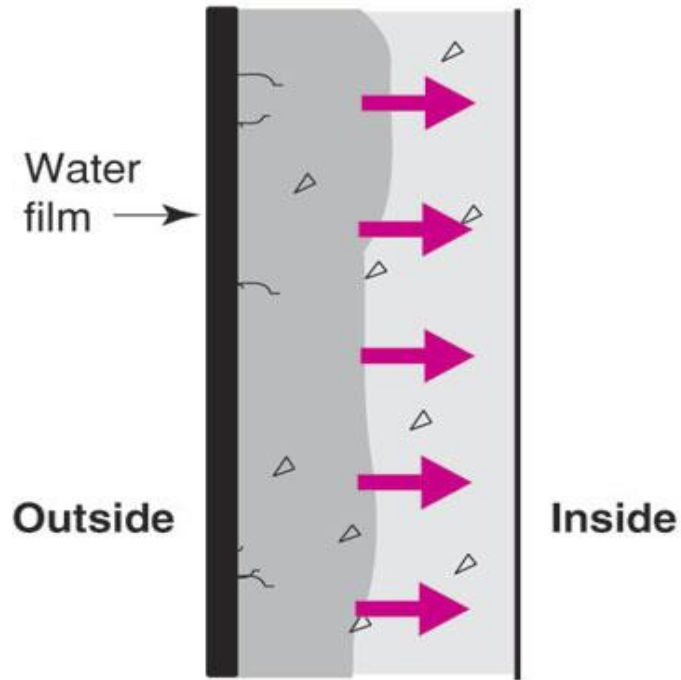
Image: The Construction Specifier

- Capture and direct bulk water away from building
- Properly flash all openings in walls and roof
- Slope grade away from building
- Remember bulk water can come as rain, sleet, and ice

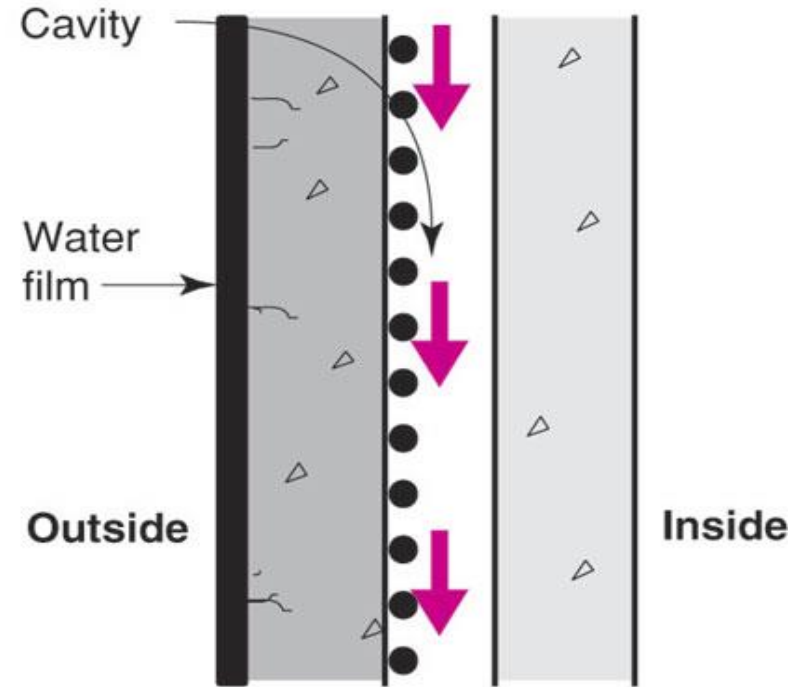


Moisture Flows Four Ways

Capillarity – Priority #2



Capillary suction draws water into porous material and tiny cracks



Cavity acts as capillary break and receptor for capillary water interrupting flow

Image: Building Science Corp.

Moisture Flows Four Ways

Air Transported Moisture – Priority #3

AIR BARRIER

- Air movement leads to both energy loss and moisture transmission.
- The air barrier prevents air movement through all parts of the envelope and must be continuous.
- Primary air barrier:
 - Exterior sheathing (e.g. Zip System, etc.)
 - Building wrap (e.g. Tyvek, etc.)
 - Seam sealing
 - Interior drywall
- Penetrations in the primary air barrier create air leaks and must be properly sealed.



Image: westerlyalberta.com



Moisture Flows Four Ways

Air Transported Moisture – Priority #3

- Uncontrolled / unknown holes that allow air into or out of a building have a negative impact on the building and its occupants.
 - 1/3 quart of water through solid gypsum board but 30 quarts through 1 in² hole!
- Minimizing envelope air leakage must be a primary goal of the building envelope.
- Energy efficient buildings have a low leakage rate.
- Controlled ventilation / fresh air intake from a known source improves indoor air quality and contributes to occupant health.

Moisture Flows Four Ways: Diffusive Moisture – Priority #4

- Moisture vapor affects and moves through common buildings materials at different rates
- Permeability, permeance, and “perms”
- Vapor permeability variability

Vapor permeance:

Perm = grain/(hr • in Hg • ft²)

Vapor Flow in Mixed Climates

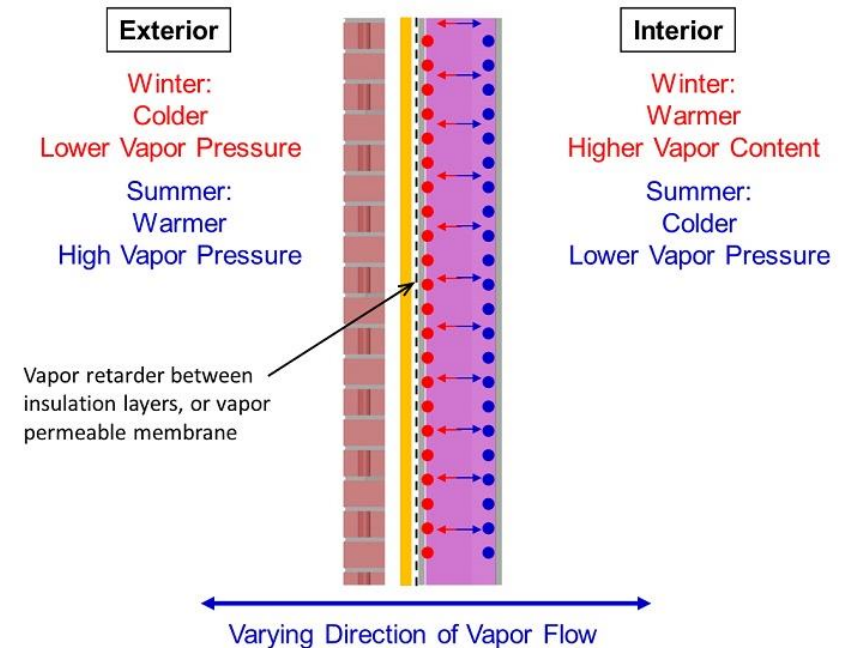


Image: Building Design+Construction



Heat Transfer

- Three types:

Conduction

Convection

Radiation

(C-Factor) (Material to Material)

(U-Factor or R Value) (Air to Air)

(SHGC) (Solar heat gain coefficient)

- All three types of heat transfer can occur in buildings and they most often occur collectively.



Building Envelope Code





General Requirements

Section C402.1


Building thermal envelope to comply with the following:

- Specific insulation requirements of Section C402.2
- Thermal requirements of either:
 - R-value-based method of Section C402.1.3
 - U-, C-, and F-factor-based method of Section C402.1.4 **OR**
 - Component performance alternative of Section C402.1.5
- Fenestration in building envelope assemblies
- Air Leakage of building envelope assemblies

Mandatory Requirements

- Air Leakage
- Air barriers
- Fenestration air leakage
- Rooms Containing Fuel-burning Appliances
- Air intakes, exhaust openings, stairways and shafts
- Loading dock weatherseals
- Vestibules
- Recessed lighting





Air Leakage

Section C402.5 (Mandatory)

- Envelope air sealing requirements must be met by:
 - Testing (blower door) in accordance with ASTM E 779 at pressure differential of 0.3 inch water gauge or an equivalent method approved by code official when tested air leakage rate < 0.40 cfm/ft²

OR

- Compliance with Sections C402.5.1 through 5.8

Air Barrier Construction

Section C402.5.1.1 (Mandatory)

- Air barrier placement allowed:
 - Inside of building envelope
 - Outside of building envelope
 - Located within envelope assemblies
- OR**
- Any combination thereof
- Must be continuous for all assemblies and joints that are part of the envelope



Image: wrmeadows.com



Rooms Containing Fuel-burning Appliances

Section C402.5.3 (Mandatory)

- Where combustion air is supplied through openings in an exterior wall to a room with a space-conditioning fuel-burning appliance, one of the following shall apply:
 - The room shall be located outside the building thermal envelope
 - The room shall be enclosed and isolated from conditioned spaces inside the building

Vestibules

Section C402.5.7 (Mandatory)

- Required to reduce infiltration into spaces
- Required for doors leading into spaces $\geq 3,000$ ft²
- Doors must have self-closing devices
- **Exceptions:**
 - Buildings in Climate Zones 1 and 2
 - Doors from a sleeping unit or dwelling unit
 - Revolving doors (adjacent swing doors are not exempted)
 - Doors that have an air curtain meeting requirements

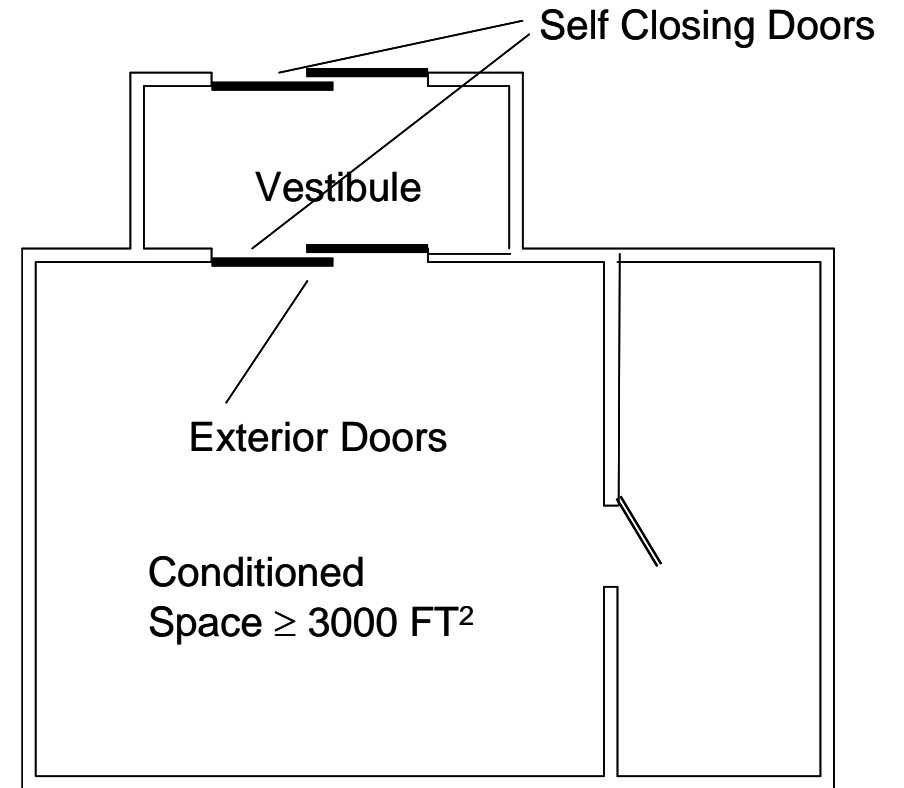


Image: U.S. Dept of Energy

Daylight Zones

Section C405.2.3 (Mandatory)

- Daylight-responsive controls shall be provided within daylight zones with the following spaces:
 - Spaces with more than 150 watts of general lighting in sidelit or toplit zones

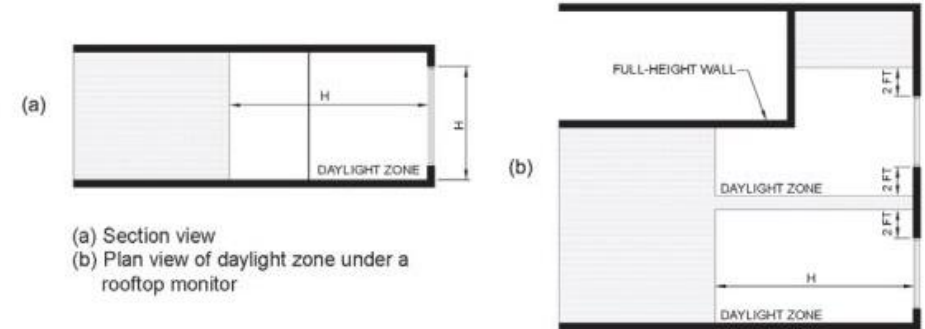


FIGURE C405.2.3.2 SIDELIT ZONE

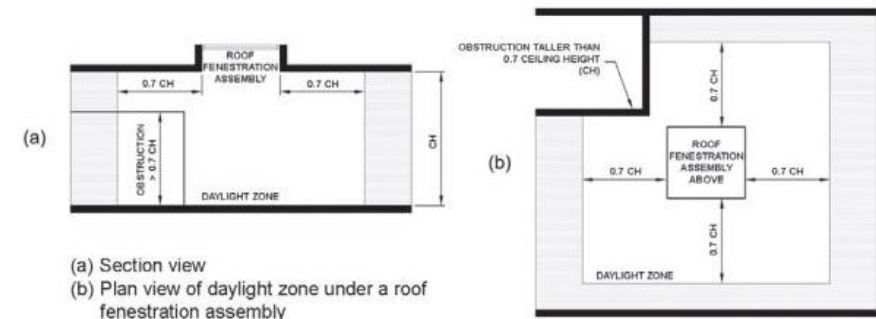


FIGURE C405.2.3.3(1) TOPLIT ZONE

Image: International Code Council

Prescriptive Compliance: Insulation

Table C402.1.3

Climate Zone 5													
	Roofs			Walls, above grade					Floors		Slab-on-grade floors		
	Insulation entirely above roof deck	Metal buildings ^b	Attic and other	Mass ^g	Metal building	Metal framed	Wood framed and other	Below grade wall ^d	Mass ^e	Joist/framing	Unheated slabs	Heated slabs ^h	Opaque, non-swinging doors
All Other	R-30ci	R-19 + R-11 LS	R-38	R-11.4ci	R-13 + R-13ci	R-13 + R7.5ci	R-13 + R3.8ci or R-20	R-7.5ci	R-10ci	R-30	R-10 for 24" below	R-15 for 36" below + R-5 full slab	R-4.75
Group R	R-30ci	R-19 + R-11 LS	R-49	R-13.3ci	R-13 + R-13ci	R-13 + R7.5ci	R-13 + R-7.5ci or R-20 + R3.8ci	R-7.5ci	R-12.5ci	R-30	R-10 for 24" below	R-15 for 36" below + R-5 full slab	R-4.75

ci – Continuous insulation

LS – Linear system

See Table C402.1.3 for other footnotes



Insulation: Types and Forms

- **Types:**

- Fiberglass
- Cellulose
- Low-density or open-cell foam
- High-density or closed-cell foam
- Foam sheathing

Installation quality is key!

- **Forms:**

- Batts and blankets
- Loose-fill and blown-in
- Damp spray (cellulose, spider micro-filament fiberglass)
- Blown-in batt system (BIBS)
- Dense pack insulation
- Foams (sheet-applied)
- Foams (spray-applied)
- Reflective systems

Prescriptive Compliance: Fenestration

Table C402.4

Climate Zone 5		
Vertical Fenestration		
U-Factor		
Fixed Fenestration	0.38	
Operable Fenestration	0.45	
Entrance Doors	0.77	
SHGC		
Orientation	SEW	N
PF < 0.2	0.38	0.51
0.2 ≤ PF < 0.5	0.46	0.56
PF ≥ 0.5	0.61	0.61
Skylights		
U-Factor	0.50	
SHGC	0.40	

Fenestration Product Rating

Section C303.1.3

- Install fenestration products rated in accordance with NFRC 100 (Windows, Doors, Skylights)
- Fenestration must be labeled and certified by the manufacturer
- Non-NFRC 100 rated fenestration uses default values
 - Default Glazed Fenestration U-factor Table C303.1.3(1)
- Difficult to meet requirements using default U-factors

 National Fenestration Rating Council CERTIFIED		World's Best Window Co. Millennium 2000* Vinyl-Clad Wood Frame Double Glazing • Argon Fill • Low E Product Type: Vertical Slider	
ENERGY PERFORMANCE RATINGS			
U-Factor (U.S./I-P)		Solar Heat Gain Coefficient	
0.35		0.32	
ADDITIONAL PERFORMANCE RATINGS			
Visible Transmittance		Air Leakage (U.S./I-P)	
0.51		0.2	
Condensation Resistance		_____	
51			
<small>Manufacturer attests that these ratings conform to applicable NFRC procedures for determining window product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. Consult manufacturer's literature for other product performance information. www.nfrc.org</small>			

NFRC PRODUCT CERTIFICATION PROGRAM NFRC Label Certificate for Site-Built Products		 World's Best Window Co. Millennium 2000* Vinyl-Clad Wood Frame Double Glazing • Argon Fill • Low E Product Type: Vertical Slider	
ENERGY PERFORMANCE RATINGS U-Factor (U.S./I-P) Solar Heat Gain Coefficient 0.35 0.32		ADDITIONAL PERFORMANCE RATINGS Visible Transmittance Air Leakage (U.S./I-P) 0.51 0.2	
Project Location Street Address: _____ City: _____ State: _____ Zip Code: _____ Project Name (Optional): _____ Designer (Optional): _____			
Product Line Information Operator Type (per Table 4-3 of NFRC 100) _____ Product Line ID No. _____ Individual Product ID No. _____ How many of this individual product _____ Location in building _____ Elevation drawing page _____ Fenestration (window & door) schedule page _____			
Frame Material Supplier Company name: _____ City: _____ State: _____ Zip Code: _____ Street Address: _____ Contact: _____ Phone: _____ Fax: _____			
Glazing Material Supplier Company name: _____ City: _____ State: _____ Zip Code: _____ Street Address: _____ Contact: _____ Phone: _____ Fax: _____			
Glazing Contractor/Installer Comp. name: _____ City: _____ State: _____ Zip Code: _____ Street Address: _____ Contact: _____ Phone: _____ Fax: _____			
Certification Authorization Independent Certification & Inspection Agency (IA): _____ Date Certification Authorization Issued: _____			





Vertical Fenestration Requirement

Section C402.4.1 – Prescriptive (Max area)

- Percentage of Vertical Fenestration Area to Gross Wall Area
 - Allowed up to 30% maximum of above grade wall
 - In Climate Zones 1-6, up to 40% maximum if daylight responsive controls installed
- Total fenestration area (includes frame and glazing)
- Does not include opaque door area

Skylight Minimum Fenestration Area

Section C402.4.1 Prescriptive

- Limited to $\leq 3\%$ of Roof Area
- Up to 6% allowed if daylight responsive controls installed in toplit zones



Image: Velux.com

Fenestration SHGC Requirements

The Effect of Overhangs on Fenestration SHGC:

- Overhangs allow a higher SHGC product to be installed
- Projection factor must be calculated
- Evaluate separately when different windows or glass doors have different PFs

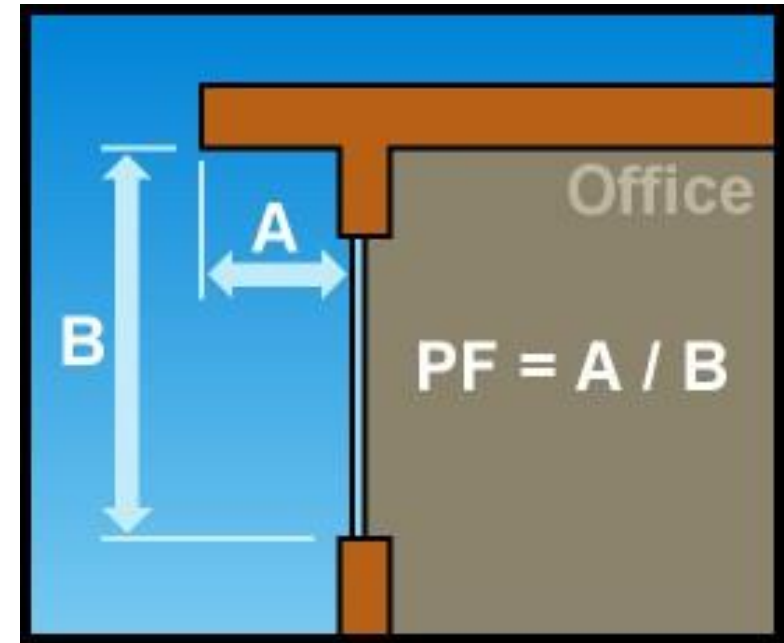


Image: energycode.pnl.gov



Questions so far?

Unmute or Enter Questions in the Chat!





Building Envelope Compliance Pathways





Building Envelope Compliance Options

3 Methods for compliance of building components:

- C402.1.3 – Insulation component R-value based method
- C402.1.4 – Assembly U-factor, C-factor or F-factor based method
- C402.1.5 – Component Performance Alternative



Insulation component R-value based method

Section C402.1.3

- Envelope assemblies shall comply with C402.2 (specific envelope requirements) and C402.4 (fenestration)
- R-value is defined as the capacity of a material to resist heat flow
- R-values shall not be less than Table 402.1.3
 - Commercial buildings with Group R occupancies shall use “*Group R*” column
 - Commercial buildings, or portions thereof, with other than *Group R* occupancies shall use “*All other*” column

R-value Method

Table C402.1.3

Table C402.1.3 - Climate Zone 5		
Roofs	All other	Group R
Insulation entirely above roof deck	R-30ci	R-30ci
Metal buildings	R-19 + R-11 LS	R-19 + R-11 LS
Attic and other	R-38	R-49
<u>Walls, above grade</u>		
Mass	R-11.4 ci	R-13.3ci
Metal building	R-13 + R-13ci	R-13 + R-13ci
Metal framed	R-13 + R-7.5ci	R-13 + R-7.5ci
Wood framed and other	R-13 + R-3.8ci or R-20	R-13 + R-7.5ci or R-20 + R-3.8ci
<u>Walls, below grade</u>		
Below-grade wall	R-7.5ci	R-7.5ci
<u>Floors</u>		
Mass	R-10ci	R-12.5ci
Joist/framing	R-30	R-30
<u>Slab-on-grade floors</u>		
Unheated slabs	R-10 for 24" below	R-10 for 24" below
Heated slabs	R-15 for 36" below + R-5 full slab	R-15 for 36" below + R-5 full slab
<u>Opaque doors</u>		
Nonswinging	R-4.75	R-4.75



Assembly U-factor, C-factor or F-factor based method

Section C402.1.4

- **U-factor:** A measure of an assembly's capacity to transfer thermal energy across its thickness. Used for roofs, above grade walls, floors, and doors.
- **C-factor:** Heat flow through the unit area of a material. Used for below grade walls.
- **F-factor:** The heat transfer through the floor. Used for slabs-on-grade.

U-Factor Method

Table C402.1.4

Table C402.1.4 - Climate Zone 5		
<u>Roofs</u>	All other	Group R
Insulation entirely above roof deck	U-0.032	U-0.032
Metal buildings	U-0.035	U-0.035
Attic and other	U-0.021	U-0.021
<u>Walls, above grade</u>		
Mass	U-0.090	U-0.080
Metal building	U-0.052	U-0.052
Metal framed	U-0.064	U-0.064
Wood framed and other	U-0.064	U-0.064
<u>Walls, below grade</u>		
Below-grade wall	C-0.119	C-0.119
<u>Floors</u>		
Mass	U-0.074	U-0.064
Joist/framing	U-0.033	U-0.033
<u>Slab-on-grade floors</u>		
Unheated slabs	F-0.54	F-0.54
Heated slabs	F-0.79/0.64	F-0.79/0.64
<u>Opaque doors</u>		
Swinging door	U-0.37	U-0.37
Garage door <14% glazing	U-0.31	U-0.31

Component Performance Alternative

Section C402.1.5

- Building envelope and fenestration in accordance with:
- $A+B+C+D+E \leq \text{Zero}$
 - **A:** Sum of (UA Dif) value for each distinct above grade assembly
 - **B:** Sum of (FL Dif) values for each distinct slab-on-grade perimeter condition
 - **C:** Sum of (CA Dif) values for each distinct below grade wall assembly
 - **D:** Calculation of vertical glazing and above wall U-value (cannot be less than zero)
 - **E:** Calculation of skylight area and U-value of roof assemblies (cannot be less than zero)



Section C406 – Additional Efficiency Package options





Additional Efficiency Package Options

Section C406

- Buildings shall comply with one or more of the following:
 - More efficient HVAC performance
 - Reduced lighting power
 - Enhanced lighting controls
 - On-site renewable energy
 - Dedicated outdoor air system
 - High efficiency water heating
 - Enhanced envelope performance
 - Reduced air infiltration



Additional Efficiency Package Options

Section C406

- Enhanced Envelope Performance
 - Total UA (total heat loss) of the building thermal envelope as designed shall not be less than 15% below the total UA of the building thermal envelope in accordance with Section C402.1.5
 - *In other words, at least a 15% more efficient building envelope than code minimum*



Additional Efficiency Package Options

Section C406

- Reduced Air Infiltration
 - Whole building pressurization testing (ASTM E779 or ASTM E1827) by independent third party
 - Measured leakage rate of ≤ 0.25 cfm/ft² (code minimum is ≤ 0.40 cfm/ft²)
 - Buildings over 250,000 square feet of conditioned floor area may conduct representative area testing
 - Test not less than 25% of conditioned floor area



Performance Testing



Air Leakage & Continuous Air Barrier Testing

Section C402.5

- Continuous Air Barrier Required
- Two Compliance Options
 - ASTM E 779 (blower door test)
 - Compliant assemblies
 - C402.5.1 through C402.5.8



Image: energyconservatory.com



2018 IECC vs ASHRAE 90.1-2016



ASHRAE 90.1 2016 Section 5: Building Envelope Overview

- **ASHRAE 90.1 is an optional compliance path allowed in the 2018 IECC (Section C401.2).**
- Applies to:
 - New, and new portions of, *buildings* and their *systems*
 - *Additions* and *alterations* to existing buildings
 - *New systems* and *equipment* in *existing buildings*
- Does not apply to:
 - Single-family houses, low-rise multi-family ≤ 3 stories above grade, manufactured houses (mobile or modular)
 - *Buildings* that use neither *electricity* nor *fossil fuel*
- Does not circumvent any safety, health, or environmental requirements

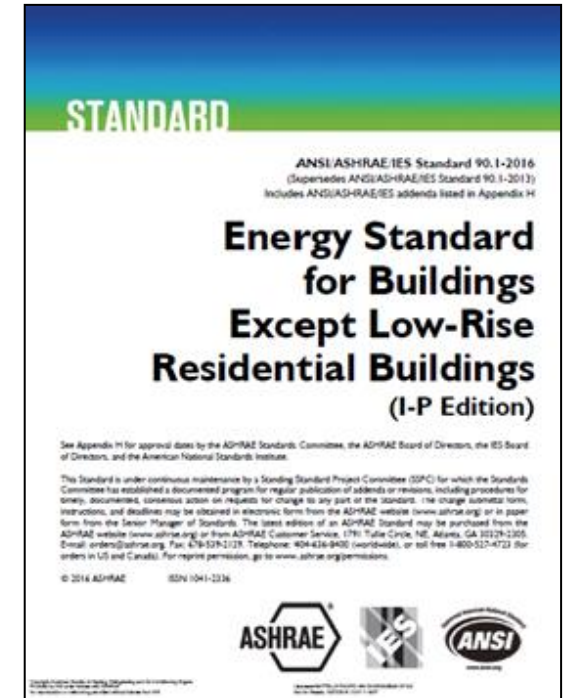


Image: ASHRAE.org

Structure of Standard 90.1-2016

1. Purpose
 2. Scope
 3. Definitions, Abbreviations, and Acronyms
 4. Administration and Enforcement
 5. Building Envelope
 6. Heating, Ventilating, and Air Conditioning
 7. Service Water Heating
 8. Power
 9. Lighting
 10. Other Equipment
 11. Energy Cost Budget Method
 12. Normative References
- Normative Appendices A-H
Appendix G – is a new compliance path!

Some of the Key Changes

- Major format changes
- New climate maps
- New performance-based compliance path
- Significant energy savings*
- Increased HVAC equipment efficiency
- Requirements for replacement equipment

*28% more efficient than 90.1 2007 in NE

See: (https://www.energycodes.gov/sites/default/files/2021-07/StateLevelCommercialCodesEnergyUseIndex_FY2021Q3.xlsx)

Some Key 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



Insulation Requirements

Table 5.5-5 (partial)

5 Building Envelope

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
<i>Roofs</i>						
<i>Insulation entirely above deck</i>	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.063	R-15 c.i.
<i>Metal building^a</i>	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
<i>Attic and other</i>	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
<i>Walls, above grade</i>						
<i>Mass</i>	U-0.090	R-11.4 c.i.	U-0.080	R-13.3 c.i.	U-0.151 ^b	R-5.7 c.i. ^b
<i>Metal building</i>	U-0.050	R-0 + R-19 c.i.	U-0.050	R-0 + R-19 c.i.	U-0.094	R-0 + R-9.8 c.i.
<i>Steel-framed</i>	U-0.055	R-13 + R-10 c.i.	U-0.055	R-13 + R-10 c.i.	U-0.084	R-13+R-3.8 c.i.
<i>Wood-framed and other</i>	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
<i>Wall, below Grade</i>						
<i>Below-grade wall</i>	C-0.119	R-7.5 c.i.	C-0.092	R-10 c.i.	C-1.140	NR
<i>Floors</i>						
<i>Mass</i>	U-0.057	R-14.6 c.i.	U-0.051	R-16.7 c.i.	U-0.107	R-6.3 c.i.
<i>Steel joist</i>	U-0.038	R-30	U-0.038	R-30	U-0.052	R-19
<i>Wood-framed and other</i>	U-0.033	R-30	U-0.033	R-30	U-0.051	R-19

Image: ASHRAE.org

New Compliance Path

Appendix G

Appendix G (Performance Rating Method) uses a stable baseline approach with set efficiency levels

- Values are not updated with each new edition of the code
- Proposed energy performance needs to exceed baseline by an amount commensurate with the efficiency of the code year being evaluated.

Appendix G credits are available for strategies not credited in Energy Cost Budget path

- Optimized window area and orientation
- More efficient HVAC and SWH equipment
- Right sizing HVAC equipment
- Efficient use of thermal mass



Existing Buildings



Existing Buildings - Scope

Chapter 5

- Applies to alterations, repairs, additions, and change of occupancy (C501.1)
- Additions must comply with code without requiring unaltered portions to comply (C502.1)
 - Specific requirements for new vertical fenestration and skylights (C502.2.1 and C502.2.2)
- Alterations shall not make building less conforming (C503.1)



Image: MontgomeryCountyMD.gov



Existing Buildings - Scope

Chapter 5

- New building envelope assemblies that are part of the alteration shall comply with new construction requirements (C503.3)
- Routine maintenance and ordinary repairs are exempt
- Change of occupancy resulting in increased demand for energy shall comply with the code (C505.1)

Resources

- DOE 2018 IECC Presentation: energycodes.gov/technical-assistance/training/courses/commercial-requirements-2018-iecc
- 90.1-2016 Overview: energy.gov/eere/buildings/articles/new-energy-code-commercial-buildings-standard-901-2016
- DOE 90.1-2016 Presentation: energycodes.gov/resource-center/training-courses/ansiashraeies-standard-901-2016
- Performance Rating Method Reference Manual: pnnl.gov/main/publications/external/technical_reports/PNNL-26917.pdf
- 2018 IECC: codes.iccsafe.org/content/iecc2018/chapter-4-ce-commercial-energy-efficiency#IECC2018_CE_Ch04_SecC408
- COMcheck: <https://www.energycodes.gov/comcheck>

Continuing Education

- Continuing Education Credits through the International Code Council are available to participants in the course
- Course ID: 29781
- CEUs: 2.0
- Following the end of the course, you will receive a certificate of completion with this information. Please contact Karin Gredvig (kgredvig@mwalliance.org) with questions.





Thank you! Questions?

Contact **Matt Belcher**: matt@verda-solutions.com

Visit our website for more online trainings this fall!

<https://www.mwalliance.org/nebraska-energy-codes-training-program>

