2021 IECC Commercial Envelope (Course 383)

Colorado Chapter of ICC
Educational Institute 2024

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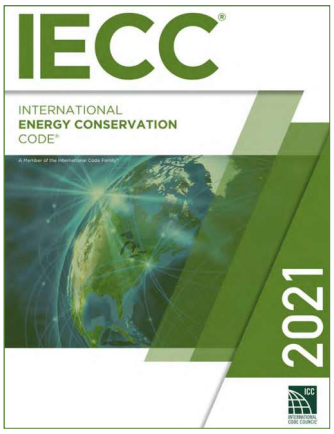
Course Outline

- Why is the building thermal envelope (BTE) important?
- PART A – Administrative & General
  - Construction Documents (C103)
  - Compliance Path (C401.2)
  - Thermal Envelope Certificate (C401.3)
  - Climate Zone (C301) & Interior Design Conditions (C302)
  - Insulation and Fenestration Product Requirements (C303)
  - "Hot Topics" for Compliance and Enforcement
- PART B – Opaque Assemblies (C402.1, C402.2, C402.3)
- PART C – Fenestration & Daylighting (C402.4)
- PART D – The Rest of the Story…
  - Component Performance Alternative (C402.1.5)
  - Air leakage (C402.5)
  - Additional Efficiency Requirements / "Credits" (C406)
  - Total Building Performance (C407)
  - Existing Buildings – Envelope Alterations (C503.2)



We'll address also address some of the major changes in 2024 IECC

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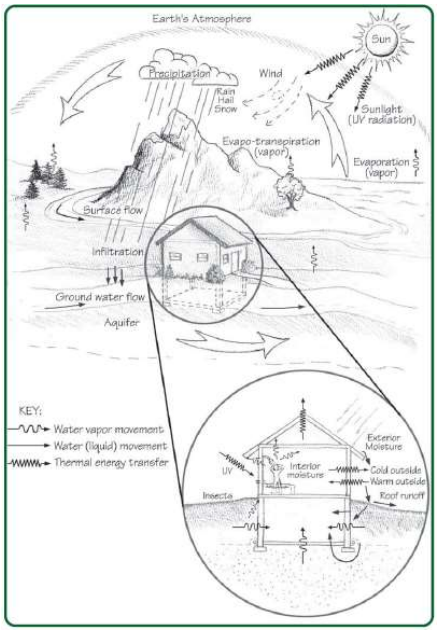
Why is the BTE important?

- The primary function of a building envelope is to separate the indoor from the outdoor environment.
- The BTE is an integrated system which also supports the design and function of other building systems.

IECC Definition:

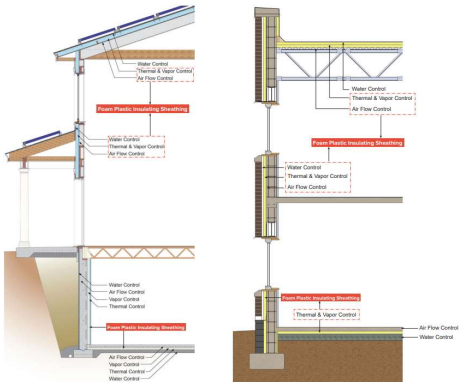
BUILDING THERMAL ENVELOPE. The basement walls, exterior walls, floors, ceilings, roofs and any other building element assemblies that enclose *conditioned space* or provide a boundary between *conditioned space* and exempt or unconditioned space.



Source: HUD, Durability by Design

Why is the BTE important?

- Allows indoor environment (conditioned space) to be controlled for comfort, productivity, and health
- Major factor in sizing HVAC equipment
- Protects the structure and its contents from the outdoor environment (wind, rain, U/V radiation, temperature and humidity cycling, etc.)
- Determines the life-cycle operational cost, energy use (heating/cooling), and carbon footprint for the building.
  - This last point is why building envelope has such a focus in the energy code



"Without a good building envelope, the previous HVAC system and design actions become more difficult and costly, and uncertain in their effectiveness."

Source: ABTG RR No. 2006-01, p10, https://www.continuousinsulation.org/topical-library/healthy-buildings

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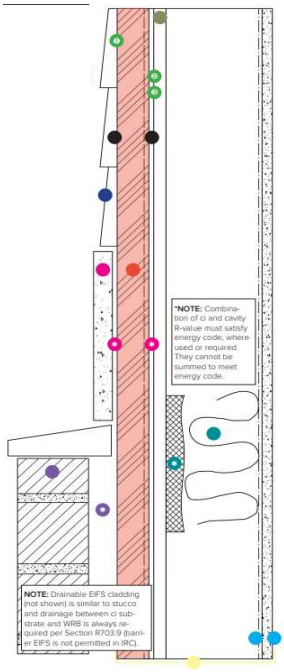
Functions of the BTE

- In addition to fire safety, structural safety, and durability the BTE must address the following control layers (functions):
  - **Water** control layers [cladding + continuous water-resistive barrier (WRB) + flashing to control water intrusion]
  - **Air** control layer [continuous air barrier (AB) to control air leakage]
  - **Thermal** control layer [continuity of thermal insulation to control heat loss/gain and surface temperatures]
  - **Water vapor** control layer [use of vapor retarders (VR) in coordination with insulation strategy and climate]
- Some "layers" or materials can perform multiple functions depending on design approach and material properties
- But, all functions must be satisfied at least to the minimum extent required by the building and energy code.



PART A: Administrative & General

- **Section C103 Construction Documents**
  - Requirements for preparation and submission of construction documents vary by local jurisdiction
- **C103.2 Information on construction documents**

  Details shall include (but not limited to):
  1. Energy compliance path (prescriptive, performance, ASHRAE 90.1) - See Section C401.2
  2. Insulation materials and their R-values
  3. Fenestration U-factors and solar heat gain coefficients (SHGCs)
  4. Area-weighted U-factor and SHGC calculations

     NOTE: Not applicable where "straight-up" prescriptive compliance is followed.

  …

  12. Location of daylight zones on floor plans
  13. Air barrier and air sealing details, including location of air barrier

NEW 2024:
6. Thermal bridges per new Section C402.7

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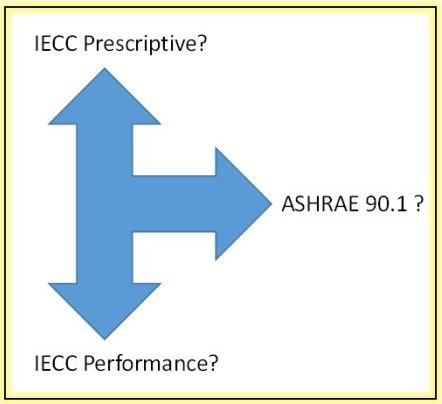
C401.2 Application

- **C401.2.1 International Energy Conservation Code**
  1. Prescriptive Compliance (Sections C402 – C406 and C408) or
  2. Total Building Performance (Section C407)
- **C401.2.2 ASHRAE 90.1**
  - Also has prescriptive and performance paths for compliance



Example Permit Application Checklist:

PART F IECC COMPLIANCE & GREEN BUILDING (see Commercial Energy Code information on DPS website)		
Requirement		On Sheet
IECC COMPLIANCE		
81	IECC Compliance Path (provide in code analysis)	☐NA
82	Thermal envelope plan	☐NA
83	Thermal envelope details, including insulation, air barriers, daylight zones, and duct insulation	☐NA
84	Fenestration schedule	☐NA
85	Electrical: lighting and lighting controls	☐NA
86	Mechanical: system design criteria and economizers	☐NA
87	Statement of design compliance – stamped, sealed, signed, and dated	☐NA
88	Energy conservation analysis/computations (e.g. ComCheck) with a statement of compliance per Part IV of the DPS Commercial Energy Code requirements document	☐NA

Declare the compliance path used.

More checklists for compliance:
https://energyoffice.colorado.gov/energy-code-adoption-toolkit

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IECC Section 105 Inspections

C105.2.2 Thermal envelope.
Inspections shall verify the correct type of insulation, *R*-values, location of insulation, fenestration, *U*-factor, SHGC and VT, and that air leakage controls are properly installed, as required by the code, *approved* plans and specifications.

NEW 2024:
Inspection of "thermal bridge mitigation" to correspond with new provisions in C402.7 for detailing of major building assembly thermal bridges

Should also include inspection of thermal envelope certificate at end of project?

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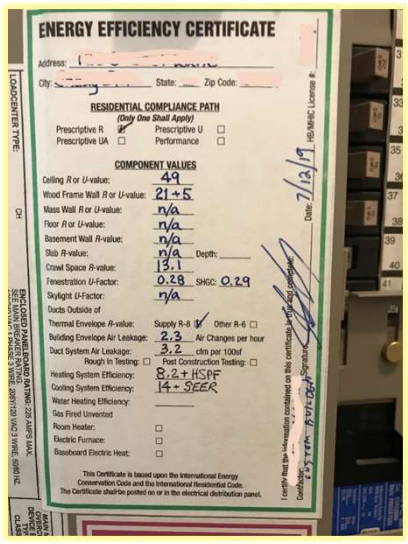
C401.3 Thermal Envelope Certificate

- Completed by an "approved party"
- Posted in place where HVAC equipment is located, utility room, or approved location
- Shall not obstruct information on electric service panel (if posted there)
- Copy shall be included in construction files
- Shall include the following information:
  1. R-values of insulation installed (walls, floors, roof, foundation, ducts, etc.)
  2. U-factor and SHGCs of all fenestration
  3. Air leakage test results (if conducted)



ENERGY EFFICIENCY CERTIFICATE

Address: [redacted]

City: [redacted] State: ___ Zip Code: ___

RESIDENTIAL COMPLIANCE PATH
(Only One Shall Apply)

Prescriptive R ☑ Prescriptive U ☐
Prescriptive UA ☐ Performance ☐

COMPONENT VALUES

Ceiling *R* or *U*-value:	49
Wood Frame Wall *R* or *U*-value:	21+5
Mass Wall *R* or *U*-value:	n/a
Floor *R* or *U*-value:	n/a
Basement Wall *R*-value:	n/a
Slab *R*-value:	n/a Depth: ___
Crawl Space *R*-value:	13.1
Fenestration *U*-Factor:	0.28 SHGC: 0.29
Skylight *U*-Factor:	n/a
Ducts Outside of Thermal Envelope *R*-value:	Supply R-8 ☑ Other R-6 ☐
Building Envelope Air Leakage:	2.3 Air Changes per hour
Duct System Air Leakage:	3.2 cfm per 100sf
Rough In Testing: ☐ Post Construction Testing: ☐	
Heating System Efficiency:	8.2+ HSPF
Cooling System Efficiency:	14+ SEER
Water Heating Efficiency:	___
Gas Fired Unvented Room Heater:	☐
Electric Furnace:	☐
Baseboard Electric Heat:	☐

This Certificate is based upon the International Energy Conservation Code and the International Residential Code. The Certificate shall be posted on or in the electrical distribution panel.

I certify that the information contained on this certificate is true and correct. Signature: ___ Date: 7/12/19

Contractor: [redacted]

LOADCENTER TYPE: CH

MAIN BREAKER RATING: 200 AMPS

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C301 Climate Zone & C302 Design Conditions

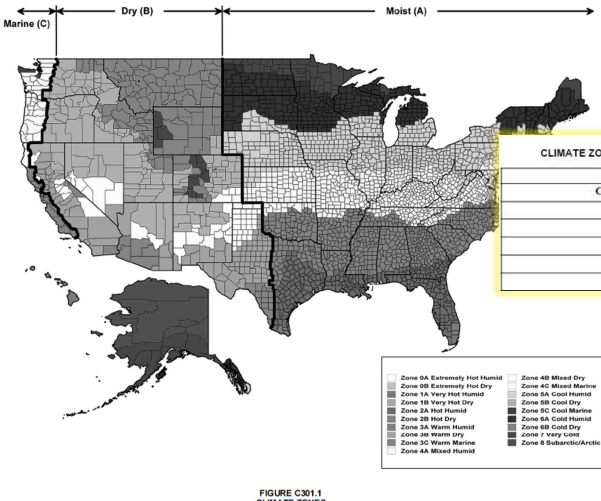

FIGURE C301.1
CLIMATE ZONES

Colorado covers climate zones 4-7

TABLE C301.1—continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY[a]

US STATES—continued	
COLORADO *(continued)*	6B San Miguel
5B Custer	5B Sedgwick
5B Delta	7 Summit
5B Denver	5B Teller
6B Dolores	5B Washington
5B Douglas	5B Weld
	5B Yuma

SECTION C302
DESIGN CONDITIONS

C302.1 Interior design conditions. The interior design temperatures used for heating and cooling load calculations shall be a maximum of 72°F (22°C) for heating and minimum of 75°F (24°C) for cooling.

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IECC Product Labeling
(Testing, Labeling/Marking, Verification)

- **IECC C303.1/R303.1 Identification**
  - Insulation materials must be identified in a manner to allow determination of compliance with the code.
  - RECOMMENDATION: Verify label (insulation mark) and product test data is certified by an *approved agency*
    - *NOTE: This is not clearly a code requirement for R-value identification or verification in the IECC, but many insulation manufacturers and products do use certified third-parties (approved agencies) to test and/or label products. The recommendation is discretionary.*

APPROVED SOURCE. An independent person, firm or corporation, *approved* by the *building official*, who is competent and experienced in the application of engineering principles to materials, methods or systems analyses.

APPROVED AGENCY. An established and recognized agency that is regularly engaged in conducting tests, furnishing inspection services or furnishing product certification where such agency has been *approved* by the *building official*.

*ANSI National Accreditation Board (ANAB) provides accreditation of approved sources/agencies in the US https://anab.ansi.org/

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Insulation Material Requirements

- **C303.1.1 Building thermal envelope insulation**
  - R-value mark on each piece or certificate (including installation details of sprayed or blown-in insulation for R-value, density, thickness, etc.)
    - **Exception:** Above-deck roof insulation per Table 1508.2 of IBC (material standards which address product marking or use of package label or certificate)
  - C303.1.2 - the above information must be readily observable or certificate left on site immediately after installation
- **C303.1.4 Insulation product rating**
  - R-value determined in accordance with test methods and procedures in the FTC R-value Rule
  - Insulated siding tested per ASTM C1369 as installed per manufacture instructions

R-value mark on batt insulation

Installation Certificate

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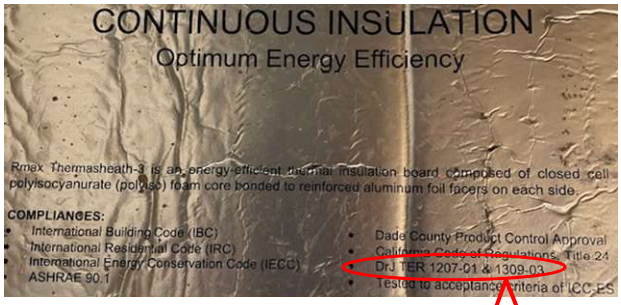
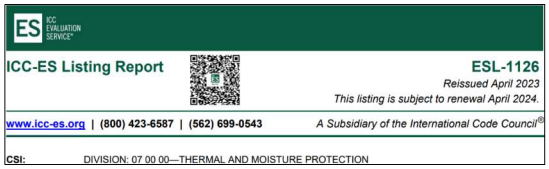
IBC Product Labeling Foam Plastics

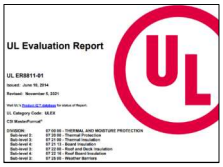
- **2021 IBC Section 2603.2 Labeling and identification.** Packages and containers of foam plastic insulation and foam plastic insulation components delivered to the job site shall bear the *label* of an *approved agency* showing the manufacturer's name, product listing, product identification and information sufficient to determine that the end use will comply with the code requirements.

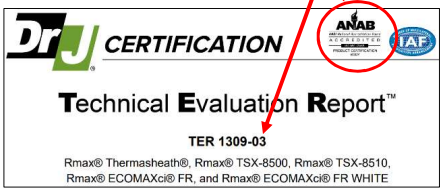
Example Product Marking/Label:



Examples of approved agencies & sources…





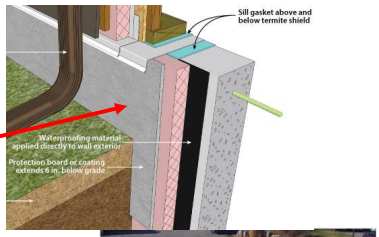


Fenestration Product Requirements

- **C303.1.3 Fenestration product rating**
  - Tom will cover this topic in greater detail later in Part C

General Installation Requirements

- C303.2 All materials, systems and equipment shall be installed in accordance with the manufacturer's installation instructions and the *International Building Code*.
- C303.2.1 Protection of exposed foundation insulation
  - Applies to exterior insulation on foundations
  - Rigid, opaque, weather-resistant protective covering required for exposed insulation and it shall extend not less than 6 inches below grade
- C303.2.2 Multiple layers of continuous insulation
  - Where two or more layers of continuous insulation are used, follow manufacturer's instructions or if no instruction, edge joints must be staggered



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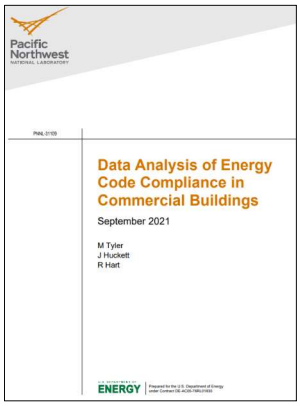
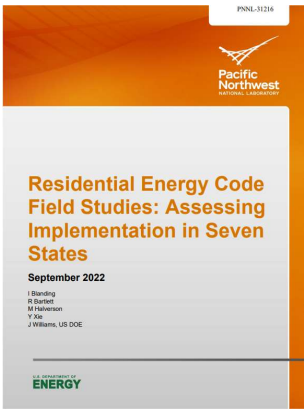
Hot Topics for Compliance and Enforcement

- Commercial Buildings
- Residential Buildings
  - Relevant also to commercial Type V construction?



www.energycodes.gov/commercial-energy-code-field-study



https://www.energycodes.gov/residential-energy-code-field-studies

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Commercial Buildings Compliance Data

- 230 new office and retail buildings sampled & surveyed
- Climate Zones 2A and 5A
- Only 4 of 230 where found to be 100% compliant
- Average annual energy cost of non-compliances was $189/1000sf/yr
- Average present value of lost energy cost savings over the life of the building was estimated at **$2,868/1000sf**
  - 7% of the sample had lost energy cost savings of **2 to 7 times this amount**.
- On average the total sample performed 15% worse than intended by code minimum requirements in terms of annual energy use per sqft (EUI).
- CONCLUSION: Focus on major non-compliances to eliminate the really bad performers and improve the overall average level of compliance.

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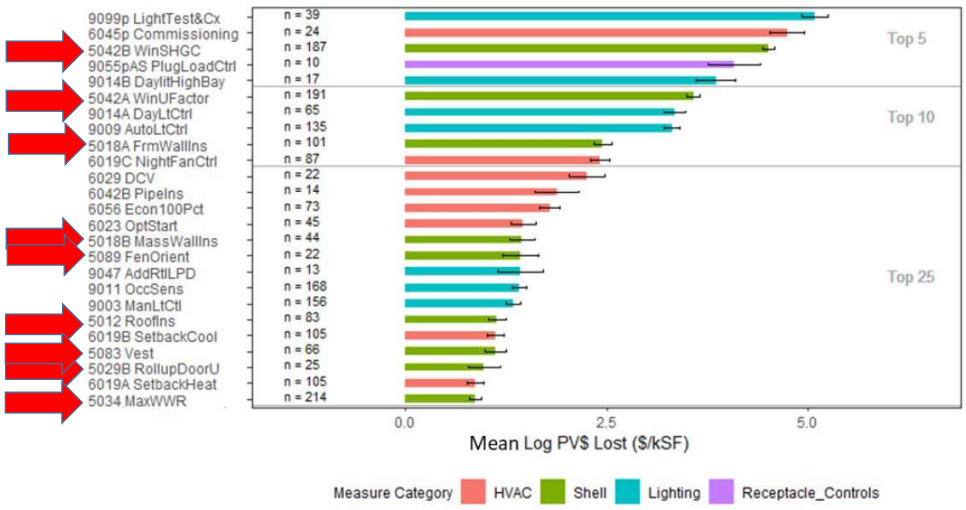
Commercial Building "Top 25" (All Measures)

9 Envelope Items in Top 25 (3 in Top 10)



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Commercial Building Envelope (Top 9)

- #1 Window SHGC rating verification
- #2 Window U-factor rating verification
- #3 Frame wall insulation
- #4 Mass wall insulation
- #5 Fenestration orientation
- #6 Roof insulation
- #7 Vestibules
- #8 Roll-up Door U-factor
- #9 Max window-to-wall ratio
- What about air-leakage? (could not conduct blower-door tests in survey to verify) – see coming slides on residential buildings.

Some specific compliance issues will be addressed as code requirements are presented.

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Residential Field Studies - Baseline

- Baseline (Phase I) annual energy cost savings possible with 100% compliance
- Based on field assessments of level of compliance for homes across seven states

Table ES.1.1 Phase I Total Annual Energy Cost Savings Potential

Rank	Measure	Energy Cost Savings Potential
1	Duct Tightness	$4,880,394
2	Lighting	$4,013,943
3	Wall Insulation	$3,625,496
4	Ceiling Insulation	$3,359,593
5	Envelope Tightness	$2,368,287
6	Foundation	$348,918
7	Window SHGC	$54,674

R-value compliance good
U-factor compliance an issue
(accounted for installation quality)

Avg = 4.5ACH
Adequate ventilation?

Window compliance universally good

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Residential Field Studies - Baseline

- Wall and ceiling insulation U-factor had some of the lowest compliance rates
- Windows had the highest compliance rates
- Lots of variation between states and measures within a given state

Table 2.2. Phase I Average Measure Level Compliance Rate (%)

State	Envelope Tightness	Duct Tightness	Wall Insulation U-factor	Ceiling Insulation U-factor	Lighting	Window U-factor	Window SHGC
PA	93%	63%	23%	49%	62%	97%	-
MD	54%	62%	25%	69%	61%	98%	-
KY	70%	77%	28%	41%	31%	98%	-
NC	88%	64%	12%	64%	57%	99%	99%
GA	96%	69%	17%	11%	38%	100%	98%
AL	46%	15%	16%	75%	21%	94%	74%
TX (CZ2a)	60%	19%	65%	59%	48%	94%	94%

U-factor for the study included R-values provided relative to code required plus accounted for impact of installation on assembly performance (U-factor) following RESNET insulation grading protocol.

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Insulation Installation Quality (e.g., Maryland)

Assembly	Grade I	Grade II	Grade III	Total Observations
Roof Cavity	86	7	0	**93**
Floor	45	11	1	**57**
Above Grade Wall	33	21	2	**56**
Basement Wall	46	6	2	**54**
Knee Wall	21	3	0	**24**
Crawlspace Wall	2	0	0	**2**

The project team reported common issues with insulation installation quality and air barriers behind bathroom tubs and showers, in particular. In addition, quality of slab edge insulation (although not included on the data collection form for the study) was typically observed as Grade III.

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Residential Field Studies – Baseline EUI

- Variance and impact of observed EUI vs. code intended EUI was worse in the more northern climate (greater heating energy load)
- Variation in stringency of adopted prescriptive code also a concern (dash vertical lines)
- EUI = energy use intensity (kBtu/sqft/yr)

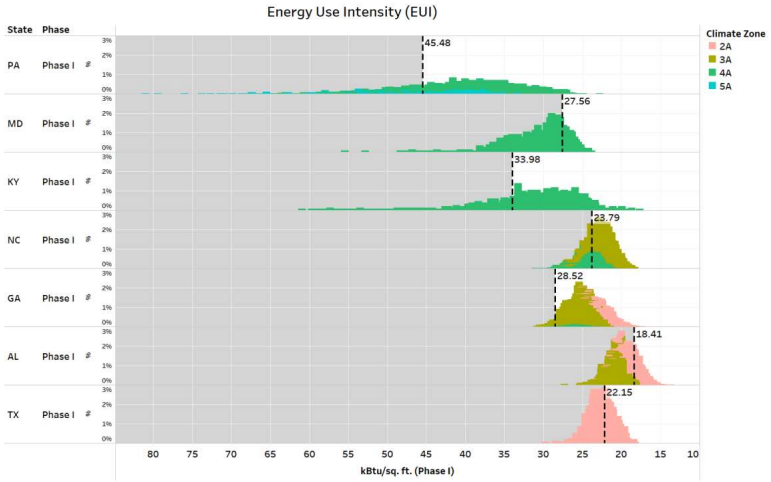

Figure 2.14 Comparison of Phase I Statewide EUIs

Residential Field Studies - Results

- Savings realized after 2 years of statewide energy code training = $8.1M/yr
- Savings yet to be realized with further enforcement and compliance improvement = $10.6M/yr

Table ES.1.2 Summary of Annual Statewide Energy Cost Savings

State	Annual Potential Savings		Statewide Savings Achieved from Phase II (Phase I – Phase III)	
	Phase I	Phase III	Annual Energy Cost Savings	% Change
Pennsylvania	$3,198,846	$3,013,497	$185,349	5.8%
Maryland	$1,542,788	$311,414	$1,231,374	79.8%
Kentucky	$1,219,856	$928,586	$291,270	23.9%
North Carolina	$2,025,958	$2,368,044	-$342,086	-16.9%
Georgia	$4,516,678	$1,751,143	$2,765,535	61.2%
Alabama	$1,299,382	$978,585	$320,797	24.7%
Texas	$4,847,797	$1,243,958	$3,603,839	74.3%
Total	**$18,651,305**	**$10,595,227**	**$8,056,078**	**43.2%**

$70 - $220/yr per home

$12-$117/yr per home

$8.7 Billion cumulative over 30 years for all homes built in that time frame

Residential Field Studies - Results

- Compliance for most measures in most states improved
- Several measures worsened in compliance
  - "Hot spots" that remain problematic

Table 4.14. Measure-level Annual Estimated Savings Potential Difference (Phase III vs. I)

	State						
	PA	MD	KY	NC	GA	AL	TX
Envelope Tightness		$560,047	$473,993	($350,593)		$78,005	$484,152
Duct Tightness	$199,710	$122,024	($299,075)	($342,700)	$470,378	$71,825	$1,744,696
Wall Insulation	($105,642)	$327,981	$19,070	$64,372	$214,435	$26,025	$152,662
Ceiling Insulation	($393,994)	$34,059	$123,870	$68,075	$1,385,758		($324,033)
High-Efficacy Lighting	$324,076	$187,263	$44,161	$222,205	$694,964	$94,802	$1,546,362
Foundation Insulation	$161,199		($70,749)	($3,445)			
Window SHGC						$50,140	
Total Savings	$185,349	$1,231,374	$291,270	($342,086)	$2,765,535	$320,797	$3,603,839

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Residential Field Studies - Results

- Still much variation in EUI relative to prescriptive code intended value
- Some states increased in EUI variation above target after training and others notably improved
- Overall positive trend, but still much work to be done to improve compliance!

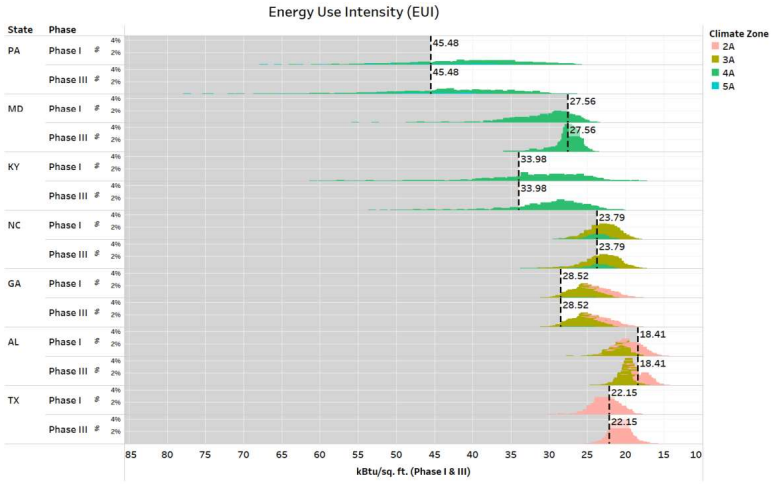

Figure 4.27. Comparison of Phase I and Phase III Statewide EUIs

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PART B: Building Envelope - Opaque Assemblies

- C402.1 General
- C402.2 Specific Building Thermal Envelope (BTE) Requirements
- C402.3 Roof Solar Reflectance and Emittance

- To be addressed later:
  - Fenestration & Daylighting (C402.4)
  - Component Performance Alternative (C402.1.5)
  - Air leakage (C402.5)

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Opaque Envelope Prescriptive Requirements

- **SECTION C402 – BUILDING ENVELOPE REQUIREMENTS**
- **C402.1 General.** *Building thermal envelope*…shall comply with the following:
  1. Opaque portions shall comply with C402.2 and:
     a. R-value method (C402.1.3),
     b. U-, C- and F-factor method (C402.1.4), or
     c. Component performance alternative (C402.1.5)
  2. Roof solar reflectance and thermal emittance (C402.3)
  3. Fenestration (C402.4)
  4. Air leakage (C402.5)

NEW 2024:
Section C402.1 reorganized & U-factor established as basis for R-values, among other clarifications

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Building Thermal Envelope - Exemptions

- **C402.1.1 Low-energy buildings and greenhouses.**
  - Low-energy building exemptions:
    1. Peak design rate of energy usage < 3.4 Btu/h (10.7 W/m^2) or 1.0 W/ft2 (10.7 W/m^2) of conditioned space floor area, or
    2. Those that do not contain *conditioned space.*
  - Includes portions thermally separated from the remainder of a conditioned building by compliant BTE assemblies
    - Examples might include an attached commercial sunroom or restaurant enclosed patio area, etc.

NOTE: If there is any space heating or cooling equipment used, #1 above should be demonstrated prior to granting this complete exemption from the BTE provisions of C402.

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Opaque Envelope - Exemptions

- **402.1.1.1 Greenhouses.** Mechanically heated or cooled greenhouses are exempted from BTE provisions provided they comply with all of the following:

1. Exterior opaque envelope assemblies comply with Sections C402.2 (specific insulation requirements) and C402.4.5 (doors).
   - For example, some greenhouses have opaque foundation stem walls, slabs, and above grade wall portions (see photo).
2. Interior partitions separating the greenhouse from conditioned space comply with Sections C402.2, C402.4.3 (fenestration U-factor), and C402.4.5 (doors).
3. Fenestration assemblies comply with Table C402.1.1.1. The U-factor for a roof shall be for the roof assembly or a roof that includes the assembly and an internal curtain system.*

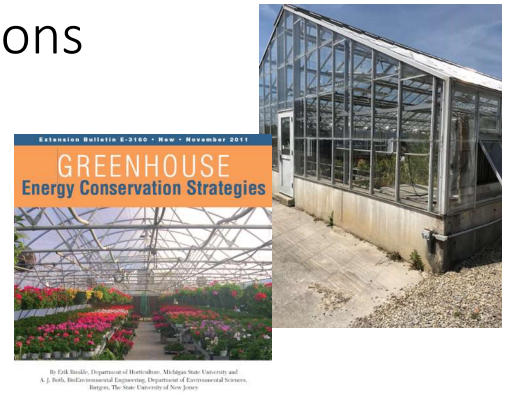

TABLE C402.1.1.1
FENESTRATION THERMAL ENVELOPE
MAXIMUM REQUIREMENTS

COMPONENT	*U*-FACTOR (BTU/h × ft^2 × °F)
Skylight	0.5
Vertical fenestration	0.7

*NOTE: These U-factors allow for multi-layer poly films or polycarbonate cellular panels, but not single poly film

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Opaque Envelope - Exemptions

- **C402.1.2 Equipment Buildings**
  - Exempt from BTE provisions if complying with the following:
    1. Separate buildings with floor area not more than 1,200 sqft
    2. Intended for electric equipment with equipment power not less than 7 W/sqft
    3. Heating system ≤ 17,000 Btu/hr (5 kW) and setpoint ≤ 50 F [NEW 2024: 20,000 Btu/hr (6 kW)]
    4. Average wall and roof U-factor < 0.200 (CZ 1-5) and < 0.120 (CZ 6-8)
    5. Roof solar reflectance and emittance provisions for CZ 1

Source: https://www.eaton.com

Source: https://about.automationdirect.com

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Opaque Envelope – R-value Method

- **C402.1.3 Insulation component R-value-based method.**
  - Shall comply with C402.2 (special insulation requirements)
  - Shall comply with C402.4 (fenestration U-factor, SHGC, area limits, etc.)
  - R-values for cavity insulation and continuous insulation shall not be less than that specified in Table C402.1.3.
  - Required minimum R-values vary by:
    - Climate Zone (Chapter 3)
    - Assembly (roof, wall, floor, foundation)
    - Construction type (metal building, wood frame, steel frame, mass, etc.)
    - Occupancy (“Group R” vs. “All other”)
    - Insulation component and location (e.g., cavity insulation and continuous insulation)

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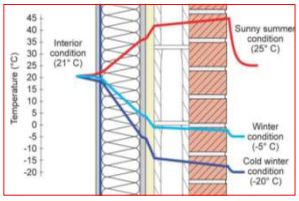
Opaque Envelope – R-value Method

***R*-VALUE (THERMAL RESISTANCE).** The inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area (h × ft² × °F/Btu) [(m² × K)/W].



- The greater the R-value the greater the resistance to heat flow
- Heat flow through the building thermal envelope can be heat loss (winter conditions) or heat gain (summer conditions)
- R-value of insulation is a rated R-value of the insulation product only
- R-value of an assembly is the "effective" R-value of all heat flow paths through an assembly, including insulation and building materials
  - R-eff,assembly = 1/U-factor
  - U-factor = 1/R-eff,assembly
- Building materials that extend through insulation are thermal bridges such that the effective R-value of the assembly is less than the rated R-value of the insulation materials

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Opaque Envelope – R-value Method

TABLE C402.1.3
OPAQUE THERMAL ENVELOPE INSULATION COMPONENT MINIMUM REQUIREMENTS, *R*-VALUE METHOD[a]

CLIMATE ZONE	0 AND 1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Roofs																
Insulation entirely above roof deck	R-20ci	R-25ci	R-25ci	R-25ci	R-25ci	R-25ci	R-30ci	R-30ci	R-30ci	R-30ci	R-30ci	R-30ci	R-35ci	R-35ci	R-35ci	R-35ci
Metal buildings[b]	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-25 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS	R-35 + R-11 LS	R-25 + R-11 + R-11 LS	R-25 + R-11 + R-11 LS
Attic and other	R-38	R-38	R-38	R-38	R-38	R-38	R-49	R-49	R-49	R-49	R-49	R-49	R-60	R-60	R-60	R-60
Walls, above grade																
Mass[f]	R-5.7ci[c]	R-5.7ci[c]	R-5.7ci[c]	R-7.6ci	R-7.6ci	R-9.5ci	R-9.5ci	R-11.4ci	R-11.4ci	R-13.3ci	R-13.3ci	R-15.2ci	R-15.2ci	R-15.2ci	R-25ci	R-25ci
Metal building	R-13 + R-6.5ci	R-13 + R-6.5ci	R13 + R-6.5ci	R-13 + R-13ci	R-13 + R-6.5ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-14ci	R-13 + R-14ci	R-13 + R-14ci	R-13 + R-14ci	R-13 + R-14ci	R-13 + R-17ci	R-13 + R-19.5ci	R-13 + R-19.5ci	R-13 + R-19.5ci
Metal framed	R-13 + R-5ci	R-13 + R-5ci	R-13 + R-5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-10ci	R-13 + R-10ci	R-13 + R-10ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-15.6ci	R-13 + R-18.8ci	R-13 + R-18.8ci
Wood framed and other	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-18.8ci	R-13 + R-18.8ci
Walls, below grade																
Below-grade wall[d]	NR	NR	NR	NR	NR	NR	NR	R-7.5ci	R-7.5ci	R-10ci	R-10ci	R-10ci	R-15ci	R-15ci	R-15ci	R-15ci
Floors																
Mass[e]	NR	NR	R-6.3ci	R-8.3ci	R-10ci	R-10ci	R-14.6ci	R-16.7ci	R-14.6ci	R-16.7ci	R-16.7ci	R-16.7ci	R-20.9ci	R-20.9ci	R-23ci	R-23ci
Joist/framing	R-13	R-13	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-38	R-38	R-38	R-38	R-38	R-38
Slab-on-grade floors																
Unheated slabs	NR	NR	NR	NR	NR	R-10 for 24″ below	R-15 for 24″ below	R-15 for 24″ below	R-15 for 24″ below	R-20 for 24″ below	R-20 for 24″ below	R-20 for 24″ below	R-20 for 48″ below	R-20 for 48″ below	R-20 for 48″ below	R-25 for 48″ below
Heated slabs[g]	R-7.5 for 12″ below+ R-5 full slab	R-7.5 for 12″ below+ R-5 full slab	R-7.5 for 12″ below+ R-5 full slab	R-7.5 for 12″ below+ R-5 full slab	R-10 for 24″ below+ R-5 full slab	R-10 for 24″ below+ R-5 full slab	R-15 for 24″ below+ R-5 full slab	R-15 for 24″ below+ R-5 full slab	R-15 for 36″ below+ R-5 full slab	R-15 for 36″ below+ R-5 full slab	R-15 for 36″ below+ R-5 full slab	R-20 for 48″ below+ R-5 full slab	R-20 for 48″ below+ R-5 full slab	R-20 for 48″ below+ R-5 full slab	R-20 for 48″ below+ R-5 full slab	R-20 for 48″ below+ R-5 full slab

LOTS OF PRESCRIPTIVE R-VALUES!

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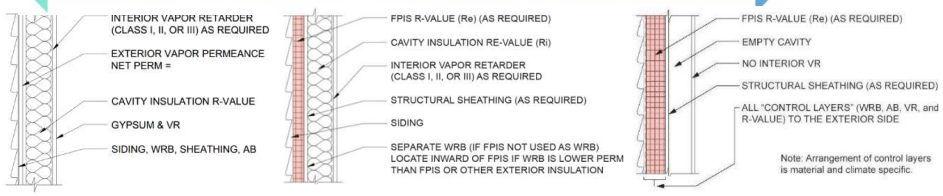
2024 IECC – added prescriptive R-value options

CLIMATE ZONE	0 AND 1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Walls, above grade																
Metal framed[a]	R-0 + R-10ci or R-13 + R-5ci or R-20 + R-3.8ci	R-0 + R-10ci or R-13 + R-5ci or R-20 + R-3.8ci	R-0 + R-10ci or R-13 + R-5ci or R-20 + R-3.8ci	R-0 + R-12.6ci or R-13 + R-7.5ci or R-20 + R-6.3ci	R-0 + R-12.6ci or R-13 + R-7.5ci or R-20 + R-6.3ci	R-0 + R-12.6ci or R-13 + R-7.5ci or R-20 + R-6.3ci	R-0 + R-12.6ci or R-13 + R-7.5ci or R-20 + R-6.3ci	R-0 + R-12.6ci or R-13 + R-7.5ci or R-20 + R-6.3ci	R-0 + R-15.2ci or R-13 + R-10ci or R-20 + R-9ci	R-0 + R-15.2ci or R-13 + R-10ci or R-20 + R-9ci	R-0 + R-17.3ci or R-13 + R-12.5ci or R-20 + R-11ci	R-0 + R-17.3ci or R-13 + R-12.5ci or R-20 + R-11ci	R-0 + R-17.3ci or R-13 + R-12.5ci or R-20 + R-11ci	R-0 + R-21ci or R-13 + R-15.6ci or R-20 + R-14.3ci	R-0 + R-24ci or R-13 + R-18.8ci or R-20 + R-17.5ci	R-0 + R-24ci or R-13 + R-18.8ci or R-20 + R-17.5ci
Wood framed and other[b]	R-0 + R-12ci or R-13 + R-3.8ci or R-20	R-0 + R-12ci or R-13 + R-3.8ci orR-20	R-0 + R-12ci or R-13 + R-3.8ci or R-20	R-0 + R-12ci or R-13 + R-3.8ci orR-20	R-0 + R-12ci or R-13 + R-3.8ci orR-20	R-0 + R-12ci or R-13 + R-3.8ci orR-20	R-0 +R-12ci or R-13 + R-3.8ci orR-20	R-0 + R-12ci or R-13 + R-3.8ci orR-20	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 +R-16ci or R-13 + R-7.5ci or R20 + R3.8ci or R-27	R-0 + R-27.5ci or R-13 + R-18.8ci or R-20 + R-14ci	R-0 + R-27.5ci or R-13 + R-18.8ci or R-20 + R-14ci

CAVITY INSULATION ONLY ➔ CAVITY + CONTINUOUS HYBRID ➔ CONTINUOUS ONLY



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Opaque Envelope – R-value Method

- **Table C402.1.3 Footnotes:**

  ci = Continuous Insulation, NR = No Requirement, LS = Liner System.

  a. Assembly descriptions can be found in ANSI/ASHRAE/IESNA 90.1 Appendix A.

  b. Where using *R*-value compliance method, a thermal spacer block shall be provided, otherwise use the *U*-factor compliance method in Table C402.1.4.

  c. R-5.7ci is allowed to be substituted with concrete block walls complying with ASTM C90, ungrouted or partially grouted at 32 inches or ~~less~~ ["more"] on center vertically and 48 inches or less on center horizontally, with ungrouted cores filled with materials having a maximum thermal conductivity of 0.44 Btu-in/h-f2 °F.

  d. Where heated slabs are below grade, below-grade walls shall comply with the exterior insulation requirements for heated slabs.

  e. "Mass floors" shall be in accordance with Section C402.2.3.

  f. "Mass walls" shall be in accordance with Section C402.2.2.

  g. The first value is for perimeter insulation and the second value is for full, under-slab insulation. Perimeter insulation is not required to extend below the bottom of the slab.

LOTS OF FOOTNOTES!

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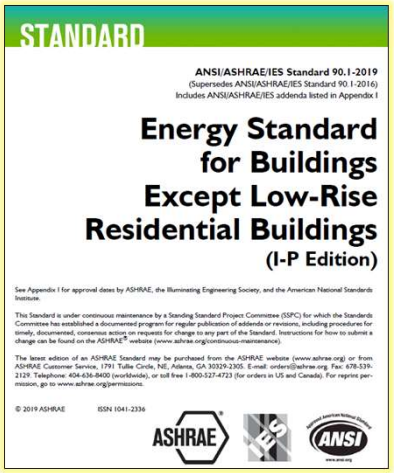
Opaque Envelope – R-value Method

- **Unpack Table C402.1.3 footnotes:**

a. Assembly descriptions can be found in ANSI/ASHRAE/IESNA 90.1 Appendix A.

- To use Table C402.1.3, the assemblies must comply with assembly descriptions in ASHRAE 90.1 Appendix A (e.g., minimum 16"oc steel or wood framing, minimum thickness/weight of "mass" construction, etc.)
- If assembly description doesn't comply then:
  - Use the "other" category in Table C402.1.4 (U-factor table) for compliance
  - NOTE: The attic and "other" or wood frame wall and "other" category in the R-value table is somewhat meaningless because the framing system is not known and this would affect the R-values and placement of insulation components required to meet intent of code.



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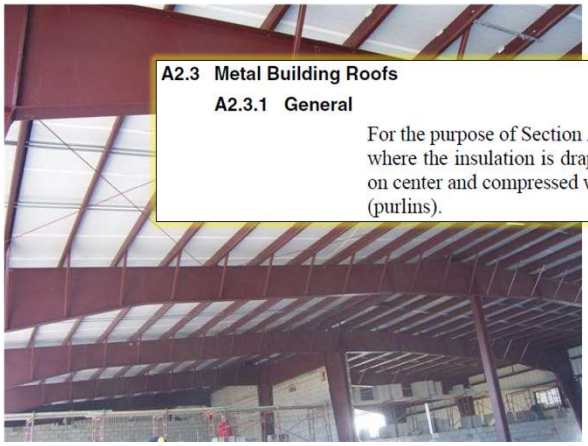
Opaque Envelope – R-value Method

- Example of Assembly Description in ASHRAE 90.1 Appendix A



A2.3 Metal Building Roofs

A2.3.1 General

For the purpose of Section A1.2, the base assembly is a *roof* with thermal spacer blocks where the insulation is draped over the steel structure (purlins), spaced nominally 5 ft on center and compressed when the metal *roof* panels are attached to the steel structure (purlins).

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Opaque Envelope – R-value Method

- Example of Assembly Description in ASHRAE 90.1 Appendix A

A3.4 Wood-Framed Walls

A3.4.1 General

For the purpose of Section A1.2, the base assembly is a *wall* where the insulation is installed between 2 in. nominal wood framing. Cavity insulation is full depth, but values are taken from Table A9.4.3 for R-19 insulation, which is compressed when installed in a 5.5 in. cavity. Headers are double 2 in. nominal wood framing. The *U-factors* include R-0.17 for exterior air film, R-0.08 for stucco, R-0.56 for 0.625 in. gypsum board on the exterior, R-0.56 for 0.625 in. gypsum board on the interior, and R-0.68 for interior air film, vertical surfaces. Additional assemblies include *continuous insulation* uncompressed and uninterrupted by framing. *U-factors* are provided for the following configurations:

a. Standard framing: Wood framing at 16 in. on center with cavities filled with 14.5 in. wide insulation for both 3.5 in. deep and 5.5 in. deep *wall* cavities. Double headers leave no cavity. Weighting factors are 75% insulated cavity, 21% studs, plates, and sills, and 4% headers.

b. Advanced framing: Wood framing at 24 in. on center with cavities filled with 22.5 in. wide insulation for both 3.5 in. deep and 5.5 in. deep *wall* cavities. Double headers leave uninsulated cavities. Weighting factors are 78% insulated cavity, 18% studs, plates, and sills, and 4% headers.

c. Advanced framing with insulated headers: Wood framing at 24 in. on center with cavities filled with 22.5 in. wide insulation for both 3.5 in. deep and 5.5 in. deep *wall* cavities. Double header cavities are insulated. Weighting factors are 78% insulated cavity, 18% studs, plates, and sills, and 4% headers.

NOTE: Tabulated R-values are based on and assume minimum 16"oc wood framing with a 25% "framing factor" allowance, but in this wall the framing factor is about 50%. What is it for the whole building? May not meet the "assembly description" in ASHRAE 90.1 Appendix A.

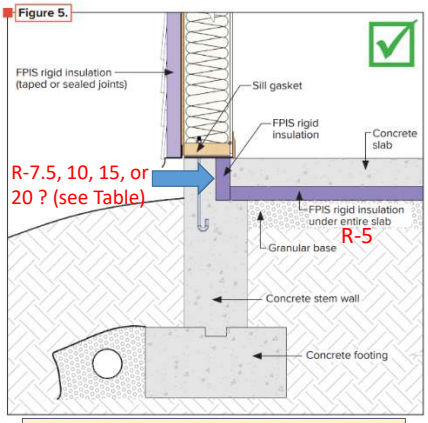
NEW 2024: Added footnote 'i' that allows unlimited framing factor if insulated with continuous insulation only to meet required R-value (additional cavity insulation may be used for sound deadening).

Opaque Envelope – R-value Method

- **Unpack Table C402.1.3 footnotes:**

  g. The first value is for perimeter insulation and the second value is for full, under-slab insulation. Perimeter insulation is not required to extend below the bottom of the slab.

  - Footnote applies only to **heated** slab-on-grade floors but is a bit "cryptic"
    - Slab perimeter insulation required for unheated slabs (full-slab can be used as F-factor alternate)
    - Full slab insulation + perimeter insulation required for heated slabs (but perimeter insulation only needs to be for depth of slab edge)
  - More to come later on slab insulation in Section C402.2.4 (specific insulation requirements)



Based on F-factors for heated slabs, R-15 edge + R-5 full slab (see Table for CZ 5) = R-5 edge + R-10 full slab

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Opaque Envelope – R-value Method

- **Unpack the "summation of R-values" text in Section C402.1.3**
  - R-values of *cavity insulation* and *continuous insulation* shall be not less than that specified in the table.
  - *Cavity insulation* and *continuous insulation* R-values cannot be summed together for compliance or as an alternative R-value
    - This would ignore thermal bridging of cavity insulation
    - The U-factor method must be used to determine alternative equivalent R-value solutions
  - Cavity insulation components layered within the cavity can be summed to meet the cavity insulation component requirement
  - Continuous insulation components layered on an assembly can be summed to meet the continuous insulation component requirement
- CONCLUSION: You can sum apples and apples. You can sum oranges and oranges. But, you can't sum apples and oranges.

That's mathematics son. You can argue with me but you can't argue with figures. Two half nuthins is a whole nuthin'. (Foghorn Leghorn, Warner Bros.)

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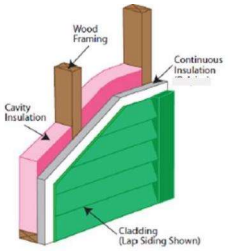
Opaque Envelope – R-value Method

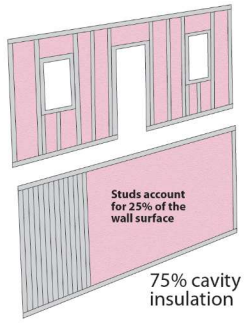
- Example of an R-value summation non-compliance for a wood frame wall (e.g., R-20 + R-5ci ≠ R25):

$$U = ff_{framing} * \frac{1}{R_{framing}} + ff_{cavity} * \frac{1}{R_{cavity}}$$



	R25 + 0ci Wall	R20 + 5ci Wall
U-factor	0.0538	0.0446
Effective R-value	**R-18.59**	**R-22.43**

- Effective R-value of **R18.6 vs. R22.4** (about R-4 difference in actual performance ➔ R-20 + R-5ci > R-25)
- The difference is much more significant for steel framing because the effective R-value of the cavity insulation component is reduced to as little as 40% of the rated R-value of the cavity insulation
  - For the wood wall example above the cavity insulation is 18.6/25 = 74% effective relative to its rated R-value



25% studs ("thermal bridges")

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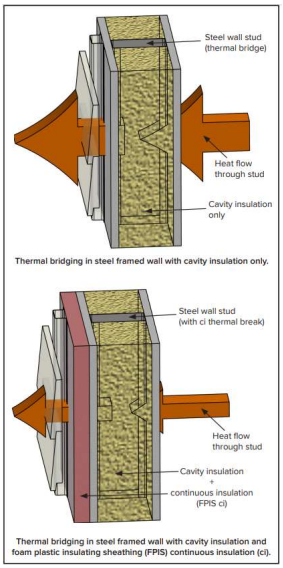
Opaque Envelope – R-value Method

- Definitions are important:
  - **CAVITY INSULATION.** Insulating material located between framing members.
  - **CONTINUOUS INSULATION (ci).** Insulating material that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral to any opaque surface of the building envelope.



NOTE: If the metal furring shown were to extend through the ci layer, it would no longer be ci; it would become more like an additional separate layer of cavity insulation.

For information on fastening cladding and furring through ci, refer to:
https://www.continuousinsulation.org/applications/cladding-connections

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Opaque Envelope – R-value Method

- Example application of Table C402.1.3 for Climate Zone 5
  - Assume: Office building (use "all other" category, not Group R)
    - Roof ("insulation entirely above deck"): R-30
    - Above-grade walls*: R-13+10ci
      ("metal framed" = cold-formed steel)
    - Foundation (below grade walls): R-7.5ci
    - Floors (over unconditioned space): R-30 (steel frame) R-14.6ci (mass floor)
    - Floor (slab on grade): R-15 for 24" below

2024 IECC:
R-0 + 15.2ci
R-13 + 10ci
R-20 + 9ci

F-factor equivalent = R-10 for 36" below

*Above-grade walls require additional attention (next slide)

CLIMATE ZONE	5 AND MARINE 4	
	All other	Group R
Insulation entirely above roof deck	R-30ci	R-30ci
Metal buildings[b]	R-19 + R-11 LS	R-19 + R-11 LS
Attic and other	R-49	R-49
Mass[f]	R-11.4ci	R-13.3ci
Metal building	R-13 + R-14ci	R-13 + R-14ci
Metal framed	R-13 + R-10ci	R-13 + R-10ci
Wood framed and other	R-13 + R-7.5ci or R20 + R3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci
Below-grade wall[d]	R-7.5ci	R-10ci
Mass[g]	R-14.6ci	R-16.7ci
Joist/framing	R-30	R-30
Unheated slabs	R-15 for 24" below	R-20 for 24" below
Heated slabs[g]	R-15 for 36" below+ R-5 full slab	R-15 for 36" below+ R-5 full slab

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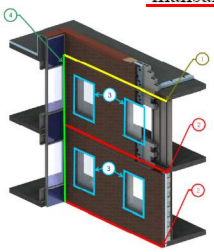
Opaque Envelope – R-value Method

- Again, definitions matter…

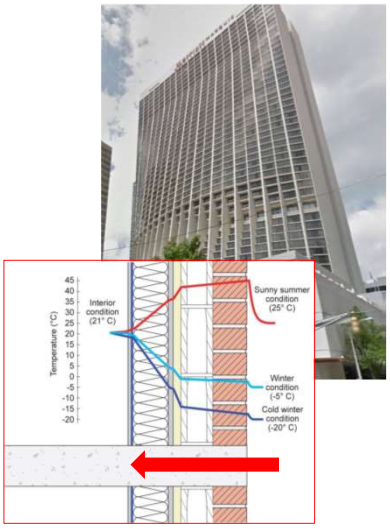
WALL, ABOVE-GRADE. A wall associated with the *building thermal envelope* that is more than 15 percent above grade and is on the exterior of the building or any wall that is associated with the *building thermal envelope* that is not on the exterior of the building. This includes, but is not limited to, between-floor spandrels, peripheral edges of floors, roof knee walls, dormer walls, gable end walls, walls enclosing a mansard roof and skylight shafts.



Source: BC Hydro BETB Guide, Morrison Hershfield LTD

NOTE: Thermal bridging at assembly intersections (e.g., wall-floor, wall-roof, window-wall, etc.) must be addressed to avoid unaccounted heat flows that can significantly degrade intended thermal performance of the building thermal envelope.

NEW 2024: Thermal bridging provisions in C402.7 enable compliance with this definition which requires assembly intersection thermal bridges to be included in the wall U-factor used to demonstrate compliance.



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Opaque Envelope – U-, C-, F-Factor Method

- **C402.1.4 Assembly U-factor, C-factor, or F-factor based method.**
  - Shall comply with C402.2 (special insulation requirements)
  - Shall comply with C402.4 (fenestration U-factor, SHGC, area limits, etc.)
  - BTE assemblies shall have a U-, C-, or F-factor not greater than that specified in Table C402.1.4.
  - Just as with minimum R-values, the required maximum U-, C-, and F-factors vary by:
    - Climate Zone (Chapter 3)
    - Assembly (roof, wall, floor, foundation)
    - Construction type (metal building, wood frame, steel frame, mass, etc.)
    - Occupancy (“Group R” vs. “All other”)

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Opaque Envelope – U-, C-, F-Factor Method

- Definitions:

***U*-FACTOR (THERMAL TRANSMITTANCE).** The coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films (Btu/h × ft^2 × °F) [W/(m^2 × K)].

***C*-FACTOR (THERMAL CONDUCTANCE).** The coefficient of heat transmission (surface to surface) through a building component or assembly, equal to the time rate of heat flow per unit area and the unit temperature difference between the warm side and cold side surfaces (Btu/h × ft^2 × °F) [W/(m^2 × K)].

***F*-FACTOR.** The perimeter heat loss factor for slab-on-grade floors (Btu/h × ft × °F) [W/(m × K)].

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Opaque Envelope – U-, C-, F-Factor Method

TABLE C402.1.4
OPAQUE THERMAL ENVELOPE ASSEMBLY MAXIMUM REQUIREMENTS, *U*-FACTOR METHOD[a, b]

CLIMATE ZONE	0 AND 1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Roofs																
Insulation entirely above roof deck	U-0.048	U-0.039	U-0.039	U-0.039	U-0.039	U-0.039	U-0.032	U-0.032	U-0.032	U-0.032	U-0.032	U-0.032	U-0.028	U-0.028	U-0.028	U-0.028
Metal buildings	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.031	U-0.029	U-0.029	U-0.029	U-0.026	U-0.026
Attic and other	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.017	U-0.017	U-0.017	U-0.017
Walls, above grade																
Mass[g]	U-0.151	U-0.151	U-0.151	U-0.123	U-0.123	U-0.104	U-0.104	U-0.090	U-0.090	U-0.080	U-0.080	U-0.071	U-0.071	U-0.071	U-0.037	U-0.037
Metal building	U-0.079	U-0.079	U-0.079	U-0.079	U-0.079	U-0.052	U-0.052	U-0.050	U-0.050	U-0.050	U-0.050	U-0.050	U-0.044	U-0.039	U-0.039	U-0.039
Metal framed	U-0.077	U-0.077	U-0.077	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.055	U-0.055	U-0.049	U-0.049	U-0.049	U-0.042	U-0.037	U-0.037
Wood framed and other[c]	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.051	U-0.051	U-0.051	U-0.051	U-0.051	U-0.051	U-0.032	U-0.032
Walls, below grade																
Below-grade wall[f]	C-1.140*	C-1.140*	C-1.140*	C-1.140*	C-1.140*	C-1.140*	C-0.119	C-0.092	C-0.119	C-0.092	C-0.092	C-0.063	C-0.063	C-0.063	C-0.063	C-0.063
Floors																
Mass[d]	U-0.322*	U-0.322*	U-0.107	U-0.087	U-0.074	U-0.074	U-0.057	U-0.051	U-0.057	U-0.051	U-0.051	U-0.051	U-0.042	U-0.042	U-0.038	U-0.038
Joist/framing	U-0.066*	U-0.066*	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027
Slab-on-grade floors																
Unheated slabs	F-0.73*	F-0.73*	F-0.73*	F-0.73*	F-0.73*	F-0.54	F-0.52	F-0.52	F-0.52	F-0.51	F-0.51	F-0.434	F-0.51	F-0.434	F-0.434	F-0.424
Heated slabs[f]	F-0.69	F-0.69	F-0.69	F-0.69	F-0.66	F-0.66	F-0.62	F-0.62	F-0.62	F-0.62	F-0.62	F-0.602	F-0.602	F-0.602	F-0.602	F-0.602
Opaque doors																
Nonswinging door	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31
Swinging door[h]	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37	U-0.37
Garage door < 14% glazing[i]	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31	U-0.31

Example applications to follow later

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2024 IECC – New U-factor Requirements

- Section C402.1.2.1.7 Spandrel Panels
  - Table of default U-factors for spandrels to be weighted into opaque wall U-factor for compliance check vs. required maximum wall U-factor for opaque wall
- Section C402.1.2.1.8 Mechanical Equipment Penetrations
  - Require wall U-factor account for heat transfer through mechanical equipment
  - Default U-0.5 (for area of equipment penetration)

~~TABLE C402.1.2.3~~TABLE C402.1.2.1.7
EFFECTIVE U-FACTORS FOR SPANDREL PANELS[a]

Rated R-value of Insulation between Framing Members		R-4	R-7	R-10	R-15	R-20	R-25	R-30
Frame Type	Spandrel Panel	Default U-factor						
Aluminum without Thermal Break[b]	Single glass pane, stone, or metal panel	0.285	0.259	0.247	0.236	0.230	0.226	0.224
	Double glazing with no low-e coatings	0.273	0.254	0.244	0.234	0.229	0.226	0.223
	Triple glazing or double glazing with low-e glass	0.263	0.249	0.241	0.233	0.228	0.225	0.223
Aluminum with Thermal Break[c]	Single glass pane, stone, or metal panel	0.243	0.212	0.197	0.184	0.176	0.172	0.169
	Double glazing with no low-e coatings	0.228	0.205	0.193	0.182	0.175	0.171	0.168
	Triple glazing or double glazing with low-e glass	0.217	0.199	0.189	0.180	0.174	0.170	0.167
Structural Glazing[d]	Single glass pane, stone, or metal panel	0.217	0.180	0.161	0.145	0.136	0.130	0.126
	Double glazing with no low-e coatings	0.199	0.172	0.157	0.143	0.135	0.129	0.126
	Triple glazing or double glazing with low-e glass	0.186	0.165	0.152	0.140	0.133	0.128	0.125
No framing or Insulation is Continuous[e]	Single glass pane, stone, or metal panel	0.160	0.108	0.082	0.058	0.045	0.037	0.031
	Double glazing with no low-e coatings	0.147	0.102	0.078	0.056	0.044	0.036	0.030
	Triple glazing or double glazing with low-e glass	0.139	0.098	0.076	0.055	0.043	0.035	0.030

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Opaque Envelope – U-, C-, F-Factor Method

- **Table C402.1.4 Footnotes:**

  a. Where assembly *U*-factors, *C*-factors and *F*-factors are established in ANSI/ASHRAE/IESNA 90.1 Appendix A, such opaque assemblies shall be a compliance alternative where those values meet the criteria of this table, and provided that the construction, excluding the cladding system on walls, complies with the appropriate construction details from ANSI/ASHRAE/IESNA 90.1 Appendix A.

  b. Where *U*-factors have been established by testing in accordance with ASTM C1363, such opaque assemblies shall be a compliance alternative where those values meet the criteria of this table. The *R*-value of continuous insulation shall be permitted to be added to or subtracted from the original tested design.

  c. Where heated slabs are below grade, below-grade walls shall comply with the *U*-factor requirements for above-grade mass walls.

  d. "Mass floors" shall be in accordance with Section C402.2.3.

  e. These *C*-, *F*- and *U*-factors are based on assemblies that are not required to contain insulation.

  f. The first value is for perimeter insulation and the second value is for full, under-slab insulation.

  g. "Mass walls" shall be in accordance with Section C402.2.2.

  h. Swinging door *U*-factors shall be determined in accordance with NFRC-100.

  i. Garage doors having a single row of fenestration shall have an assembly *U*-factor less than or equal to 0.44 in Climate Zones 0 through 6 and less than or equal to 0.36 in Climate Zones 7 and 8, provided that the fenestration area is not less than 14 percent and not more than 25 percent of the total door area.

LOTS OF FOOTNOTES!

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Opaque Envelope – U-, C-, F-Factor Method

- **Unpack Table C402.1.4 footnote 'a':**
  a. Where assembly U-factors, C-factors and F-factors are established in ANSI/ASHRAE/IESNA 90.1 Appendix A, such opaque assemblies shall be a compliance alternative where those values meet the criteria of this table, and provided that the construction, excluding the cladding system on walls, complies with the appropriate construction details from ANSI/ASHRAE/ISNEA 90.1 Appendix A.
  - ASHRAE 90.1 Appendix A provides tabulated U-, C-, F-factors for various combinations of insulation R-values on different types of assemblies
  - They must still comply with the "assembly descriptions" (i.e., "construction details") in ASHRAE 90.1 Appendix A as noted earlier for use of the R-value method.
  - If not, then an appropriate calculations, modeling, or test data must be provided to establish the U-factor for a given assembly and its method of insulation.
    - See footnote 'b' to Table C402.1.4
- Footnotes are important for compliance and enforcement.

Table A2.3.3 Assembly *U-Factors* for *Metal Building Roofs*

Insulation System	Rated R-Value of Insulation	Overall U-Factor for Entire Base Roof Assembly	Overall U-Factor for Assembly of Base Roof Plus Continuous Insulation (Uninterrupted by Framing)								
			Rated R-Value of Continuous Insulation								
			R-6.5	R-9.8	R-13	R-16.8	R-19	R-22.1	R-25	R-32	R-38
Standing Seam *Roofs* with Thermal Spacer Blocks[a, b]											
Single Layer	None	1.280	0.137	0.095	0.073	0.060	0.051	0.044	0.039	0.031	0.026
	R-10	0.115	0.066	0.054	0.046	0.041	0.036	0.032	0.030	0.025	0.021
	R-11	0.107	0.063	0.052	0.045	0.040	0.035	0.032	0.029	0.024	0.021
	R-13	0.101	0.061	0.051	0.044	0.039	0.035	0.031	0.029	0.024	0.021
	R-16	0.096	0.059	0.049	0.043	0.038	0.034	0.031	0.028	0.024	0.021
	R-19	0.082	0.053	0.045	0.040	0.036	0.032	0.029	0.027	0.023	0.020
Double Layer	R-10 + R-10	0.088	0.056	0.047	0.041	0.037	0.033	0.030	0.028	0.023	0.020
	R-10 + R-11	0.086	0.055	0.047	0.041	0.036	0.033	0.030	0.027	0.023	0.020
	R-11 + R-11	0.085	0.055	0.046	0.040	0.036	0.033	0.030	0.027	0.023	0.020
	R-10 + R-13	0.084	0.054	0.046	0.040	0.036	0.032	0.029	0.027	0.023	0.020
	R-11 + R-13	0.082	0.053	0.045	0.040	0.036	0.032	0.029	0.027	0.023	0.020
	R-13 + R-13	0.075	0.050	0.043	0.038	0.034	0.031	0.028	0.026	0.022	0.019
	R-10 + R-19	0.074	0.050	0.043	0.038	0.034	0.031	0.028	0.026	0.022	0.019
	R-11 + R-19	0.072	0.049	0.042	0.037	0.034	0.030	0.028	0.026	0.022	0.019
	R-13 + R-19	0.068	0.047	0.041	0.036	0.033	0.030	0.027	0.025	0.021	0.019
	R-16 + R-19	0.065	0.046	0.040	0.035	0.032	0.029	0.027	0.025	0.021	0.019
	R-19 + R-19	0.060	0.043	0.038	0.034	0.031	0.028	0.026	0.024	0.021	0.018
Liner System	R-19 + R-11	0.037									
	R-25 + R-8	0.037									
	R-25 + R-11	0.031									
	R-30 + R-11	0.029									
	R-25 + R-11 + R-11	0.026									
Filled Cavity with Thermal Spacer Blocks[c]											
	R-10 + R-19	0.041	0.032	0.029	0.027	0.025	0.023	0.022	0.020	0.018	0.016
	R-19 + R-11	0.037									

Example of metal building roof R-values compliant with U-factor of 0.035 for Climate Zone 5.

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Opaque Envelope – U-, C-, F-Factor Method

- Example wood frame wall U-factor calculation (parallel path method):

Wall Thermal Resistance by Component	2x4 Wall R-13 Batt		
	R-value Studs	R-value Cavity	Assembly Value
Wall - Outside Winter Air Film	0.17		
Siding - Vinyl	0.62		
Continuous Insulation	**0**		
OSB - 7/16"	0.62		
SPF Stud/Cavity Insulation	**4.375**	**13**	
1/2" Drywall	0.45		
Inside Air Film	0.68		
Studs at 16" o.c.	25%	75%	
Total Wall R-values	6.92	15.54	11.8
Total Wall U-factors	0.145	0.064	0.084

Wall Thermal Resistance by Component	2x4 Wall R-13 Batt + R-7.5ci		
	R-value Studs	R-value Cavity	Assembly Value
Wall - Outside Winter Air Film	0.17		
Siding - Vinyl	0.62		
Continuous Insulation	**7.5**		
OSB - 7/16"	0.62		
SPF Stud/Cavity Insulation	**4.375**	**13**	
1/2" Drywall	0.45		
Inside Air Film	0.68		
Studs at 16" o.c.	25%	75%	
Total Wall R-values	14.42	23.04	**20.0**
Total Wall U-factors	0.069	0.043	**0.050**

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Opaque Envelope – U-, C-, F-Factor Method

- Example cold-formed steel frame wall calculation (C402.1.4.2, Eq 4-1):

C402.1.4.2 Thermal resistance of cold-formed steel walls. *U*-factors of walls with cold-formed steel studs shall be permitted to be determined in accordance with Equation 4-1.

$U = 1/[R_s + (ER)]$ **(Equation 4-1)**

where:

R_s = The cumulative *R*-value of the wall components along the path of heat transfer, excluding the *cavity insulation* and steel studs.

ER = The effective *R*-value of the *cavity insulation* with steel studs as specified in Table C402.1.4.2.

TABLE C402.1.4.2
EFFECTIVE R-VALUES FOR STEEL STUD WALL ASSEMBLIES

NOMINAL STUD DEPTH (inches)	SPACING OF FRAMING (inches)	CAVITY R-VALUE (insulation)	CORRECTION FACTOR (F_c)	EFFECTIVE R-VALUE (ER) (Cavity R-Value × F_c)
3½	16	13	0.46	5.98
		15	0.43	6.45
3½	24	13	0.55	7.15
		15	0.52	7.80
6	16	19	0.37	7.03
		21	0.35	7.35
6	24	19	0.45	8.55
		21	0.43	9.03
8	16	25	0.31	7.75
	24	25	0.38	9.50

	3-1/2" Stud 16"oc 13+10ci	6" Stud 16"oc 20+9ci	Any stud size Any spacing 0+15.2ci
Cavity Rated R-value	13	20	0.9
Correction Factor (Fc)	0.46	0.36	1
Core Wall Eff. R-value (ER)	5.98	7.2	0.9
Ci R-value	10	9	15.2
5/8" Gyp (interior)	0.56	0.56	0.56
5/8" Gyp (exerior)	0.56	0.56	0.56
Stucco	0.08	0.08	0.08
Interior air film	0.68	0.68	0.68
Exterior air film	0.17	0.17	0.17
Rs	12.05	11.05	17.25
U-Factor	**0.055**	**0.055**	**0.055**
Effective R-value	**18.0**	**18.3**	**18.2**

NEW 2024: Deletes Eq 4-1 and references AISI S250 standard. But, standard only addresses studs at layout spacing (omits tracks and headers and built-up studs). Significantly underestimates actual wall U-factor. Suggest retaining Eq 4-1 and limit AISI S250 for use on tall curtain walls without framing other than layout studs.

U-factor per Eq 4-1 ≤ U-factor 0.055 required by Table C402.1.4 (OK)

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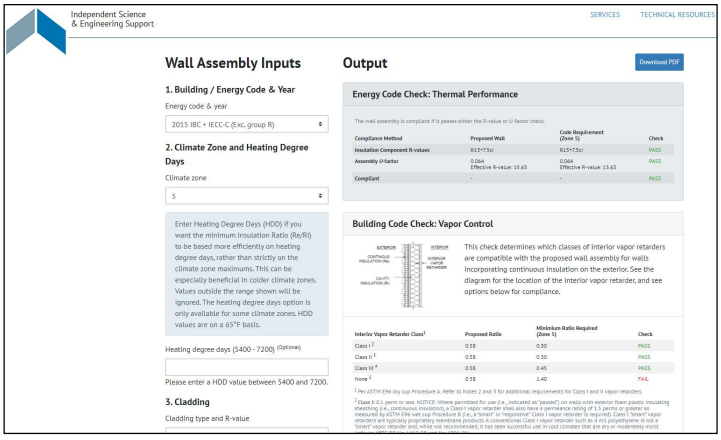
Opaque Envelope – U-, C-, F-Factor Method

- Live demo of on-line wall calculator tool for code compliance
  - www.continuousinsulation.org



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Opaque Envelope – U-, C-, F-Factor Method

- Example slab F-factor from ASHRAE 90.1 Appendix A tables:
  - 2021 IECC Climate Zone 5:
    - R-15 for 24"below or **F-0.52 (unheated slab)**
    - R-15 for 36" below + R-5 full slab or **F-0.62 (heated slab)**

Table A6.3.1-2 Assembly *F-Factors* for Fully Insulated Heated *Slab-on-Grade Floors*

Insulation Description	Rated R-Value of Edge Insulation							
	R-3.5	R-5	R-7.5	R-10	R-15	R-20	R-25	R-30
Heated Slabs								
R-3.5 under slab	0.81	0.78	0.74	0.71	0.69	0.671	0.670	0.669
R-5 under slab	0.77	0.74	0.69	0.66	0.62	0.602	0.602	0.601
R-7.5 under slab	0.71	0.67	0.64	0.60	0.58	0.566	0.564	0.563
R-10 under slab	0.66	0.62	0.58	0.55	0.51	0.496	0.494	0.493
R-15 under slab	0.57	0.54	0.50	0.47	0.45	0.433	0.432	0.431
R-20 under slab	0.51	0.48	0.44	0.41	0.39	0.371	0.370	0.369

Alternate R-values for same F-factor

Table A6.3.1-1 Assembly *F-Factors* for *Slab-on-Grade Floors*

Insulation Description	Rated R-Value of Insulation												
	R-3.5	R-5	R-7.5	R-10	R-15	R-20	R-25	R-30	R-35	R-40	R-45	R-50	R-55
Unheated Slabs													
Uninsulated: 0.73													
12 in. horizontal		0.72	0.71	0.71	0.71								
24 in. horizontal		0.70	0.70	0.70	0.69								
36 in. horizontal		0.68	0.67	0.66	0.66								
48 in. horizontal		0.67	0.65	0.64	0.63								
12 in. vertical		0.61	0.60	0.58	0.57	0.567	0.565	0.564					
24 in. vertical		0.58	0.56	0.54	0.52	0.510	0.505	0.502					
36 in. vertical		0.56	0.53	0.51	0.48	0.472	0.464	0.460					
48 in. vertical		0.54	0.51	0.48	0.45	0.434	0.424	0.419					
Fully insulated slab		0.46	0.41	0.36	0.30	0.261	0.233	0.213	0.198	0.186	0.176	0.168	0.161
Heated Slabs													
Uninsulated: 1.35													
12 in. horizontal		1.31	1.31	1.30	1.30								
24 in. horizontal		1.28	1.27	1.26	1.25								
36 in. horizontal		1.24	1.21	1.20	1.18								
48 in. horizontal		1.20	1.17	1.13	1.11								
12 in. vertical		1.06	1.02	1.00	0.98	0.968	0.964	0.961					
24 in. vertical		0.99	0.95	0.90	0.86	0.843	0.832	0.827					
36 in. vertical		0.95	0.89	0.84	0.79	0.762	0.747	0.740					
48 in. vertical		0.91	0.85	0.78	0.72	0.688	0.671	0.659					
Fully insulated slab		0.74	0.64	0.55	0.44	0.373	0.326	0.296	0.273	0.255	0.239	0.227	0.217
Underslab insulation only	1.06	1.01	0.95	0.90	0.82	0.76							

"vertical" is much better than "horizontal" placement

"fully insulated" gives best (lowest) F-factor for given R-value

NOTE: "Fully insulated slab" has insulation extending to cover the slab edge. If not, it must be considered "Underslab insulation only" with higher F-factor

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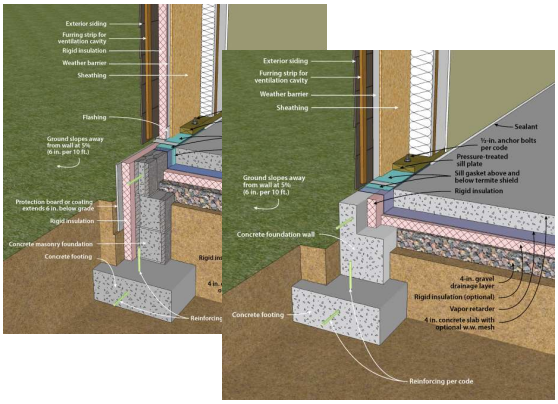
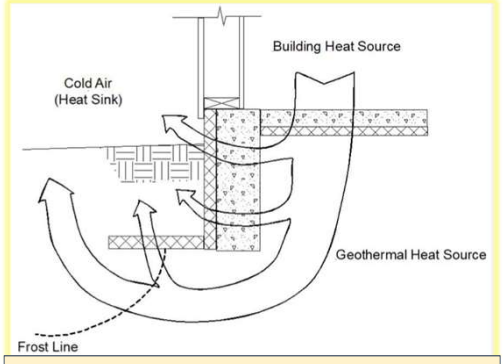
Opaque Envelope – U-, C-, F-Factor Method

- Slab insulation configurations (examples):



https://foundationhandbook.ornl.gov/handbook/



Frost-protected shallow foundation designed to meet energy code and building code frost-protection (IBC 1809.5 & ASCE 32 standard)

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C402.2 Specific BTE insulation requirements

- C402.2.1 Roof Assembly
- C402.2.2 Above-grade walls
- C402.2.3 Floors
- C402.2.4 Slabs-on-grade
- C402.2.5 Below-grade walls
- C402.2.6 Insulation of radiant heating systems
- C402.2.7 Airspaces

NEW 2024: C402.2 charging language revised to explicitly allow an *approved* design as an alternative to any of the specific insulation requirements. But, must demonstrate compliance/equivalency (see Section C102 Alternative Materials, Design and Methods of Construction).

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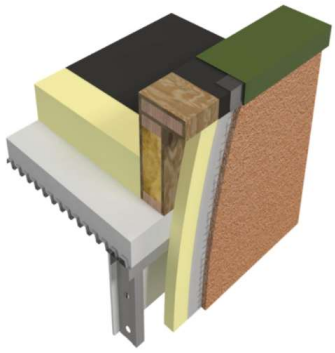
C402.2 Specific BTE insulation requirements

- **C402.2.1 Roof Assembly**
  - Insulation materials (cavity insulation or continuous insulation) shall be as specified in Table C402.1.3 (R-values)
    - Shouldn't these "specific" requirements also apply when determining R-values to comply with maximum U-factors in Table C402.1.4? (YES, see Sections C402.1 and C402.1.4)
  - Must be based on "construction materials" used in the roof assembly
    - This is referring to the assembly descriptions in Tables C402.1.3 and C402.1.4 which ultimate rely on the detailed assembly descriptions in ASHRAE 90.1 Appendix A (see footnote 'a' of Table C402.1.3).



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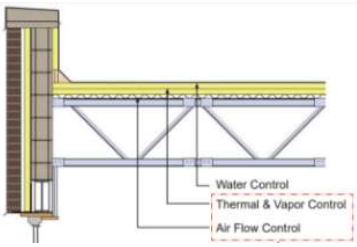
C402.2 Specific BTE insulation requirements

- **C402.2.1 Roof Assembly**
  - Subsections generally apply to roofs with <u>insulation entirely above deck</u>:
    - **C402.2.1.1 Tapered above-deck insulation based on thickness.** Permits use of an average R-value based on the average thickness of tapered insulation (e.g., volume of roof insulation installed divided by the area of the roof).
    - **C402.2.1.2 Minimum thickness, lowest point.** Not less than 1" thick at lowest point of tapered insulation (e.g., at drains or scuppers, gutter edges, etc.)
    - **C402.2.1.3 Suspended ceilings.** Insulation on suspended ceilings with removable tiles installed below an insulated roof deck shall is not counted toward the R-value of the roof assembly. (Air leakage bypasses the ceiling insulation into the plenum or concealed space under the roof deck – at best the ceiling insulation is partially effective).



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C402.2 Specific BTE insulation requirements

- **C402.2.1 Roof Assembly (cont'd)**
  - **C402.2.1.4 Joints staggered.** Continuous insulation boards shall be installed in not less than two layers with joints staggered, except where insulation tapers to a single layer. This is intended to apply to continuous insulation installed above the roof deck and ensures improved resistance to airflow into and within the roof assembly which typically uses the roof covering (membrane) as the "declared" air barrier.
  - **C402.2.1.5 Skylight curbs.** Must be insulated to the "level" of roofs with insulation entirely above deck or R-5, whichever is less. This is intended to insulate the skylight curb up to the transition to the skylight frame to prevent thermal bridging.
    - Exception for unit skylight curbs that are included as part of a skylight listing and labeling (U-factor) per NFRC 100

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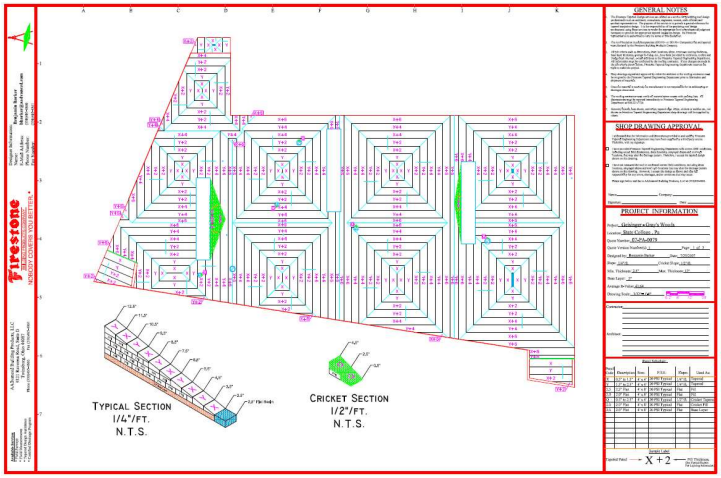
C402.2 Specific BTE insulation requirements

- Often, tapered roof insulation systems are addressed by manufacturer “shop drawings”



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C402.2 Specific BTE insulation requirements

- **C402.2.2 Above-grade walls**
  - R-values for cavity insulation and continuous insulation shall be as specified in Table C402.1.3
    - Unless using U-factor compliance per C402.1.4
  - Masonry integral insulation only permitted for R-value compliance where permitted by Table C402.1.3 (e.g., Climate Zones 0-2 per footnote ‘c’)
    - Integral insulation can be used for U-factor compliance per Table C402.1.4 without restriction

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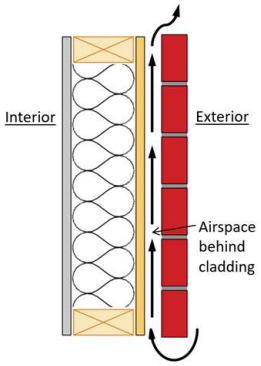
C402.2 Specific BTE insulation requirements

- **C402.2.2 Above-grade walls (cont'd)**
  - A "Mass Wall" can be concrete, masonry, or thick wood/CLT) R-values or U-factors
  - The wall assembly must comply with:
    - Minimum weight requirement:
      - 35 psf of wall area
      - 25 psf of wall area if material density is <= 120 pcf
    - Minimum heat capacity:
      - 7 Btu/ft2-F
      - 5 Btu/ft2-F if material density is <= 120 pcf
  - How do you determine if a "mass wall" is really a "mass wall"?
    - The heat capacity requirements are part of the "assembly description" mentioned earlier and can be found in ASHRAE 90.1 Appendix A.
    - The weight values must be determined based on density and thickness of concrete or, for masonry, block specs plus grout if any.



Is this a mass wall if it is 35 psf with the mass of a vented masonry veneer included?

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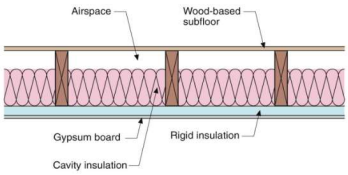
C402.2 Specific BTE insulation requirements

- **C402.2.3 Floors**

C402.2.3 Floors. The thermal properties (component *R*-values or assembly *U*-, *C*- or *F*-factors) of floor assemblies over outdoor air or unconditioned space shall be as specified in Table C402.1.3 or C402.1.4 based on the construction materials used in the floor assembly. Floor framing *cavity insulation* or structural slab insulation shall be installed to maintain permanent contact with the underside of the subfloor decking or structural slabs.

"Mass floors" where used as a component of the thermal envelope of a building shall provide one of the following weights:

1. 35 pounds per square foot (171 kg/m^2) of floor surface area.
2. 25 pounds per square foot (122 kg/m^2) of floor surface area where the material weight is not more than 120 pounds per cubic foot (1923 kg/m^3).



Exceptions:

1. The floor framing *cavity insulation* or structural slab insulation shall be permitted to be in contact with the top side of sheathing or continuous insulation installed on the bottom side of floor assemblies where combined with insulation that meets or exceeds the minimum *R*-value in Table C402.1.3 for "Metal framed" or "Wood framed and other" values for "Walls, above grade" and extends from the bottom to the top of all perimeter floor framing or floor assembly members.
2. Insulation applied to the underside of concrete floor slabs shall be permitted an airspace of not more than 1 inch (25 mm) where it turns up and is in contact with the underside of the floor under walls associated with the *building thermal envelope*.

Photo by Shaunna Mozingo

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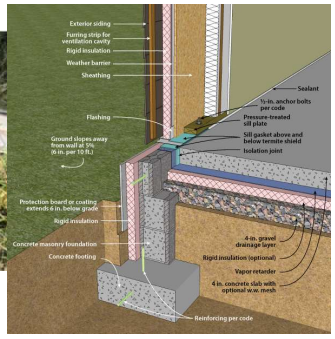
C402.2 Specific BTE insulation requirements

- **C402.2.4 Slabs-on-grade**

C402.2.4 Slabs-on-grade. The minimum thermal resistance (*R*-value) of the insulation for unheated or heated slab-on-grade floors designed in accordance with the *R*-value method of Section C402.1.3 shall be as specified in Table C402.1.3.

Photo by Shaunna Mozingo
(commonly uninsulated slab edge or unprotected if placed on exterior side)



C402.2.4.1 Insulation installation. Where installed, the perimeter insulation shall be placed on the outside of the foundation or on the inside of the foundation wall. The perimeter insulation shall extend downward from the top of the slab for the minimum distance shown in the table or to the top of the footing, whichever is less, or downward to not less than the bottom of the slab and then horizontally to the interior or exterior for the total distance shown in the table. Insulation extending away from the building shall be protected by pavement or by not less than 10 inches (254 mm) of soil. Where installed, full slab insulation shall be continuous under the entire area of the slab-on-grade floor, except at structural column locations and service penetrations. Insulation required at the heated slab perimeter shall not be required to extend below the bottom of the heated slab and shall be continuous with the full slab insulation.

Exception: Where the slab-on-grade floor is greater than 24 inches (61 mm) below the finished exterior grade, perimeter insulation is not required.

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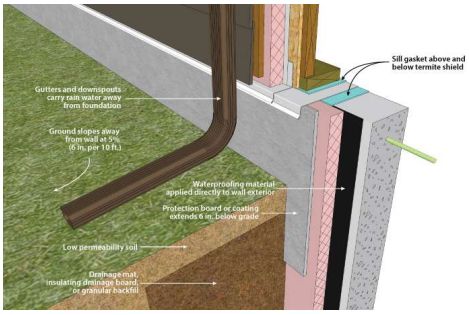
C402.2 Specific BTE insulation requirements

- **C402.2.5 Below-grade walls**

C402.2.5 Below-grade walls. The *C*-factor for the below-grade exterior walls shall be in accordance with Table C402.1.4. The *R*-value of the insulating material installed continuously within or on the below-grade exterior walls of the building envelope shall be in accordance with Table C402.1.3. The *C*-factor or *R*-value required shall extend to a depth of not less than 10 feet (3048 mm) below the outside finished ground level, or to the level of the lowest floor of the conditioned space enclosed by the below-grade wall, whichever is less.



https://foundationhandbook.ornl.gov/handbook/

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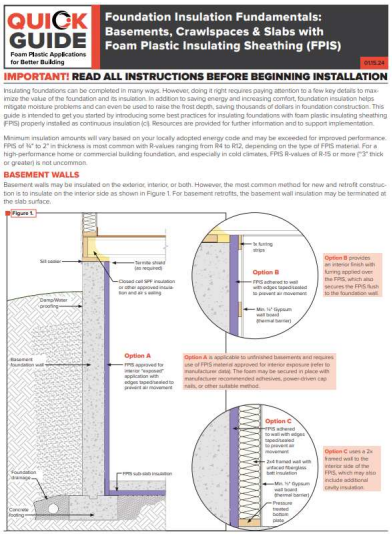
Foundation Insulation Fundamentals


QUICK GUIDE
Foam Plastic Applications for Better Building

Foundation Insulation Fundamentals: Basements, Crawlspaces & Slabs with Foam Plastic Insulating Sheathing (FPIS)

01/5.24

IMPORTANT! READ ALL INSTRUCTIONS BEFORE BEGINNING INSTALLATION

Insulating foundations can be completed in many ways. However, doing it right requires paying attention to a few key details to maximize the value of the foundation and its insulation. In addition to saving energy and increasing comfort, foundation insulation helps mitigate moisture problems and can even be used to raise the frost depth, saving thousands of dollars in foundation construction. This guide is intended to get you started by introducing some best practices for insulating foundations with foam plastic insulating sheathing (FPIS) properly installed as continuous insulation (ci). Resources are provided for further information and to support implementation.

Minimum insulation amounts will vary based on your locally adopted energy code and may be exceeded for improved performance. FPIS of ¾" to 2" in thickness is most common with R-values ranging from R4 to R12, depending on the type of FPIS material. For a high-performance home or commercial building foundation, and especially in cold climates, FPIS R-values of R-15 or more ("3" thick or greater) is not uncommon.

BASEMENT WALLS

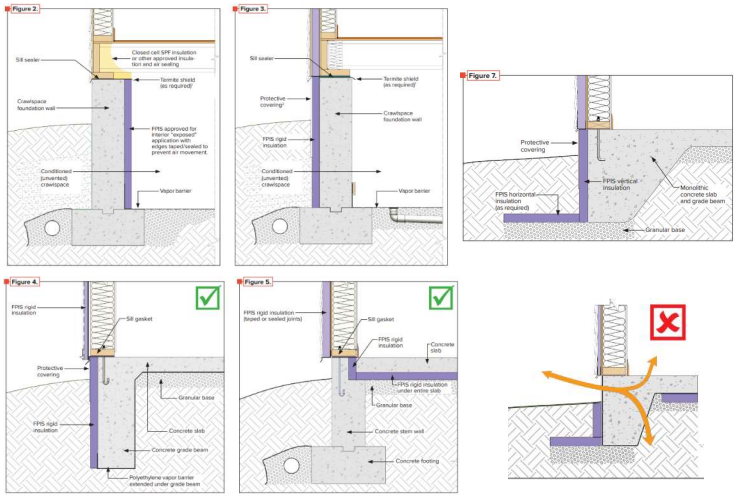
Basement walls may be insulated on the exterior, interior, or both. However, the most common method for new and retrofit construction is to insulate on the interior side as shown in Figure 1. For basement retrofits, the basement wall insulation may be terminated at the slab surface.

Figure 1.

Option A

Option B

Option C



https://www.continuousinsulation.org/resources/quick-guides

C402.2 Specific BTE insulation requirements

- **C402.2.6 Insulation of radiant heating systems**

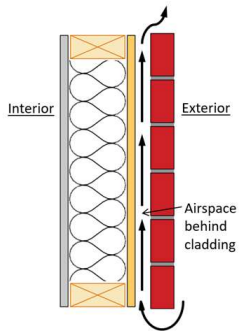
C402.2.6 Insulation of radiant heating systems. *Radiant heating system* panels, and their associated components that are installed in interior or exterior assemblies, shall be insulated to an *R*-value of not less than R-3.5 on all surfaces not facing the space being heated. *Radiant heating system* panels that are installed in the *building thermal envelope* shall be separated from the exterior of the building or unconditioned or exempt spaces by not less than the *R*-value of insulation installed in the opaque assembly in which they are installed or the assembly shall comply with Section C402.1.4.

Exception: Heated slabs on grade insulated in accordance with Section C402.2.4.

C402.2 Specific BTE insulation requirements

C402.2.7 Airspaces. Where the thermal properties of airspaces are used to comply with this code in accordance with Section C401.2, such airspaces shall be enclosed in an unventilated cavity constructed to minimize airflow into and out of the enclosed airspace. Airflow shall be deemed minimized where the enclosed airspace is located on the interior side of the continuous air barrier and is bounded on all sides by building components.

Exception: The thermal resistance of airspaces located on the exterior side of the continuous air barrier and adjacent to and behind the exterior wall-covering material shall be determined in accordance with ASTM C1363 modified with an airflow entering the bottom and exiting the top of the airspace at an air movement rate of not less than 70 mm/second.



NOTE: Exception and figure applies to any vented or air-permeable cladding, not just brick.

NEW 2024: Allowance to count R-value for airspace behind brick veneer with weeps only at base and airspace closed at top.

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C402.2 Specific BTE insulation requirements

- What is the impact of airflow into and out of a non-ideal air space?
  - Air changes per hour can approach 400 ACH or more for vented or ventilated air spaces behind cladding (typical 90 – 150 ACH)
    - Ventilation of cladding for moisture control and drying competes with the ability to use those same air spaces for R-value.
    - ACH varies widely and depends on cladding type, arrangement of vents, vent screens, air-flow pathways, wind speed (point-in-time or annualized), solar heating, etc.
  - This airflow can help lower solar heat gain through southerly-facing facades in the summer, but the same effect reduces apparent R-value of the air-space in the winter for all façade orientations.

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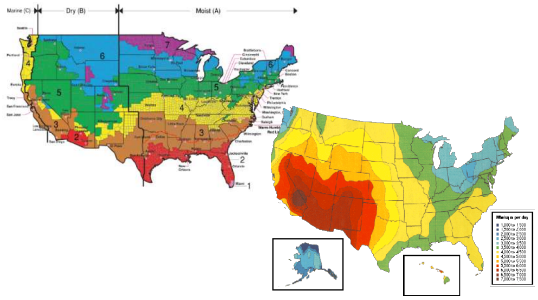
C402.3 Roof solar reflectance and thermal emittance

C402.3 Roof solar reflectance and thermal emittance. Low-sloped roofs directly above cooled conditioned spaces in *Climate Zones* 0 through 3 shall comply with one or more of the options in Table C402.3.

TABLE C402.3
MINIMUM ROOF REFLECTANCE AND EMITTANCE OPTIONS[a]

Three-year-aged solar reflectance index[b] of 55 and 3-year aged thermal emittance[c] of 0.75
Three-year-aged solar reflectance index[d] of 64

a. The use of area-weighted averages to comply with these requirements shall be permitted. Materials lacking 3-year-aged tested values for either solar reflectance or thermal emittance shall be assigned both a 3-year-aged solar reflectance in accordance with Section C402.3.1 and a 3-year-aged thermal emittance of 0.90.
b. Aged solar reflectance tested in accordance with ASTM C1549, ASTM E903 or ASTM E1918 or CRRC-S100.
c. Aged thermal emittance tested in accordance with ASTM C1371 or ASTM E408 or CRRC-S100.
d. Solar reflectance index (SRI) shall be determined in accordance with ASTM E1980 using a convection coefficient of 2.1 Btu/h × ft^2 × °F (12 W/m^2 × K). Calculation of aged SRI shall be based on aged tested values of solar reflectance and thermal emittance.



C402.3.1 Aged roof solar reflectance. Where an aged solar reflectance required by Section C402.3 is not available, it shall be determined in accordance with Equation 4-3.

$$R_{aged} = [0.2 + 0.7(R_{initial} - 0.2)] \quad \textbf{(Equation 4-3)}$$

where:

R_{aged} = The aged solar reflectance.
$R_{initial}$ = The initial solar reflectance determined in accordance with CRRC-S100.

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C402.3 Roof solar reflectance and thermal emittance

- Several exceptions…

NEW 2024: Requirements added for above grade wall solar reflectance for Climate Zone 0.

Exceptions: The following roofs and portions of roofs are exempt from the requirements of Table C402.3:

1. Portions of the roof that include or are covered by the following:
   1.1. Photovoltaic systems or components.
   1.2. Solar air or water-heating systems or components.
   1.3. Vegetative roofs or landscaped roofs.
   1.4. Above-roof decks or walkways.
   1.5. Skylights.
   1.6. HVAC systems and components, and other opaque objects mounted above the roof.
2. Portions of the roof shaded during the peak sun angle on the summer solstice by permanent features of the building or by permanent features of adjacent buildings.
3. Portions of roofs that are ballasted with a minimum stone ballast of 17 pounds per square foot (74 kg/m^2) or 23 psf (117 kg/m^2) pavers.
4. Roofs where not less than 75 percent of the roof area complies with one or more of the exceptions to this section.

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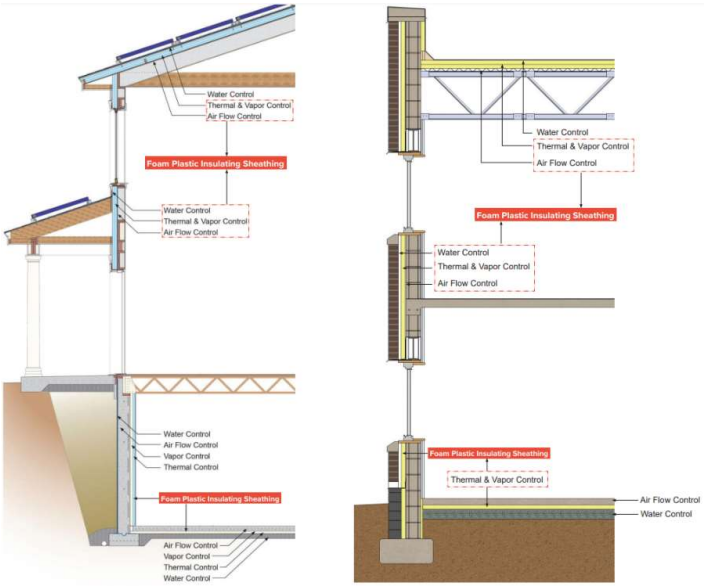
2024 IECC – New Thermal Bridging Requirements

- What?
- Why?
- How?



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What is a thermal bridge?

A thermal bridge is not a burning bridge, although both have something to do with an increased rate of heat transfer or energy loss.

Burning bridge releasing the embodied (stored) energy.
Source: Steve Dadds; as published in azfamily.com by 3TV/CBS 5, posted Aug. 17, 2015.

Thermal imaging illustration of unmitigated framing thermal bridges releasing heating energy (no continuous insulation).

Why address thermal bridges?

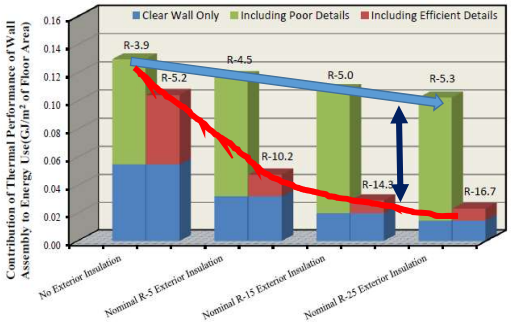


Figure 4.7: Additional building energy use based on thermal performance of the building wall assembly for varying amounts of nominal exterior insulation for a mid-rise MURB in Edmonton (overall assembly thermal resistance in ft²·°F·h/Btu also given)

Source: Morrison Hershfield Ltd

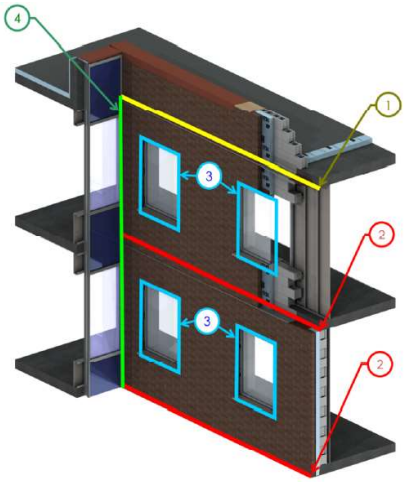
- Unaccounted thermal bridges can result in significantly over-estimated building performance (under-estimated energy use).
- Inaccurate heating and cooling loads for HVAC equipment sizing
- Moisture problems (condensation, corrosion, mold, rot).
- Diminishes the effective R-value of insulation materials (devalues insulation to extent bridged)
- Use of continuous insulation with good detailing to mitigate thermal bridges is key to meeting intended performance.

Types of Thermal Bridges

Clear-field thermal bridge

Linear thermal bridge

Point thermal bridge



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

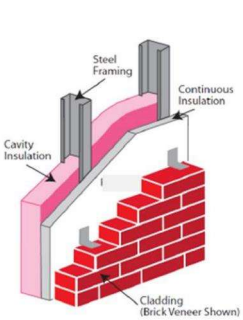
Clear-Field Thermal Bridge

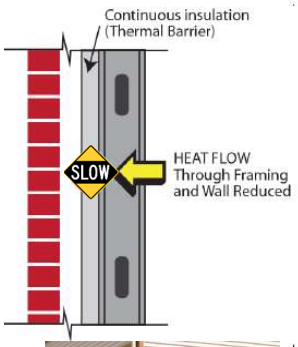
- Thermal bridges distributed over entire area of an opaque BTE assembly that interrupts cavity or integral insulation.
- Addressed in assembly U-factor calculations for code compliance (which prescriptive R-values also are based on).
- U-factor varies with amount of framing ("framing factor")
- Impact:
  - For example, cavity insulation in steel framing is only ~35-50% effective relative to the cavity insulation R-value.
  - Cavity insulation in wood framing is roughly 85% effective.
- Generally, small distributed elements such as fasteners and brick ties are ignored (although the impact on U-factor can range from 2% to 40% depending on wall type, attachment schedule and material properties, insulation configuration, etc.)

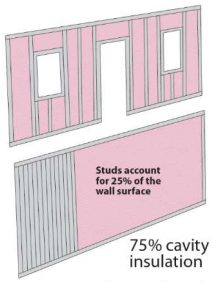
https://www.trufastwalls.com/thermal-grip-masonry-veneer-anchor

Fig1: Solid metal fastening solution

Fig. 2: Version with plastic sleeve and shorter fastener



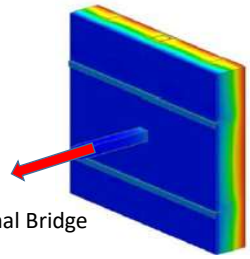




25% studs ("thermal bridges")

2024 IECC Definitions

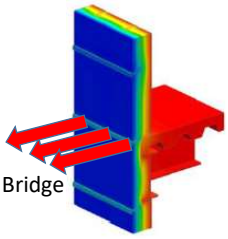
- **THERMAL BRIDGE.** An element or interface of elements that has a higher thermal conductivity than the surrounding *building thermal envelope*, which creates a path of least resistance for heat transfer.
- **CHI-FACTOR (χ-FACTOR).** The heat loss factor for a single thermal bridge characterized as a **point element** of a *building thermal envelope* (Btu/h x °F)[W/K].
- **PSI-FACTOR (ψ-FACTOR).** The heat loss factor per unit length of a thermal bridge characterized as a **linear element** of a *building thermal envelope* (Btu/h × ft × °F)[W/(m × K)].



Point Thermal Bridge

Point Element

Source: Morrison Hershfield LTD
ASHRAE RP 1365



Linear Thermal Bridge

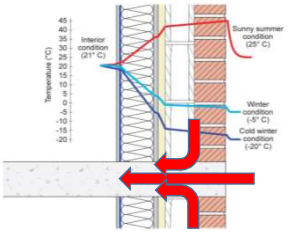
Linear Element

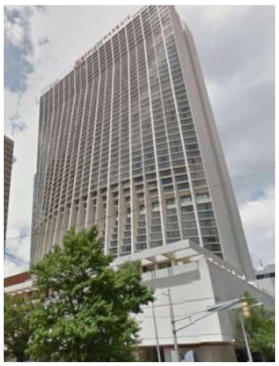
Source: Morrison Hershfield LTD
ASHRAE RP 1365

2024 IECC Construction Documents

- **C105.2 Information on construction documents.**
  1. Energy compliance path.
  2. Insulation materials and their *R*-values.
  3. *Fenestration U*-factors and solar heat gain coefficients (SHGCs).
  4. Area-weighted *U*-factor and solar heat gain coefficient (SHGC) calculations.
  5. *Air barrier* and air sealing details, including the location of the *air barrier* .
  6. Thermal bridges as identified in Section C402.6.

  Etc.





2024 IECC – Prescriptive Thermal Bridging Mitigation (TBM)

- **C402.7 Thermal bridges in above-grade walls** Thermal bridges in above-grade walls shall comply with this section or an *approved* design.
- **Exceptions:**
  1. *Buildings* and structures located in Climate Zones 0 through 3.
  2. Any *thermal bridge* with a material thermal conductivity not greater than 3.0 Btu/h-ft-°F. ← EXCLUDES WOOD AND OTHER "LOW-CONDUCTIVITY" MATERIALS PENETRATING BTE

     (e.g., wood beam or joist penetration, but does not exempt wood framing in building assemblies)
  3. Blocking, coping, flashing, and other similar materials for attachment of roof coverings.
  4. *Thermal bridges* accounted for in the *U*-factor or *C*-factor for a *building thermal envelope*. ← AVOIDS DOUBLE-COUNTING (I.E., FRAMING)

2024 IECC – Prescriptive TBM

- **C402.7.1 Balconies and floor decks** Balconies and concrete floor decks shall not penetrate the *building thermal envelope*. Such assemblies shall be separately supported or shall be supported by structural attachments or elements that minimize thermal bridging through the *building thermal envelope*.
- **Exceptions:** Balconies and concrete floor decks shall be permitted to penetrate the *building thermal envelope* where:
  1. an area-weighted *U*-factor is used for *above-grade wall* compliance which that includes a *U*-factor of 0.8 Btu/h-F-ft^2 for the area of the *above-grade wall* penetrated by the concrete floor deck in accordance with Section C402.1.2.1.5;
  2. an *approved* thermal break device with not less than R-10 insulation material installed in accordance with the manufacturer's instructions ; or,
  3. an *approved* design where the *above-grade wall* U-factor used for compliance accounts for all balcony and concrete floor deck *thermal bridges*.

Cantilevered Balcony Structural Thermal Break

Source: Google search

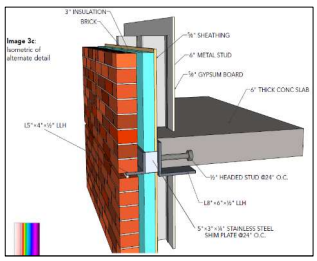
2024 IECC – Prescriptive TBM

- **C402.7.2 Cladding supports** Linear elements supporting opaque cladding shall be off-set from the structure with attachments that allow the continuous insulation, where present, to pass behind the cladding support element except at the point of attachment.

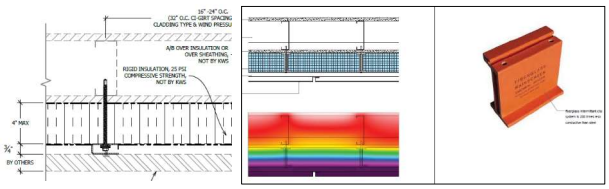
  Exceptions:

  1. An *approved* design where the *above-grade wall U*-factor used for compliance accounts for the cladding support element *thermal bridge*.
  2. Anchoring for *curtain wall* and window wall systems where *curtain wall* and window wall systems comply with C402.7.4.

See IBC Section 2603.12 and .13 for fastening cladding or furring through FPIS ci. Z-furring penetrating through exterior insulation is cavity insulation – doesn't meet continuous insulation definition. See also: https://www.continuousinsulation.org/cladding-connections



OFFSET SHELF ANGLE (AISC/SEI article)



Low thermal conductivity furring/cladding/ledger supports

Sources: Payette/AIA report and product info from Google search

Examples: Offset shelf angle, offset furring with shear tab attachments, cladding/furring fastening through ci, etc.

2024 IECC – Prescriptive TBM

- **C402.7.3 Structural beams and columns** Structural steel and concrete beams and columns that project through the *building thermal envelope* shall be covered with not less than R-5 insulation for not less than 2 feet (610 mm) beyond the interior or exterior surface of an insulation component within the *building thermal envelope*.

  Exceptions:

  1. Where an *approved* thermal break device is installed in accordance with the manufacturer's instructions.

  2. An *approved* design where the *above-grade wall* U-factor used to demonstrate compliance accounts for the beam or column thermal bridge.

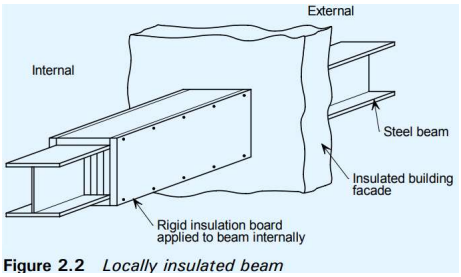
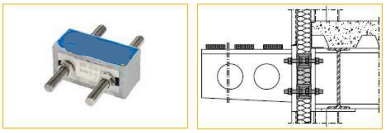


Figure 2.2 *Locally insulated beam*

Photo by Shaunna Mozingo

Avoidance of Thermal Bridging in Steel Construction
https://www.steelconstruction.info/images/5/53/SCI_P380.pdf



Structural thermal block for steel beam projections through building envelope
Source: Google search

2024 IECC – Prescriptive TBM

- **C402.7.4 Vertical fenestration** Vertical *fenestration* intersections with above grade walls shall comply with one or more of the following:

  1. Where above-grade walls include continuous insulation, the plane of the exterior glazing layer or, for metal frame *fenestration* , a non-metal thermal break in the frame shall be positioned within 2 inches (610 mm) of the interior or exterior surface of the continuous insulation.

  2. Where above-grade walls do not include continuous insulation, the plane of the exterior glazing layer or, for metal frame *fenestration* , a non-metal thermal break in the frame shall be positioned within the thickness of the integral or *cavity insulation* .

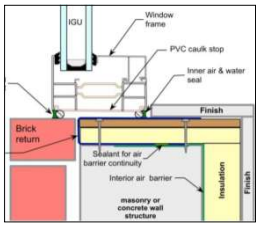
  3. The surface of the rough opening, not covered by the fenestration frame, shall be insulated with insulation of not less than R-3 material or covered with a wood buck that is not less than 1.5 inches (457 mm) thick.

  4. For the intersection between vertical fenestration and opaque spandrel in a shared framing system, manufacturer's data for the spandrel *U*-factor shall account for *thermal bridges*.

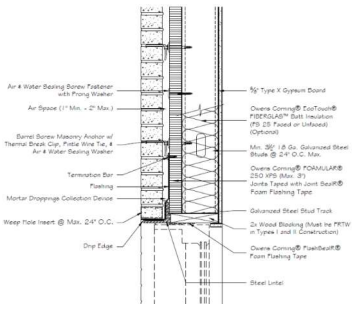
  Exceptions:

  1. Where an *approved* design for the *above-grade wall U*-factor used for compliance accounts for *thermal bridges* at the intersection with the vertical fenestration.

  2. Doors.



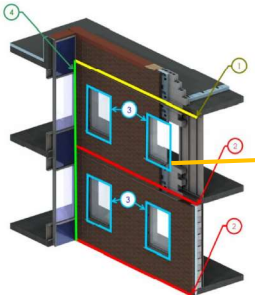
INSULATED WINDOW ROUGH OPENING DETAIL
(USACE report)



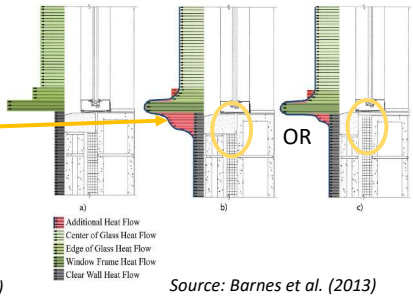
Source: Owens Corning, Enclosure Solutions NFPA 285 Guide, May 2019

Mitigating Thermal Bridging at Fenestration-Wall Interface

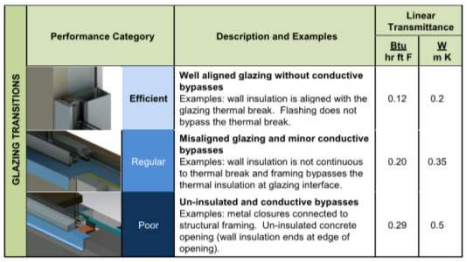
- Linear thermal bridge around perimeter of window opening
  - Not accounted for in window component U-factor
    (NFRC whole assembly U-factor does account for thermal bridging in the window frame, but not the surrounding materials.)
  - Not accounted for in wall clear-field assembly U-factor



Source: Morrison-Hershfield (2020)



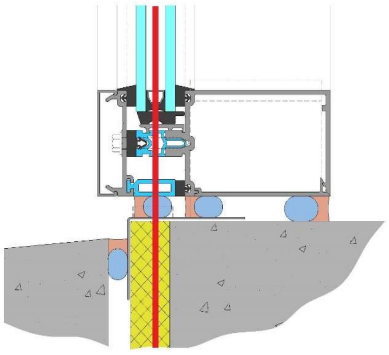
Source: Barnes et al. (2013)



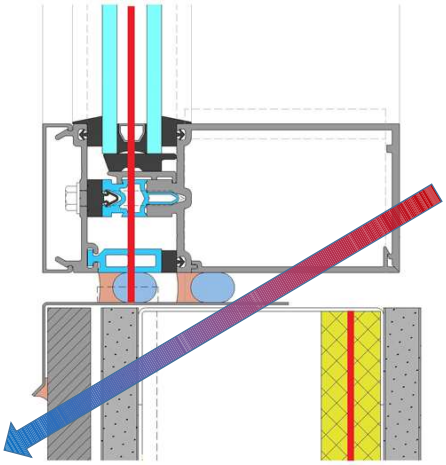
Source: Morrison-Hershfield (2020)

Mitigating Thermal Bridging at Fenestration-Wall Interface

- Design issue - it's all about the alignment
- Control water, air, *and* thermal lines



Efficient: Well aligned glazing without conductive bypasses (thermal line illustrated in red)



Poor: Cavity-insulated and conductive bypasses (thermal line illustrated in red)

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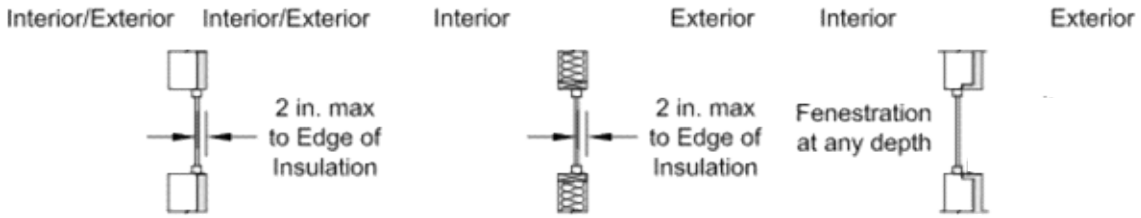
Mitigating Thermal Bridging at Fenestration-Wall Interface

- 2024 IECC and ASHRAE 90.1-2022 requirements
  - Simple approach: align the glazing layer and frame thermal break within 2” of the wall insulation, *OR*
  - Wrap the exposed area between the window frame and the opaque wall insulation with R3 insulation or wood framing member.



- Or can do detailed analysis accounting for the thermal bridging using a calculated psi-factor for the construction detail.

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2024 IECC – Prescriptive TBM

- **C402.7.5 Parapets** Parapets shall comply with one or more of the following as applicable:

  1. Where continuous insulation is installed on the exterior side of the *above-grade wall* and the roof is insulated with insulation entirely above deck, the continuous insulation shall extend up both sides of the parapet not less than 2 feet (610 mm) above the roof covering or to the top of the parapet, whichever is less. Parapets that are an integral part of a fire-resistance rated wall, and the exterior continuous insulation applied to the parapet, shall comply with the fire resistance ratings of the building code.

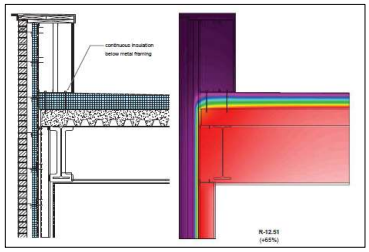
  2. Where continuous insulation is installed on the exterior side of the *above-grade wall* and the roof insulation is below the roof deck, the continuous insulation shall extend up the exterior side of the parapet to not less than the height of the top surface of the *roof assembly* .

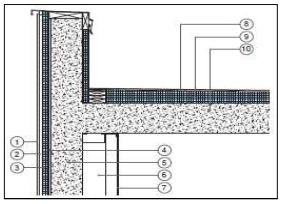
  3. Where continuous insulation is not installed on the exterior side of the *above-grade wall* and the roof is insulated with insulation entirely above deck, the wall cavity or integral insulation shall extend into the parapet up to the exterior face of the roof insulation or equivalent R-value insulation shall be installed not less than 2 feet (610 mm) horizontally inward on the underside of the roof deck.

  4. Where continuous insulation is not installed on the exterior side of the *above-grade wall* and the roof insulation is below the roof deck, the wall and roof insulation components shall be adjacent to each other at the roof-ceiling-wall intersection.

  5. Where a thermal break device with not less than R-10 insulation material aligned with the *above-grade wall* and roof insulation is installed in accordance with the manufacturer's instructions.

Exception: An *approved* design where the *above-grade wall U*-factor used for compliance accounts for the parapet *thermal bridge*.





INSULATED PARAPET DETAILS
(Payette/AIA report)

2024 IECC – Prescriptive TBM (UA trade-off method)

TABLE C402.1.4 - PSI- and CHI-FACTORS TO DETERMINE THERMAL BRIDGES FOR THE COMPONENT PERFORMANCE METHOD

Thermal Bridge per Section C402.7	Thermal Bridge Compliant with Section C402.7		Thermal Bridge Non-Compliant with Section C402.7	
	psi-factor (Btu/h-ft-°F)	chi-factor (Btu/h-~~ft-~~°F)	psi-factor (Btu/h-ft-°F)	chi-factor (Btu/h-~~ft-~~°F)
C402.7.1 Balconies, slabs, and decks	0.2	n/a	0.5	n/a
C402.7.2 Cladding supports	0.2	n/a	0.3	n/a
C402.7.3 Structural beams and columns	n/a	1.0-carbon steel 0.3-concrete	n/a	2.0-carbon steel 1.0-concrete
C402.7.4 Vertical fenestration	0.15	n/a	0.3	n/a
C402.7.5 Parapets	0.2	n/a	0.4	n/a

For SI: W/m-K = 0.578 Btu/h-ft-°F; 1 W/K = 1.90 Btu/h-°F

2024 IECC – Performance (Simulation) Path TBM

TABLE C407.4.1(1) - SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT CHARACTERISTICS	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Walls, above-grade	Type: same as proposed	As proposed
	Gross area: same as proposed	As proposed
	U-factor: as specified in **Table C402.1.2**	As proposed
	Thermal bridges: Account for heat transfer consistent with compliant *psi-* and *chi*-factors from Table C402.1.4 for *thermal bridges* as identified in Section C402.7 that are present in the proposed design.	As proposed; *psi-* and *chi*-factors for proposed *thermal bridges* shall be determined in accordance with requirements in Section C402.1.4.

PART C - Fenestration & Daylighting (C402.4 and related)

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Before we get into the detailed code requirements

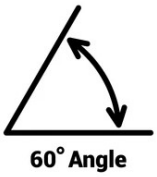
… First, what is fenestration – and what is not – in the IECC?

Fenestration
(Common sense says all windows, doors, skylights, but …)

"Vertical Fenestration" ≥ 60 degrees
Windows
Doors

Opaque Doors
≤ 50% glazed

Glazed Doors
> 50% glazed



"Skylights" < 60 degrees
Unit skylights
TDDs (tubular daylighting devices)
Sloped glazing

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Vertical and Sloped Glazing

Note that **IBC** and **IECC** use different angles!

- **IBC:** overhead glazing **> 15 degrees** from vertical must be laminated or have screens.
- **IECC: < 60 degrees** from horizontal considered a skylight.

This is *vertical fenestration* in the IECC, and a *skylight / sloped glazing* in the IBC.
Actually makes sense because two purposes – energy efficiency & heat flow vs. safety.

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Vertical Fenestration and Spandrel

- Spandrel area is treated as an opaque wall in the energy code.
- Must be insulated according to R-value table, meet opaque wall U-factor, or use trade-off options.

Vertical Fenestration

NOT Vertical Fenestration

Side comment:
Spandrel is not addressed well in the code. U-factors are set for steel-stud walls, and not very realistic for spandrel. Charles Pankow Foundation is sponsoring research to characterize better with DOE assistance.

New: spandrel is a good area to include building-integrated photovoltaics (BIPV)!

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Key Fenestration Criteria and Terminology

- Fenestration area (vertical and skylight)
- U-factor – thermal transmittance
- SHGC – solar heat gain coefficient
- AL - air leakage
- VT - visible transmittance

- Low-e Glass
- Gas fill
- Spacer / warm edge spacer
- Thermally broken frames

We'll talk about both code criteria and how to get / verify these numbers.

Note on units:

- IECC primarily uses IP units for U-factor (Btu / hr ft^2 F) so that's what I'll use.
- If you see European products, to convert U-factor from W/m^2K to Btu / hr ft^2 F, divide by 5.675.
- Also note that Europeans call SHGC the "g-factor".

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Fenestration Terminology - Low-E Coated Glass

Besides computer chips, one of the first widespread uses of nanotechnology …

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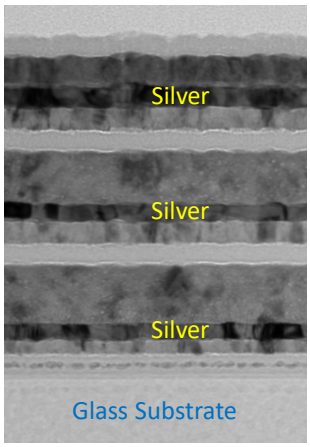
Low-E Glass

- Low Emissivity coatings
  - Transparent, microscopic coating which reflects infrared heat.
  - Reduces building energy usage by reducing radiative heat loss.
  - Reduces overall U-factor (lower U-factor = more insulating)
  - Can be designed to also control solar heat gain.

Triple Silver Low-E Coating



↕ 10 nm = 0.00000001 m

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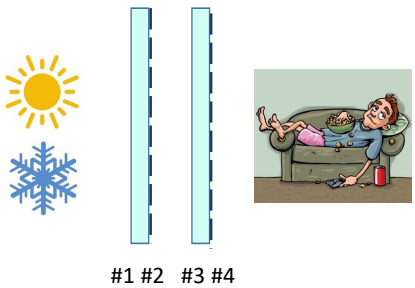
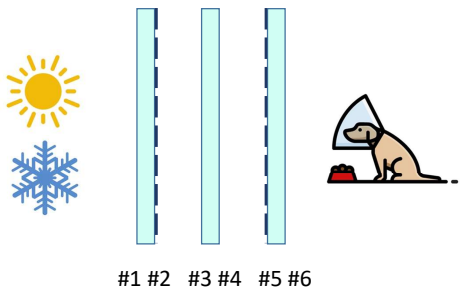
Low-E Glass Surface Numbering

- Doesn't really matter for code verification, but you might see this is submittals or product information.
- Glass surfaces numbered from outside to inside.



Low-e coating usually on #2, or for higher performance, both #2 and #4



Low-e coating on just #2, or both #2 and #5

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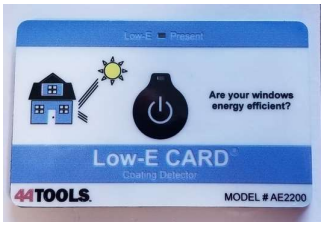
Field Verification

- How can you [illegible] low-e coating?



Easy and cheap
Can identify presence of low-e and which glass surface, although not what type of low-e.

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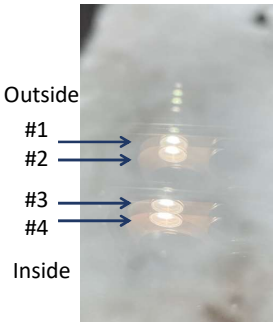
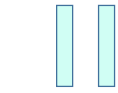
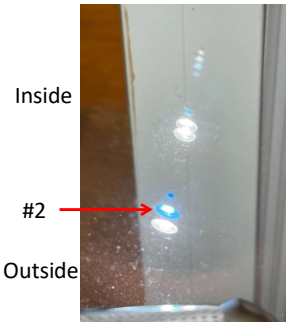
Field Verification

- With smart phone light, can see reflection from each glass surface … look for different color (blue, green, red) to identify low-e coating.

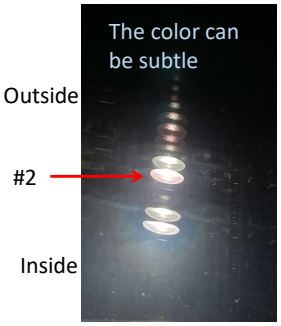


Double Clear



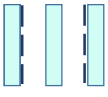


Double pane, low-e #2



Double pane, low-e #2

Triple pane, low-e #2 + #5



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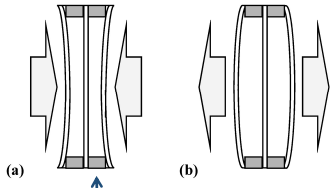
Fenestration Terminology

- Gas fill
  - Using a gas with lower thermal conductivity (argon or krypton) in place of air in the insulating gap between glass.
  - ***For the mountains*** … difference in air pressure from manufacturing to final location can cause some issues. Flexing also happens with normal temperature changes, but adds stress to the edge seal. Fairly common to use breather tubes for high altitude … but then you are limited to air fills.
  - There is also technology called ”pressure-equalized units” where the unit is manufactured with gas-fill for the proper final altitude.
- Spacer – the thing that holds the glass apart.
  - Surprisingly very high tech – multiple layer systems that must insulate, seal, flex, control gas diffusion, and weather for 20+ years.
  - “Warm edge” options reduce the thermal conductivity at the edge compared to metal box spacers.



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Fenestration Terminology – Thermally Broken Frames

- Using a material with lower thermal conductivity to break the heat loss path while still maintaining high structural performance (dead load, wind load, deflection limits over wide spans, durability).
- Thermally improved or thermally separated
  - Smaller separation with nonmetal material < ¼”, more often seen in older or basic curtain wall and storefront.
- Thermally broken
  - Wider separation with nonmetal structural material.
  - Terms you might see: polyamide struts, pour-and-debridge polyurethane, fiberglass, double thermal barriers.
  - Can also be combined with nonmetal pressure plates, wider / more complex shaped thermal breaks.

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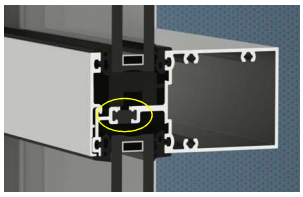
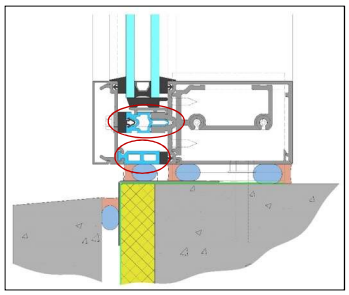
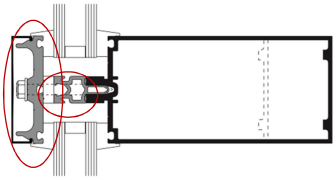
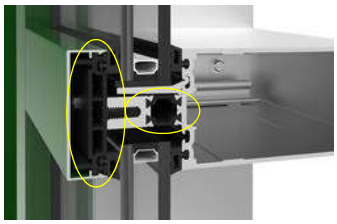
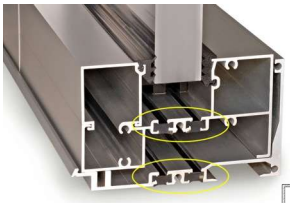
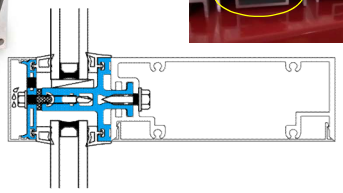
Fully Thermally Broken Frames

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C303.1.3 Fenestration Product Ratings

- All fenestration U-factor, SHGC, VT numbers in the code are for the ***whole assembly*** including both the framing and glazing, *not just center-of-glass only.*
- Depends on glazing, spacer, framing, and product type (e.g. curtain wall, slider, casement, picture window, skylight, glazed door – all different NFRC standard size).
- For example, for IG with center-of-glass U_{cog}-0.24 and $SHGC_{cog}$-0.39 …
  - U in different curtain walls could range from 0.32 to 0.49 depending on specific frame and spacer.
  - U in different operable windows could range from 0.38 to 0.65 depending on frame, spacer, and window type (e.g. slider vs. vent).
  - SHGC will also vary, but whole assembly SHGC will always be lower than center-of-glass SHGC

- *HINT:* If you specifically see U = 0.29 or 0.24, take a second look … these are common *center-of-glass* values for double pane low-e + air and low-e + argon.

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C303.1.3 Ratings for Fenestration Code Compliance

- U, SHGC, VT performance ratings shall be *determined in accordance with NFRC 100 and NFRC 200 by an accredited, independent laboratory.*
  - Doesn't require full NFRC certification, just the NFRC technical procedures and numbers.
  - If don't use NFRC numbers, have to use punitive default values.
  - Garage doors and rolling doors can also use ANSI/DASMA 105.
  - Tubular daylighting devices also use a different metric VT_{annual} from NFRC 203.

- Acceptable Options:

1. NFRC certified ratings (product label or CMA label certificate)
2. AAMA 507 certificate
3. Test report from independent lab as long as done in accordance with NFRC technical procedures
4. Default values – but useless for prescriptive path – only useful for plugging something into the performance path and trading off.

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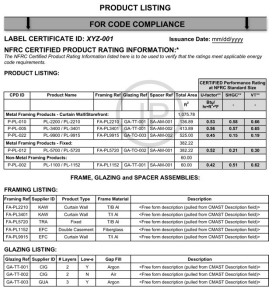
C303.1.3 Ratings for Fenestration Code Compliance

NFRC label

(primarily residential windows)

NFRC label certificate (CMA)



(commercial projects)

- Unfortunately, current NFRC commercial program still not widely used. (Cadmus report found < ½ % of projects use certified ratings.)
- NFRC working on new more streamlined rating method for commercial projects (one certificate for all products on a building) and individual products.

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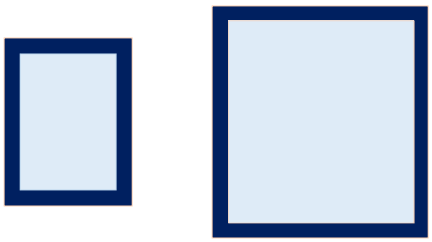
Fenestration Ratings – Size Matters

- Also, real performance will be different than NFRC rating
  - NFRC provides ratings at a ***standard size*** for apples-to-apples product comparisons and code compliance.
  - Product performance at the ***actual size*** will be different because of the different ratio of frame-to-glass.



Same frame, same glass
Different U, SHGC, VT.

For bigger product, actual U will be lower and SHGC higher than NFRC number.

- Use NFRC size for code compliance, but be careful …
  actual size is more accurate for load calculations and actual performance.

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Center of Glass vs. Whole Assembly

Not for code compliance,
but to *roughly* estimate whole product based on center-of-glass:

- Rules of thumb on **VT**
  - Curtain wall, storefront, window wall: lower VT by 10%
  - Sliding window: lower VT by 25-35%
  - Casement: lower VT by 35-45%
- Rules of thumb on **SHGC**
  - Curtain wall, storefront, window wall: lower SHGC by 5-10%
  - Sliding window: lower SHGC by 10-25%
  - Casement: lower SHGC by 10-30%
- *What about a rule of thumb for U-factor?*
  - Sorry. Frame U-factor is very influential and there is too much variation in product types.
  - Code official needs to ask for more info.
    Glazing contractor needs to consult with the frame supplier.

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Main fenestration requirements:
area, daylighting, U, SHGC, air leakage

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C402.4 Fenestration Requirements - Area

Base level prescriptive maximums in C402.4.1:

- Vertical fenestration area ≤ 30% of gross above-grade wall area.
  - Also known as window-to-wall ratio or WWR.
  - Opaque doors and spandrel area count as wall, not fenestration.
  - Below-grade wall area not included.
- Skylight area ≤ 3% of gross roof area.
  - Also known as skylight-to-roof ratio or SRR.
  - Remember that skylights defined as < 60 degrees from horizontal and includes sloped glazing as well as unit skylights.
- This covers most buildings and is the base level, but there are allowances for increased area in both the prescriptive path and performance path …

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Increased Fenestration Area with Daylighting

- Baseline vertical fenestration area and skylight area allowed to be increased if meet minimum daylighting requirements. (C402.4.1.1 and .2)
  - Baseline vertical fenestration area can be increased to 40% in zones 0-6.
  - Baseline skylight area can be increased to 6%.
- Based on energy analyses showing overall energy savings from reduced electrical lighting loads from daylight controls.
- Not part of the energy code, but also tied into studies showing increased occupant health and well-being from access to natural daylight and views.
  - Increased student performance in schools, patient recovery in healthcare, employee productivity and decreased absenteeism in offices.

Increased Fenestration Area with Daylighting

- Daylight responsive controls must be installed in the daylight zones.
- For increased vertical fenestration area,
  - At least 50% of net floor area must be in daylight zones for 1-2 story buildings.
  - At least 25% of net floor area must be in daylight zones for 3+ story buildings.
    (For this section, daylight zones = primary sidelit + toplit daylight zones.)
  - Fenestration VT / SHGC ratio ≥ 1.1
    Solar selective glazing to provide more light than solar heat gain.
- Different daylight area percentages in low vs. high buildings because lower buildings can have more contribution from toplighting as well as sidelighting.
- Remember *net floor area* is the main occupied area, not including corridors, stairways, bathrooms, closets, mechanical rooms.
- As for the *daylight zone area* and *daylight responsive controls* …

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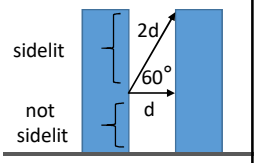
Daylight Zones

- *Daylight zones* and *toplit daylight zones* referred to in envelope section are defined in lighting section along with requirements for *daylight responsive controls*. (C402.4.4 points to C405.2.4)
- To count as a sidelit daylight zone,
  - Need to draw the area adjacent to the windows (next slide).
  - *Not overly small:* fenestration area ≥ 24 ft^2.
  - *Not overly dark:* VT ≥ 0.20
  - *Not overly shaded*
    - By adjacent tall buildings: distance from window to adjacent building or geologic feature is greater than ½ the height from the bottom of the window to the top of the building. Mostly relevant in urban infill.
    - By large projections (e.g. large canopy or porte-cochère): PF not over 1.0 when north-facing, nor over 1.5 for other orientations.

  (Still ok to have the above, just doesn't count as a sidelit daylight zone.)



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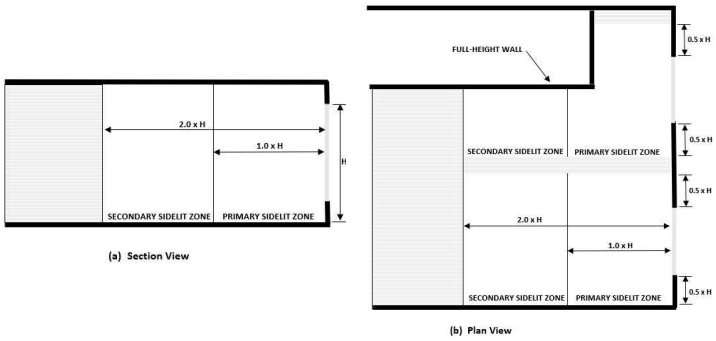
Sidelit Daylight Zones

- *New for 2021 IECC:* Look at both **primary** and **secondary** sidelit zones, based on the depth into the space.



- *Depth* of sidelit zones is distance of 1 or 2 head-heights (primary, secondary) or where hits a wall.
- *Width* of sidelit zones extends on the sides adjacent to the window by ½ head-height, or where hits a wall.

NEW for 2024 IECC:
These thresholds are being cut in half, to 75 W and 150 W.

- Daylight controls required when > 150 W general lighting in primary zone, > 300 W general lighting in primary + secondary zone.
- Secondary zone not considered when determining if can use increased vertical fenestration area in section C402.4.1.1, only primary sidelit + toplit daylight zones.

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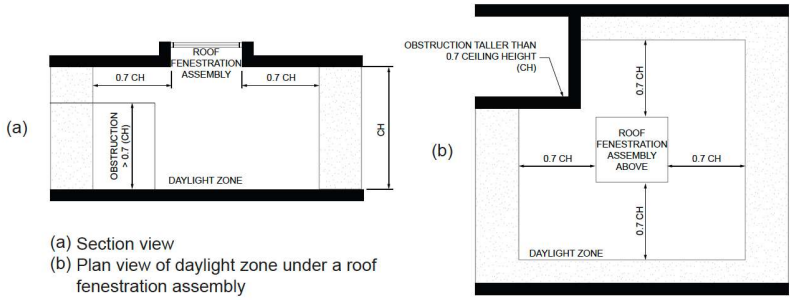
Toplit Daylight Zones

- To count as a toplit daylight zone,
  - Need to draw the area adjacent to the windows (below).
  - *Not overly shaded:* direct sunlight not blocked from hitting the roof fenestration on peak solar angle on summer solstice.
  - *Not overly small or dark:* skylight aperture ≥ 0.008.
    This is skylight VT times the rough opening area / toplit zone area.



(a) Section view
(b) Plan view of daylight zone under a roof fenestration assembly

FIGURE C405.2.4.3
TOPLIT DAYLIGHT ZONE

- Basically extends beyond each side of the skylight by 0.7 x ceiling height, or until hit a wall or obstruction.
- Daylight controls required when > 150 W general lighting in toplit zone.

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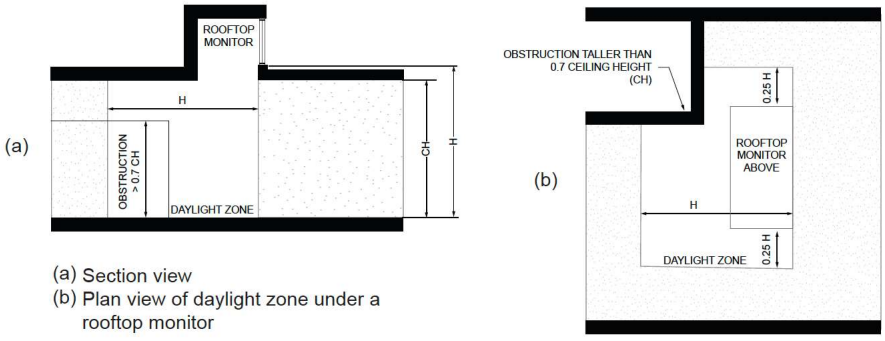
Other Daylight Zones Considerations – Rooftop Monitors

- Daylight zones under rooftop monitors are considered sidelit zones even though coming from above, because related to vertical fenestration.



(a) Section view
(b) Plan view of daylight zone under a rooftop monitor

FIGURE C405.2.4.2(2)
DAYLIGHT ZONE UNDER A ROOFTOP MONITOR

Same for rectangular or sloped rooftop monitors:

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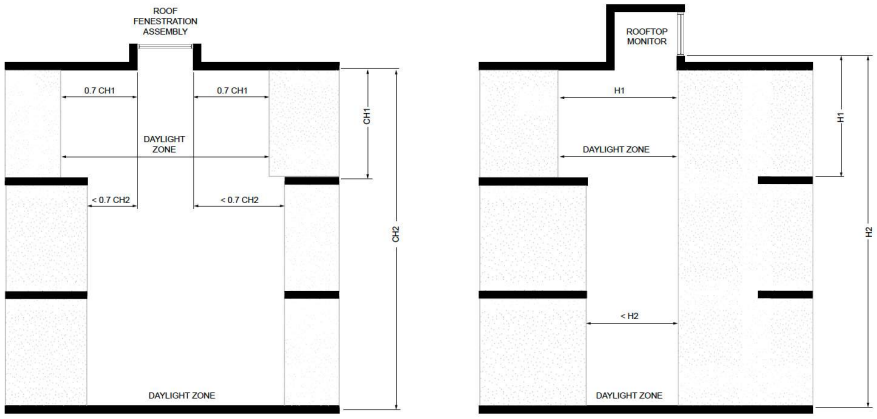
Other Daylight Zones Considerations - Atriums

- New info in 2021 IECC on how to handle multistory atriums based on top and bottom floors (not intermediate floors).



(a) Section view of roof fenestration assembly at atrium

(b) Section view of roof monitor at atrium

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Identification of Daylight Zones on Floor Plans

- New since 2018 IECC: construction documents submitted to code official are supposed to include the location of daylight zones on floor plans. (C103.2)
- This will help both the designer and code official in multiple ways:
  - Encourage the architect / design team to consider daylighting and involve a lighting designer earlier in the process, before the envelope layout is completely locked in.
  - Help determine daylight zone area when needed for C402.4.1.1 or C402.4.2.
  - Help identify which lighting fixtures are in daylight zones, and when daylight responsive controls are required.
    - Simply look at a zone on the floor plans and count up the fixtures. Does it add up to > 150 W in primary, > 300 W in primary + secondary, or > 150 W in toplit zones?
    - Note: C405.2.4 has certain exceptions for patient care, retail, LPA adjustments.

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Daylight Responsive Controls

- Daylight responsive controls in daylight zones must meet certain requirements in C405.2.4.1
  - Lights in primary sidelit, secondary sidelit, and toplit daylight zones must be controlled independently.
  - Be continuous dimming down to 15% with full off.
  - Coordinate with occupancy sensor controls.
  - Readily accessible for calibration.
  - Undergo function testing as part of final commissioning (C408.3)

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Minimum Toplighting in Certain Spaces (C402.4.2)

- Based on overall energy savings, certain spaces with high ceilings are required to have a minimum amount of skylight area with daylight controls.
  - Climate zones 0-5 only.
  - Top floor spaces **> 2500 ft^2** where > 75% of the **ceiling heights are over 15 ft.**
  - Office, lobby, atrium, concourse, corridor, storage space, gymnasium/exercise center, convention center, automotive service area, manufacturing, nonrefrigerated warehouse, retail store, distribution/sorting area, transportation depot, or workshop.
  - Some of the main ones: **grocery stores, big box retail, warehouses, manufacturing, distribution centers.**
- Exceptions for where have low lighting power densities, excessive shading of the roof, use rooftop monitors instead of skylights, use sidelighting with daylight controls, or ICC 500 storm shelters.
- Prescriptive requirement – can be traded off in the performance path.

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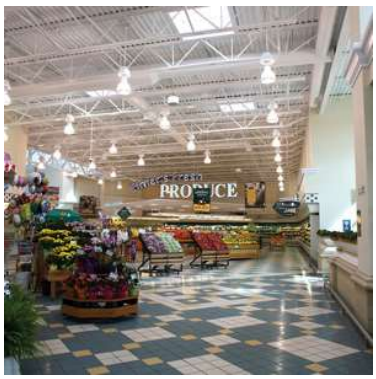
Minimum Toplighting in Spaces with High Ceilings





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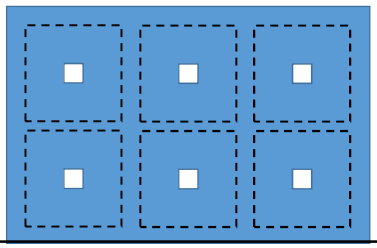
Minimum Toplighting in Certain Spaces (C402.4.2)

- To comply:
  - *Minimum skylight area* – one of two options on next slide.
  - To ensure *distributed properly*, total toplit daylight zones must be ≥ 50% of floor area (can't just be clumped on one side).
  - *Daylight responsive controls* must be used in all toplit daylight zones.
  - Skylights must have *diffusive* glazing material with > 90% haze factor, or use baffles, light well geometry, or other diffusing components to exclude direct sunlight onto the occupied space.

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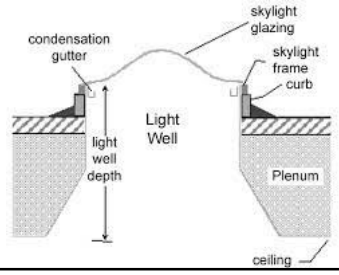
Minimum Toplighting in Certain Spaces (C402.4.2)

- Minimum skylight area as determined by either:
  - a) Skylight area:
    - Ratio of skylight area to toplit daylight zone area > 3%.
    - All skylights must have VT > 0.40 (or VT_{annual} > 0.26 for tubular daylighting devices)
  - b) Skylight effective aperture:

    Skylight effective aperture ≥ 1% for skylights, or ≥ 0.66% for tubular daylighting devices

    $$= \frac{0.85 \times Skylight\ Area \times Skylight\ VT \times Well\ Factor}{Toplit\ Daylight\ Zone\ Area}$$

    - Use VT_{annual} for tubular daylighting devices instead of normal skylight VT.
    - Well factor = 0.9 for light well depth < 2 ft, 0.7 for light well depth ≥ 2 ft, 1.0 for TDDs



What about fenestration areas over the baseline limit?

If a building designer wants to go above the baseline 30% / 40% vertical fenestration area or the 3% / 6% skylight area, three options:

1. Use section C402.1.5 Component Performance Alternative.
   - UA based trade-off that allows alterative U-factors and areas across the entire envelope (walls, roofs, floors, vertical fenestration, skylights).
   - Excess fenestration area above the baseline (30% or 40% vertical and 3% or 6% skylight depending on daylighting) must be compensated elsewhere in the envelope such as higher performance windows, walls, roof.
   - Prescriptive SHGC requirements must still be met.
2. Use the performance path in C407.
   - Demonstrate overall energy equivalency compared to the prescriptive baseline building. Must make up for excess fenestration area over 40%.
3. Use ASHRAE 90.1 Appendix C, Chapter 11, or Appendix G.
   - Demonstrate overall energy equivalency compared to the prescriptive baseline building. Must make up for excess fenestration area over 40%.
   - If choose this option, must use ASHRAE 90.1 in its entirety – can't pick and choose.

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C402.4.3 Fenestration Requirements – U-factor

- Prescriptive maximum U-factor from Table C402.4

2018 IECC

Zone	4	5	6	7
Fixed vertical fenestration	0.38	0.38	0.36	0.29
Operable vertical fenestration	0.45	0.45	0.43	0.37
Glazed Entrance doors	0.77	0.77	0.77	0.77
Skylights	0.50	0.50	0.50	0.50

Note: ASHRAE 90.1-2016 values are little different (higher), especially in zone 7

2021 IECC

Zone	4	5	6	7
Fixed vertical fenestration	0.36	0.36	0.34	0.29
Operable vertical fenestration	0.45	0.45	0.42	0.36
Glazed Entrance doors	0.63	0.63	0.63	0.63
Skylights	0.50	0.50	0.50	0.44

Note: ASHRAE 90.1-2019 values are the same

So what does this mean in terms of real windows?

ROUGHLY What is needed to meet U-factor for 2018 IECC?

- **Zone 4:** Low-e double glazing, thermally broken frame and ***pick 1***:*
- **Zone 5:** Low-e double glazing, thermally broken frame and ***pick 1***:*
- **Zone 6:** Low-e double glazing, thermally broken frame and ***pick 2***:
- **Zone 7:** Low-e double glazing, thermally broken frame and ***pick 4***:

… or more likely, go to triple glazing

* Note: warm edge spacer may not be enough on its own in zones 4-5

Pick list

- argon
- warm edge spacer
- high performance thermal break
- two low-e coatings (#2 / #4)

How about 2021 IECC and 90.1-2019?

- **Zone 4:** Low-e double glazing, thermally broken frame and ***pick 2***:
- **Zone 5:** Low-e double glazing, thermally broken frame and ***pick 2***:
- **Zone 6:** Low-e double glazing, thermally broken frame and ***pick 3***:
- **Zone 7:** Low-e double glazing, thermally broken frame and ***pick 4***:

… or more likely, go to triple glazing

General guideline – do not use for code compliance.

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C402.4.3 Fenestration Requirements – U-factor

NEW for 2024 IECC

Small changes to the max U-factor for fixed fenestration based on new cost effectiveness analysis:

2021 IECC → 2024 IECC

Zone	4	5	6	7
Fixed vertical fenestration	~~0.36~~ → 0.34	~~0.36~~ → 0.34	0.34	~~0.29~~ → 0.28
Operable vertical fenestration	0.45	0.45	0.42	0.36
Glazed Entrance doors	0.63	0.63	0.63	0.63
Skylights	0.50	0.50	0.50	0.44

Note: ASHRAE 90.1-2022 values remain the same as 2021 IECC, but are being updated

- **Zone 4-6:** Low-e double glazing, thermally broken frame and ***pick 3***:
  - argon
  - warm edge spacer
  - high performance thermal break
  - two low-e coatings (#2 / #4)
- **Zone 7:** Low-e double glazing, thermally broken frame and ***pick 4***:
  … or more likely, go to triple glazing

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C402.4.3 Fenestration Requirements – SHGC

Main SHGC requirement over time:

Climate Zone	0	1	2	3	4	5	6	7	8	
SHGC		0.25	0.25	0.25	**0.40**	**0.40**	**0.40**	**0.45**	0.45	90.1-2007 2009 IECC 90.1-2010 2012 IECC 90.1-2013 2015 IECC
	0.22	0.25	0.25	0.25	**0.36**	**0.38**	**0.40**	**0.45**	0.45	90.1-2016 2018 IECC
Fixed:	0.22	0.23	0.25	0.25	**0.36**	**0.38**	**0.38**	**0.40**	0.40	90.1-2019 2021 IECC
Operable:	0.20	0.21	0.23	0.23	**0.33**	**0.33**	**0.34**	**0.36**	0.36	90.1-2022 2024 IECC

- These are the main SHGC requirements for the overall building, but there are variations based on *exterior shading*, *orientation*, and *product type*.
- Both IECC and 90.1 give credit towards SHGC for exterior shading from overhangs, eaves, and sun shades based on *projection factor* (PF).
  - IECC directly lists required SHGC for given PF
  - 90.1 uses multipliers for effective SHGC

PF = A/B

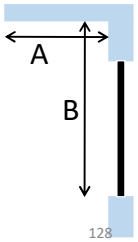

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Table C402.4 Prescriptive SHGC – 2018 IECC

2018 IECC

	Zone 4		Zone 5		Zone 6		Zone 7	
Orientation:	SEW	N	SEW	N	SEW	N	SEW	N
PF < 0.2	**0.36**	0.48	**0.38**	0.51	**0.40**	0.53	**0.45**	NR
0.2 ≤ PF < 0.5	0.43	0.53	0.46	0.56	0.48	0.58	NR	NR
PF ≥ 0.5	0.58	0.58	0.61	0.61	0.64	0.64	NR	NR
Skylights:	0.40		0.40		0.40		NR	

- Look up required max SHGC based on PF and orientation.
- Higher allowance for north side vs. south/east/west.
- Or easy button is just to have all comply with lowest number (in bold).

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Table C402.4 Prescriptive SHGC – 2021 IECC

2021 IECC and 2024 IECC

	Zone 4		Zone 5		Zone 6		Zone 7	
	Fixed	Oper	Fixed	Oper	Fixed	Oper	Fixed	Oper
PF < 0.2	0.36	0.33	0.38	0.33	0.38	0.34	0.40	0.36
0.2 ≤ PF < 0.5	0.43	0.40	0.46	0.40	0.46	0.41	0.48	0.43
PF ≥ 0.5	0.58	0.53	0.61	0.53	0.61	0.54	0.64	0.58
Skylights:	0.40		0.40		0.40		NR	

- ***New** in 2021 IECC:* for vertical fenestration, SHGC by orientation was removed and replaced with separate SHGC for fixed vs. operable products, similar to U-factor. Also in 90.1-2019, and will stay same in 2024 IECC
- In reality, changes are small, as both require the *same glazing type* – it is just accounting for the higher frame-to-glass ratio in operable products.
- Honestly, SHGC is a bigger issue in the southern zones – for Colorado, this mainly just uses regular double silver low-e glazing for SHGC, although higher SHGC low-e can be used with shading. Has more impact on performance path credit than prescriptively.

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C402.4.3 Fenestration Requirements – U and SHGC Exceptions

- Allowances:
  - **Vertical fenestration SHGC with shading:** higher SHGC allowed with exterior shading over vertical fenestration - already discussed.
  - **Skylights used with daylighting:** for skylights used in spaces with daylight responsive controls, U-factor allowed to be increased to 0.75 and SHGC allowed to be increased to 0.60 (or NR in zone 7).

    Common for plastic dome skylights used in grocery stores and big box retail.

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C402.4.3 Fenestration Requirements – U and SHGC Exceptions

- Allowances:
  - **Dynamic glazing:** Dynamic glazing allows SHGC and VT to be changed throughout the day and season to optimize energy efficiency, peak loads, and daylighting/glare.

  - SHGC can vary from 0.10 to 0.50 … what do you use for code compliance?
  - Deemed to comply if the dynamic ratio of high to low SHGC ≥ 2.4. Must be automatically controlled in multiple steps and considered separately from other fenestration.

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C402.4.5 Doors

Remember: ≤ 50% glazed = opaque door
> 50% glazed = vertical fenestration

- Opaque doors comply with opaque table C402.1.4

  - Swinging doors: U-0.37
  - Nonswinging doors: U-0.31 except …
  - Sectional garage doors with one row of glazing (14-25% of door area): U-0.44 in zones 4-6, U-0.36 in zone 7.
  - Remember garage doors can use ANSI/DASMA 105 instead of NFRC 100.
  - Also, only applies if they are part of the building thermal envelope in conditioned space.
- Glazed doors comply with vertical fenestration requirements in Table C402.4.

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C402.5.4 Air Leakage of Fenestration

- Mandatory unless show compliance by whole building air leakage testing.

Product Type	Max Leakage	Min Test Pressure	Test Method
Windows, skylights, sliding glass doors, swinging doors	0.2 cfm/ft2 or 0.3 cfm/ft2	1.57 psf or 6.24 psf	AAMA/WDMA/CSA 101/I.S.2/A440 or NFRC 400
Curtain wall / Storefront	0.06 cfm/ft2	1.57 psf	ASTM E283 or NFRC 400
Commercial swinging entrance doors, revolving doors, power operated sliding doors	1.0 cfm/ft2	1.57 psf	ASTM E283 or NFRC 400

- Usually won't see labels. Most common to see test reports or product literature showing AAMA/WDMA/CSA 101/I.S.2/A440 or ASTM E283 test result. NFRC 400 hardly ever used for commercial.

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Other fenestration considerations:
- additions, alterations, repairs
- credit for new technologies

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Chapter 5 - Fenestration in repairs, alterations, additions

- *Glass-only replacements* are considered repairs (C504.2)
  - Don't have to meet the current energy code
  - Do have to meet safety glazing requirements if in hazardous location defined by the IBC / IRC.
- *Full window or sash replacement* and other *new fenestration* must meet prescriptive requirements same as new. (C502.1, C503.2)
- Added *storm windows, interior panels, commercial secondary windows* installed over existing windows are exempted because improving the efficiency. (C503.1) Preferably low-e!

  Note → These are a valuable new tool for improving existing buildings, especially with the coming new Building Performance Standards!
- When *replacing doors*, do not have to add a vestibule or revolving door, but can't remove existing one either. (C504.2)
- When adding new *fenestration area* in addition or alteration, either comply with area limits for whole building, addition / alteration alone, or use envelope trade-off in C402.1.5 or performance path. (C502.3, C503.2)
  - In alterations where not changing fenestration area, use same area in baseline for performance path – area treated neutrally, and do not have to remove windows. (C503.2.2)

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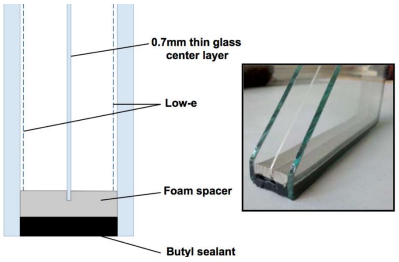
New fenestration technologies you may see

- Higher performance products and new technologies can get credit in:
  - C402.1.5 envelope component performance alternative (lower U)
  - C406 additional efficiency points (lower U, on-site renewable energy)
  - C407 performance path (lower U, optimized SHGC, shading, daylighting, dynamic performance, 5% on-site renewable energy)

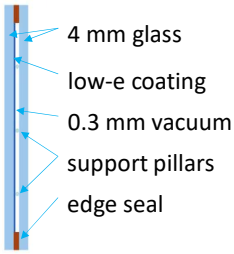
Thin triples with krypton

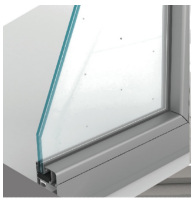
Possible solution for less expensive, lighter triple glazing. Uc ~ 0.12



Vacuum Insulated Glass

Uc ≈ 0.10 compared to typical Uc 0.24 in double glazing low-e argon





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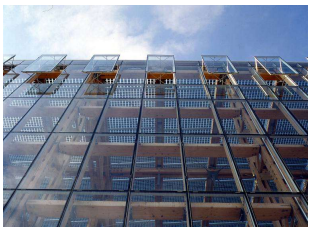
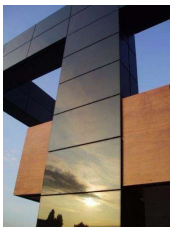
New fenestration technologies you may see

- BIPV (Building Integrated Photovoltaics) in overhead glazing, vision glazing, opaque spandrel, sun shades

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PART D – The Rest of the Story

- Component Performance Alternative (C402.1.5)
- Air leakage (C402.5)
- Additional Efficiency Requirements / "Credits" (C406)
- Total Building Performance (C407)

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C402.1.5 Component Performance Alternative

"Envelope Trade-off Method"

C402.1.5 Component performance alternative. Building envelope values and fenestration areas determined in accordance with Equation 4-2 shall be an alternative to compliance with the *U*-, *F*- and *C*-factors in Tables C402.1.4 and C402.4 and the maximum allowable fenestration areas in Section C402.4.1. *Fenestration* shall meet the applicable SHGC requirements of Section C402.4.3.

$A + B + C + D + E \leq Zero$ **(Equation 4-2)**

NEW 2024: Equation and terms clarified and "T" added to address new thermal bridging requirements in Section C402.7. Default Psi- and Chi-factors also provided in new Table C402.1.5

- This provides a simplified "math" approach to allow for trade-offs
- Baseline performance is defined by maximum U-, F-, C-factor requirements in Table C402.1.4 (opaque assemblies) and Table C402.4 (glazing).
- Some assemblies or components increase, others must decrease in an offsetting fashion
- COMcheck provides an "equivalent" approach
  - But is based on modeling to evaluate the trades, not just based on simple heat conduction through assemblies and components as represented by U-, F-, and C-factors
  - Hence the answers can be somewhat different than found by Eq 4-2.

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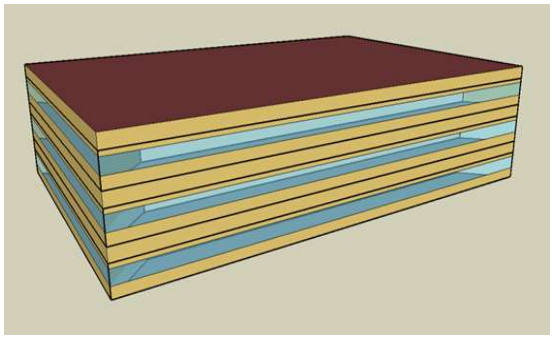
C402.1.5 Component Performance Alternative

- **Simple Office Building Example:**
- 53,600 sqft
- 3 story
- 30% fenestration (C402.4.1 prescriptive limit % gross wall area)
- 164 ft x 109 ft
- 13 ft story height



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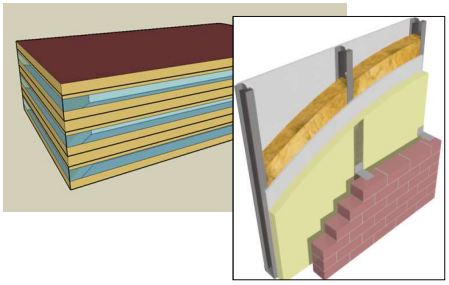
C402.1.5 Component Performance Alternative



A = Sum of the (UA Dif) values for each distinct assembly type of the *building thermal envelope*, other than slabs on grade and below-grade walls.

UA Dif = UA Proposed – UA Table.

UA Proposed = Proposed *U*-value × Area.

UA Table = (*U*-factor from Table C402.1.3, C402.1.4 or C402.4) × Area.

- Determine "UA Dif" for Walls:
- Opaque Wall Area = 15,014 sqft
- U-factor Table = 0.055 (same as R13+10ci)
- U-factor Proposed = 0.064 (R13+7.5ci)
- UA Dif = (0.064)(15,014 sqft) - (0.055)(15,014 sqft) = **135**
  - "0" means exactly equals code prescription for this BTE assembly
  - "-" means lower U-factor than code prescribes (better than code) for this assembly type
  - "+" means higher U-factor than code prescribes (worse than code) for this assembly type

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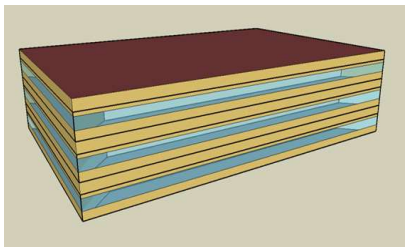
C402.1.5 Component Performance Alternative



A = Sum of the (UA Dif) values for each distinct assembly type of the *building thermal envelope*, other than slabs on grade and below-grade walls.
UA Dif = UA Proposed – UA Table.
UA Proposed = Proposed *U*-value × Area.
UA Table = (*U*-factor from Table C402.1.3, C402.1.4 or C402.4) × Area.

- Determine "UA Dif" for Fenestration:
- Vertical fenestration area = 6,435 sqft
- 6,267 sqft fixed windows, 168 sqft glazed entrance doors, no skylights
- U-factor Table = 0.36 fix windows, 0.63 entrance doors
- U-factor Proposed = 0.34 fixed windows, 0.77 entrance doors
- UA Dif = (0.34-0.36)(6267) + (0.77-0.63)(168) = **-101.8**

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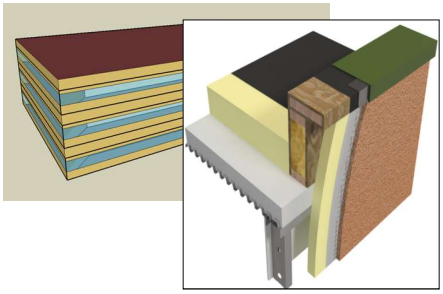
C402.1.5 Component Performance Alternative



A = Sum of the (UA Dif) values for each distinct assembly type of the *building thermal envelope*, other than slabs on grade and below-grade walls.
UA Dif = UA Proposed – UA Table.
UA Proposed = Proposed *U*-value × Area.
UA Table = (*U*-factor from Table C402.1.3, C402.1.4 or C402.4) × Area.

- Determine UA Dif for Roof:
- Opaque Roof Area = 17,887 sqft
- U-factor Table = 0.032 (R-30ci)
- U-factor Proposed = 0.032 (R-30ci)
- UA Dif = (0.032)(17,887) – (0.032)(17,887) = 0

- Determine "A" for all assembly areas:
- A = UA Dif walls + UA Dif roof
- A = 135 + (-101.8) + (0) = **33.2**

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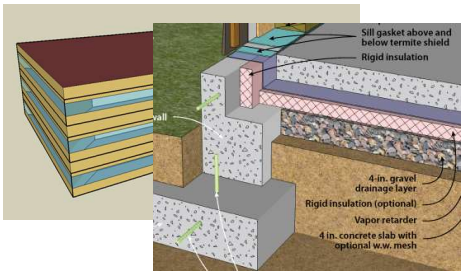
C402.1.5 Component Performance Alternative



B = Sum of the (FL Dif) values for each distinct slab-on-grade perimeter condition of the *building thermal envelope*.

FL Dif = FL Proposed – FL Table.

FL Proposed = Proposed *F*-value × Perimeter length.

FL Table = (*F*-factor specified in Table C402.1.4) × Perimeter length.

- Determine "B" for slab-on-grade
- Foundation perimeter length = 2(164 ft) + 2(109 ft) = 546 ft
- F-factor Table = 0.52 (R-15, 24")
- F-factor Proposed = 0.36 (R-10, fully insulated)
- FL Dif = 0.36(546 ft) – 0.52(546 ft) = -87.4
- B = **-87.4**

RECOMMENDATION: For more accurate F-factors for use with UA trades, refer to new Appendix RF in 2024 IECC-R. Not an issue if using COMcheck.

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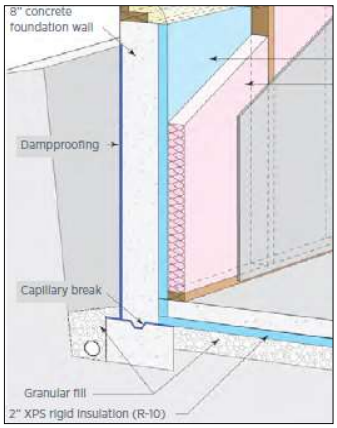
C402.1.5 Component Performance Alternative



- Determine "C" for below-grade walls
  - No below-grade walls
  - **C = 0**

C = Sum of the (CA Dif) values for each distinct *below-grade wall* assembly type of the *building thermal envelope*.

CA Dif = CA Proposed – CA Table.

CA Proposed = Proposed *C*-value × Area.

CA Table = (Maximum allowable *C*-factor specified in Table C402.1.4) × Area.

RECOMMENDATION: For more accurate "effective" U-factors of below-grade walls (adjusted for depth above/below grade), use new 2024 IECC-R Appendix RF. Not an issue if using COMcheck.

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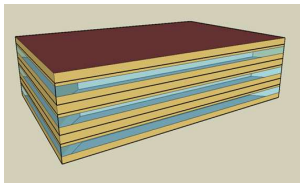
C402.1.5 Component Performance Alternative



Where the proposed vertical glazing area is less than or equal to the maximum vertical glazing area allowed by Section C402.4.1, the value of D (Excess Vertical Glazing Value) shall be zero. Otherwise:

D = (DA × UV) – (DA × U Wall), but not less than zero.

DA = (Proposed Vertical Glazing Area) – (Vertical Glazing Area allowed by Section C402.4.1).

UA Wall = Sum of the (UA Proposed) values for each opaque assembly of the exterior wall.

U Wall = Area-weighted average *U*-value of all above-grade wall assemblies.

UAV = Sum of the (UA Proposed) values for each vertical glazing assembly.

UV = UAV/total vertical glazing area.

- Determine "D" for excess vertical fenestration
  - Fenestration/Glazing Area = 6,280 sqft
  - Glazing Area is 30%
  - Glazing area is less than or equal to the vertical glazing area allowed by Section C402.4.1
  - Therefore, **D = 0**
- We'll do an example later with excess vertical glazing (D > 0)

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C402.1.5 Component Performance Alternative

Where the proposed skylight area is less than or equal to the skylight area allowed by Section C402.4.1, the value of E (Excess Skylight Value) shall be zero. Otherwise:

E = (EA × US) – (EA × U Roof), but not less than zero.

EA = (Proposed Skylight Area) – (Allowable Skylight Area as specified in Section C402.4.1).

U Roof = Area-weighted average *U*-value of all roof assemblies.

UAS = Sum of the (UA Proposed) values for each skylight assembly.

US = UAS/total skylight area.

- Determine "E" for skylights
  - No skylights (or < 3% of roof area)
  - E = 0

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C402.1.5 Component Performance Alternative

- Now, solve Equation 4-2:
  - A = 33.2 R13+7.5ci walls, U-0.34 fixed windows, U-0.77 entrance door, & R-30ci roof insulation entirely above deck
  - B = -87.4 R-10ci, fully insulated slab
  - C = 0 No below grade walls
  - D = 0 Windows < 30% gross wall area and SHGC complies
  - E = 0 No skylights
- A+B+C+D+E = -54.2 ≤ 0
  - OK (better than code minimum)

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C402.1.5 Component Performance Alternative

- COMcheck of same building
  - But with all assemblies exactly complying with prescriptive R-values / U-factors for 2021 IECC
- COMcheck report was done for 2018 IECC

COMcheck Software Version COMcheckWeb

Envelope Compliance Certificate

Project Information

Energy Code:	2018 IECC
Project Title:	DOE Medium Office Building
Location:	Loveland, Colorado
Climate Zone:	5b
Project Type:	New Construction
Vertical Glazing / Wall Area:	30%

Construction Site: Owner/Agent: Designer/Contractor:

Additional Efficiency Package(s)
Credits: 1.0 Required 1.0 Proposed
Dedicated Outdoor Air System, 1.0 credit

Building Area	Floor Area
1-Office : Nonresidential	53660

Envelope PASSES: Design 6% better than code

Envelope Compliance Statement

Compliance Statement: The proposed envelope design represented in this document is consistent with the building plans, specifications, and other calculations submitted with this permit application. The proposed envelope systems have been designed to meet the 2018 IECC requirements in COM*check* Version COMcheckWeb and to comply with any applicable mandatory requirements listed in the Inspection Checklist.

Name - Title Signature Date

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C402.1.5 Component Performance Alternative

Proposed U-factors and F-factors are 2021 code prescriptive values in all cases (no trades)

For this building and climate zone, COMcheck shows 2021 IECC total UA is 6% better (lower) than the 2018 IECC

Envelope Assemblies

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Roof: Insulation Entirely Above Deck, [Bldg. Use 1 - Office]	17887	---	30.0	0.032	0.032
Floor: Unheated Slab-On-Grade, Vertical 2 ft., [Bldg. Use 1 - Office] (c)	546	---	15.0	0.520	0.540
NORTH					
Ext. Wall: Steel-Framed, 16in. o.c., [Bldg. Use 1 - Office]	6388	13.0	10.0	0.055	0.064
Window: Metal Frame with Thermal Break: Fixed, Perf. Specs.: Product ID Typical fix metal, SHGC 0.38, [Bldg. Use 1 - Office] (b)	1884	---	---	0.360	0.380
EAST					
Ext. Wall: Steel-Framed, 16in. o.c., [Bldg. Use 1 - Office]	4259	13.0	10.0	0.055	0.064
Window: Metal Frame with Thermal Break: Fixed, Perf. Specs.: Product ID Typical fix metal, SHGC 0.38, [Bldg. Use 1 - Office] (b)	1256	---	---	0.360	0.380
SOUTH					
Ext. Wall: Steel-Framed, 16in. o.c., [Bldg. Use 1 - Office]	6388	13.0	10.0	0.055	0.064
Window: Metal Frame with Thermal Break: Fixed, Perf. Specs.: Product ID Typical fix metal, SHGC 0.38, [Bldg. Use 1 - Office] (b)	1884	---	---	0.360	0.380
WEST					
Ext. Wall: Steel-Framed, 16in. o.c., [Bldg. Use 1 - Office]	4259	13.0	10.0	0.055	0.064
Window: Metal Frame with Thermal Break: Fixed, Perf. Specs.: Product ID Typical fix metal, SHGC 0.38, [Bldg. Use 1 - Office] (b)	1256	---	---	0.360	0.380

(a) Budget U-factors are used for software baseline calculations ONLY, and are not code requirements.
(b) Fenestration product performance must be certified in accordance with NFRC and requires supporting documentation.

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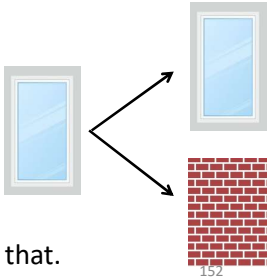
C402.1.5 Component Performance Alternative

- How do you handle buildings that exceed baseline fenestration area in C402.4.1?
  - Max baseline vertical fenestration area
    = 30% of gross above-grade wall area
    = 40% if meet daylighting requirements in C402.4.1.1
  - Max baseline skylight area
    = 3% of gross roof area
    = 6% if meet daylighting requirements in C402.4.1.2
- COMcheck will handle it automatically.
- C402.1.5 handles excess area in terms D and E.
- Concept is same in both:
  - Compare proposed fenestration to prescriptive fenestration up to the max prescriptive area.
  - Compare proposed excess fenestration to corresponding wall above that.



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C402.1.5 Component Performance Alternative

- **Same example as before, but with 50% vertical fenestration.**
  (10,724 sqft opaque wall area, 10,556 sqft fixed windows, 168 sqft glazed doors)
- Calculate A term like before but with new areas and change roof to R-35ci (U-0.028) instead of R-30ci
  = 96.5 (walls) – 71.5 (roofs) – 211.1 (windows) + 23.5 (doors) = -162.6
- B (slabs) = -87.4, C (below-grade walls) = 0, E (excess skylights) = 0 same as before

Where the proposed vertical glazing area is less than or equal to the maximum vertical glazing area allowed by Section C402.4.1, the value of D (Excess Vertical Glazing Value) shall be zero. Otherwise:

D	= (DA × UV) – (DA × U Wall), but not less than zero.
DA	= (Proposed Vertical Glazing Area) – (Vertical Glazing Area allowed by Section C402.4.1).
UA Wall	= Sum of the (UA Proposed) values for each opaque assembly of the exterior wall.
U Wall	= Area-weighted average *U*-value of all above-grade wall assemblies.
UAV	= Sum of the (UA Proposed) values for each vertical glazing assembly.
UV	= UAV/total vertical glazing area.

- D term adjusts for the excess vertical fenestration area.
  - DA (excess area) = 10724 – 6435 = 4289 sqft based on 30% WWR
    For 40% with daylighting, it would be 10724 – 8579 = 2145
  - UV (average fenestration U-factor) = UAV / fen area
    = (0.34 × 10556 + 0.77 × 168)/10724 = 0.347
  - U Wall (average wall U-factor) = 0.064
  - D = (DA×UV) – (DA×U Wall) = (4289 × 0.347)-(4289 × 0.064) = 1212.7
- Overall A+B+C+D+E = 962.7 (fails)
- If add daylighting per C402.4.1.1, new A+B+C+D+E = 356.5 (fails)
- If also use lower window 0.31 U-factor, new A+B+C+D+E = -23.5 (passes)

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C402.5 Air Leakage – thermal envelope

- C402.5.1 Air barriers
  - C402.5.1.1 Air barrier construction
  - C402.5.1.2 Air barrier compliance
  - C402.5.1.3 Materials
  - C402.5.1.4 Assemblies
  - C402.5.1.5 Verification
- C402.5.2 Dwelling and sleeping unit enclosure testing
- C402.5.3 Building thermal envelope testing
- C402.5.4 Air leakage of fenestration – Addressed in Tom's presentation
- Other related requirements (Section C402.5.5 – C402.5.11)

NEW for 2024 IECC:
- Re-organization of requirements
- Testing expanded to cover more buildings
- Air leakage rate decreased from 0.40 cfm/ft^2 to 0.35 cfm/ft^2 @ 75Pa
- For Group R2 and I-1 buildings, it changed from 0.30 cfm/ft^2 to 0.27 cfm/ft^2 @ 50 Pa

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C402.5 Air Leakage – thermal envelope

- Comply with Sections C402.5.1 through C402.5.11.1 (basically the entirety of C402.5)

  OR

- Tested in accordance with Section C402.5.2 or C402.5.3
  - Including requirements of C402.5.7, C402.5.8, and C402.5.9
- Testing can always be done, if specified, but it is now required in certain conditions

C402.5 Air leakage—thermal envelope. The *building thermal envelope* shall comply with Sections C402.5.1 through Section C402.5.11.1, or the building *thermal envelope* shall be tested in accordance with Section C402.5.2 or C402.5.3. Where compliance is based on such testing, the building shall also comply with Sections C402.5.7, C402.5.8 and C402.5.9.

Source: https://www.swinter.com/

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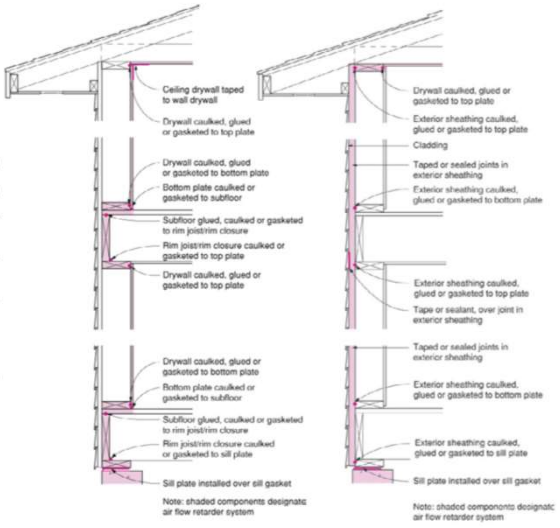
C402.5 Air Leakage – thermal envelope

C402.5.1 Air barriers. A continuous air barrier shall be provided throughout the *building thermal envelope*. The continuous air barriers shall be located on the inside or outside of the building thermal envelope, located within the assemblies composing the building thermal envelope, or any combination thereof. The air barrier shall comply with Sections C402.5.1.1, and C402.5.1.2.

Exception: Air barriers are not required in buildings located in *Climate Zone* 2B.



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C402.5 Air Leakage – thermal envelope

- **C402.5.1.1 Air barrier construction.** All of the following apply:

1. Continuous for all building thermal envelope assemblies and across the joints and assemblies
2. All joints and seams securely sealed to resist pressure differential from wind, stack effect, and mechanical ventilation
3. Penetrations durably caulked, gasketed, or otherwise sealed in a manner compatible with construction materials and location
   - For fire sprinkler penetration follow method recommended by manufacturer's instructions. Do not use caulk or other adhesive sealants.
4. Recessed lighting fixtures shall comply with C402.5.10 (and other similar penetrating "objects").

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C402.5 Air Leakage – thermal envelope

- **C402.5.1.2 Air barrier compliance.**
  - Compliance varies by building occupancy group with exceptions based on climate zone and building size:

Building Occupancy	Testing Requirements	Exceptions by Building Size and Climate Zone	Climate Zones where testing required
Group R & I	Section C402.5.2	Any Size: 2B, 3C, and 5C	0, 1, 2A, 3A/B, 4, 5A/B, 6, 7, 8
All Other Groups	Section C402.5.3	SF ≤ 5,000: 2B, 3B, 3C and 5C	0, 1, 2A, 3A, 4, 5A/B, 6, 7, 8
		5,000 < SF < 50,000: 0, 1, 2, 3, 4B/C and 5B/C	4A, 5A, 6, 7, 8
		SF ≥ 50,000: 0B, 1, 2, 3B/C, 4B/C, and 5C	0A, 3A, 4A, 5A/B, 6, 7, 8
Any Occupancy Group where testing is excepted and not otherwise specified	Comply with Sections C402.5.1.3, C402.5.1.4, and C402.5.1.5 (materials, assemblies, and inspection/verification) – These are not required when testing, but often done to ensure achieving test requirement.		

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C402.5 Air Leakage – thermal envelope

- **C402.5.1.3 Materials**
  - A material with air permeability ≤ 0.004 cfm/ft^2 at 0.3" H_2O (75 Pa) per ASTM E2178
  - The following 16 materials are deemed to comply provided joints are sealed and installed per manufacturer's instructions:

1. Plywood with a thickness of not less than $^3/_8$ inch (10 mm).
2. Oriented strand board having a thickness of not less than $^3/_8$ inch (10 mm).
3. Extruded polystyrene insulation board having a thickness of not less than $^1/_2$ inch (12.7 mm).
4. Foil-back polyisocyanurate insulation board having a thickness of not less than $^1/_2$ inch (12.7 mm).
5. Closed-cell spray foam having a minimum density of 1.5 pcf (2.4 kg/m^3) and having a thickness of not less than $1^1/_2$ inches (38 mm).
6. Open-cell spray foam with a density between 0.4 and 1.5 pcf (0.6 and 2.4 kg/m^3) and having a thickness of not less than 4.5 inches (113 mm).
7. Exterior or interior gypsum board having a thickness of not less than $^1/_2$ inch (12.7 mm).
8. Cement board having a thickness of not less than $^1/_2$ inch (12.7 mm).
9. Built-up roofing membrane.
10. Modified bituminous roof membrane.
11. Single-ply roof membrane.
12. A Portland cement/sand parge, or gypsum plaster having a thickness of not less than $^5/_8$ inch (15.9 mm).
13. Cast-in-place and precast concrete.
14. Fully grouted concrete block masonry.
15. Sheet steel or aluminum.
16. Solid or hollow masonry constructed of clay or shale masonry units.

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C402.5 Air Leakage – thermal envelope

- **C402.5.1.4 Assemblies**
- Assemblies of materials and components with air permeability ≤ 0.04 cfm/ft^2 at 0.3" H_2O (75 Pa) per ASTM E2357, E1677, D8052, or E283
- The following 3 assemblies are deemed to comply provided joints are sealed and air barrier construction requirements of C402.5.1.1 are met

1. Concrete masonry walls coated with either one application of block filler or two applications of a paint or sealer coating.
2. Masonry walls constructed of clay or shale masonry units with a nominal width of 4 inches (102 mm) or more.
3. A Portland cement/sand parge, stucco or plaster not less than $^1/_2$ inch (12.7 mm) in thickness.

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C402.5 Air Leakage – thermal envelope

- **C402.5.1.5 Building envelope performance verification**
- Installation of continuous air barrier shall be verified by the building official, a registered design professional, or an approved agency
- The verification shall include the following:
  1. Review of construction documents and data to assess compliance with C402.5.1.1 air barrier construction requirements
  2. Inspections during construction while air barrier components are accessible to verify compliance with C402.5.1.3 and C402.5.1.4 and make any necessary repairs
  3. A final commissioning report for inspections conducted by a registered design professional or approved agency provided to building owner or owner's agent and to the building official. The report documents inspections and corrective actions during construction.

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C402.5 Air Leakage – thermal envelope

- **C402.5.2 Dwelling and sleeping unit enclosure testing**
  - Tested per ASTM E779, ANSI/RESNET/ICC 380, ASTM E1827 or an equivalent method approved by the building official
  - Air Leakage Test Criteria: ≤ 0.30 cfm/ft^2 at 50 Pa
  - Units are tested separately
  - Building air leakage is weighted average of all tested units
  - Sampling permitted where building have 8 or more units
    - Greater of 7 units or 20% of units must be tested
    - Sampling must include ground floor, top floor, and unit with largest enclosure area
    - For each failed test, two additional units shall be tested from the "mixture of testing unit types and locations"

NEW for 2024 IECC:
- For Group R2 and I-1 buildings, changing from 0.30 cfm/ft^2 to 0.27 cfm/ft^2 @ 50 Pa

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C402.5 Air Leakage – thermal envelope

- **C402.5.3 Building thermal envelope testing**
- Same test methods as C402.5.2 plus another option: ASTM E3158
- Air Leakage Test Criteria: ≤ 0.40 cfm/ft^2 at 75 Pa
- Sampling of specified portions of the building permitted to determine a weighted average building air leakage rate provided the following are included:
  1. Entire envelope area of all stories with any spaces directly below a roof
  2. Entire envelope area of any story with building entrance, exposed floor, loading dock, or below grade
  3. Representative above-grade sections of building totaling at least 25 percent of the wall area enclosing the remaining conditioned space.

NEW for 2024 IECC:
- Air leakage rate decreasing from 0.40 cfm/ft^2 to 0.35 cfm/ft^2 @ 75Pa

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C402.5 Air Leakage – thermal envelope

- **EXCEPTION** ("training wheels" for Section C402.5.3 testing)
  - Applies where tested air leakage is > 0.40 cfm/ft^2 but not more than 0.60 cfm/ft^2
  - An additional test to demonstrate final compliance is not required where:
    1. A diagnostic evaluation is conducted while the building is pressurized using smoke tracer or infrared imaging together with a visual inspection of the air barrier
    2. Observed leaks shall be noted and sealed without requiring destruction of existing building components
    3. An additional report (to the test report) shall be provided to the building owner or owner's agent and the building official detailing corrective actions to seal leaks and this shall be deemed to comply with the testing requirement.

Source: https://www.toolexperts.com/

NEW for 2024 IECC:
- Exception limit decreasing from 0.60 cfm/ft^2 to 0.45 cfm/ft^2 @ 75Pa

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C402.5 Air Leakage – thermal envelope

- **402.5.5 Rooms containing fuel-burning appliances**
- Applies to:
  - Climate Zones 3-8 where combustion air supplied through exterior wall to a room or space containing a space conditioning fuel-burning appliance
- Must comply with one of the following:
  1. Room or space located outside the BTE
  2. Room inside BTE enclosed and isolated from conditioned spaces by:
     - Enclosure assemblies complying with insulation for below-grade walls per Table C402.1.3 or Table C402.1.4
     - Assemblies sealed per C402.5.1.1 to prevent air leakage to conditioned space
     - Fully-gasketed doors
     - Water lines and ducts in enclosed space insulated per Section C403
     - Combustion air supply ducts passing through conditioned space to the enclosed space shall be insulated to not less than R-8.
  - **Exceptions:** Fireplaces and stoves complying with IMC 901-905 and IBC 2111.14

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C402.5 Air Leakage – thermal envelope

- **C402.5.6 Doors and access openings to shafts, chutes, stairways and elevator lobbies**
  - Where not covered by fenestration air-leakage requirements of Section C402.5.4, such doors and access openings must be
    - Gasketed
    - Weather-stripped, or
    - Sealed
  - **Exceptions:**
    - Door openings required to comply with Section 716 of IBC
    - Doors and door openings required to comply with UL 1784 by the IBC

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C402.5 Air Leakage – thermal envelope

- **C402.5.7 Air intakes, exhaust openings, stairways, and shafts**
  - These items that are integral to the building envelope shall be provided with dampers in accordance with C403.7.7 (motorized shut-off dampers) meeting air tightness requirements.

- **C402.5.8 Loading dock weather seals**
  - Cargo and loading door openings shall be equipped with weather seals that restrict infiltration and provide direct contact along top and sides of vehicles parked in the doorway.

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C402.5 Air Leakage – thermal envelope

- **C402.5.9 Vestibules**
- Applies to "building entrances" and requires:
  - Doors equipped with self-closing devices
  - Designed for passage that does not require that both sets of doors be opened at the same time
  - A revolving door(s) in the building entrance does not negate requirement for a vestibule for adjacent doors
- Exceptions:
  - Climate Zones 0-2
  - Doors not intended for use by the public
  - Doors directly to a sleeping or dwelling unit
  - Doors opening directly from a space < 3,000 sf
  - Revolving doors
  - Doors primarily for vehicles, material handling, and adjacent personnel doors
  - Doors with an "air curtain" that meet certain performance and control requirements

School security vestibule in addition to dual entry outer vestibule

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C402.5 Air Leakage – thermal envelope

- **C402.10 Recessed lighting**
- Where installed in the BTE, shall comply with all of the following:
  - IC-rated ("insulated contact")
  - Labeled with air leakage rate < 2.0 cfm per ASTM E283 test at 75 Pa
  - Sealed with a gasket or caulk between the housing and interior finish

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C402.5 Air Leakage – thermal envelope

- **C402.5.11 Operable openings interlocking**
  - More of a mechanical heating/cooling control issue when large openings (> 40 sf) open a conditioned space to the outdoors.
  - Requires that openings are "interlocked" (used to control) the heating set point and cooling set point to 55F and 90F, respectively, when the operable opening is open.
  - Set point control must occur within 10 minutes of opening
  - Controls shall comply with C403.13
  - **Exceptions:**
    1. Separately zoned food prep areas that contain appliances contributing to HVAC loads of a restaurant or similar type of occupancy
    2. Warehouses that utilized o/h doors for the function of the occupancy, where approved by the code official
    3. The first entrance doors in the exterior wall and are part of a vestibule system

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C406 Additional Efficiency Requirements

- **C406.1 Additional efficiency credit requirements**
  - New buildings shall achieve a total of 10 credits
  - Tables provide credits by efficiency measure, climate zone, and building occupancy group
- Two efficiency measures address building thermal envelope:
  7. Enhanced envelope performance in accordance with Section C406.8
  8. Reduced air infiltration in accordance with Section C406.9

  Also, Building Integrated PV as a part of on-site renewable energy credit

  Addressed in Tom's presentation

NEW 2024
- Point system changed to include Efficiency + Load Mgmt & Renewables
- Required credits vary by climate and building use group
- Many more credit measures added

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C406 Additional Efficiency Requirements

- **C406.8 Enhanced envelope performance**
  - Total UA of building thermal envelope shall be not less than 15 percent below the total UA of the building thermal envelope in accordance with Section C402.1.5
    - NOTE: Section C402.1.5 changed to a different format such that a total UA value is no longer transparent when using the component performance alternative.
    - General approach intended:
      - Sum (UA for all envelope proposed) <= 0.85 x Sum (UA for same envelope complying with U-factors in Table C402.1.4 and C402.4)
    - Can also use COMcheck, but with a "PASSES" result indicating that "Design is 15% better than code" (or more than 15% better)
  - Allowed points for Colorado (Climate Zones 4-7) range from 2 to 14 depending on building occupancy group and climate zone
    - See Tables C406.1(1) – (5)

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C406 Additional Efficiency Requirements

- **C406.9 Reduced air infiltration**
  - Whole building pressurization test required
    - Exception for buildings > 250,000 sqft to allow tested area of 25%
  - Measured air leakage rate shall not exceed 0.25 cfm/ft^2 at 75 Pa
  - Test report required
  - Allowed points for Colorado (Climate Zones 4-7) range from 1 to 14 depending on building occupancy group and climate zone
    - See Tables C406.1(1) – (5)

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C406 Additional Efficiency Requirements

NEW for 2024 IECC - new credits added so available envelope-related credits include:

- Improved overall envelope performance factor calculated from COMCheck
- Reduced envelope UA
- Reduced air leakage
- Added roof insulation
- Added wall insulation
- High performance fenestration

} But can't double count with improved envelope performance factor or reduced envelope UA

- Increased daylight area
- Automated shading for fenestration (load management credit)
- On-site renewable energy including BIPV (load management credit)

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Section C407 – Total Building Performance

- Total building performance analysis is required to include energy use from the following systems and loads:
  - Heating and cooling systems
  - Service water heating
  - Fan systems
  - Lighting power
  - Receptacle and process loads
  - **Exception:** EV charging used for "on-road and off-site transportation purposes"
- Allows trade-offs between various systems, components, and assemblies.
- More flexibility than C402.1.5 Component Performance Alternative, but more effort and compliant computer modeling software required.

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Section C407 – Total Building Performance

- Key elements for compliance with C407 include:
  1. Mandatory requirements in Table C407.2
     - NOTE: The only mandatory envelope requirement listed is C402.5 Air leakage
  2. Annual energy cost for the proposed design is less than or equal to 80 percent of the annual energy cost of the standard reference design.
  3. Reduction in energy cost of the proposed design associated with on-site renewable energy shall be not more than 5 percent of the total energy cost and no "trade-off" credit for off-site renewable energy
  4. Details for modeling reference and proposed design must comply with Table C407.4.1(1)
  5. Compliance report, documentation, and inspection checklist.

NEW 2024
The 80 percent factor will vary as required additional efficiency credits (C406) vary based on climate and building use Group.
Also, thermal bridging criteria added for reference and proposed design.

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2024 IECC Ch5 – Existing Bldgs - Alterations

- Section C503 Alterations
  - Exemptions remain same for storm windows, glazing films, roof recover, and roof replacement where insulation is integral to or below roof deck.
  - Exemption added for whole-building complying with C407 (e.g., major renovation achieved by modeling to current code).
  - Section C503.2 Building Thermal Envelope Alterations
    - Reorganized and triggers added for improving or bringing insulation up to current code based on type of alteration occurring to:
    - C503.2.1 Roof, ceiling, and attic alterations
    - C503.2.2 Vertical Fenestration (no changes – addressed by Tom earlier)
    - C503.2.3 Skylight Area (no changes)
    - C503.2.4 Above-grade wall alterations
    - C503.2.5 Floor alterations
    - C503.2.6 Below-grade wall alterations
    - C503.2.7 Air barrier

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2024 C503.2 Building thermal envelope

C503.2 Building thermal envelope. Alterations of existing *building thermal envelope* assemblies shall comply with this section. New *building thermal envelope* assemblies that are part of the *alteration* shall comply with Section C402 . An area-weighted average *U*-factor for new and altered portions of the *building thermal envelope* shall be permitted to satisfy the *U*-factor requirements in Table C402.1.4. The existing *R*-value of insulation shall not be reduced or the *U*-factor of a *building thermal envelope* assembly be increased as part of a *building thermal envelope alteration* except where complying with Section C407.

Exception: Where the existing *building* exceeds the *fenestration* area limitations of **Section C402.5.1** prior to *alteration* , the *building* is exempt from **Section C402.5.1** provided that there is no increase in *fenestration* area.

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2024 C503.2.1 Roof, ceiling, and attic alterations

C503.2.1 Roof, ceiling, and attic alterations. Insulation complying with Section C402.1 and Section C402.2.1, or an *approved* design that minimizes deviation from the insulation requirements, shall be provided for the following alterations:

1. An *alteration* of roof-ceiling construction other than *reroofing* where existing insulation located below the roof deck or on an attic floor above *conditioned space* does not comply with Table C402.1.2.
2. *Roof replacement* or a roof *alteration* that includes removing and replacing the *roof covering*, where the *roof assembly* includes insulation entirely above the *roof* deck.

   Exceptions: Where compliance with Section C402.1 cannot be met due to limiting conditions on an existing roof, an *approved* design shall be submitted with the following:

   1. *Construction documents* that include a report by a *registered design professional* or an *approved* third party documenting details of the limiting conditions affecting compliance with the insulation requirements.
   2. *Construction documents* that include a roof design by a *registered design professional* or *approved* third party that minimizes deviation from the insulation requirements.

3. Conversion of unconditioned attic space into *conditioned space* .
4. Replacement of ceiling finishes exposing cavities or surfaces of the roof-ceiling construction.

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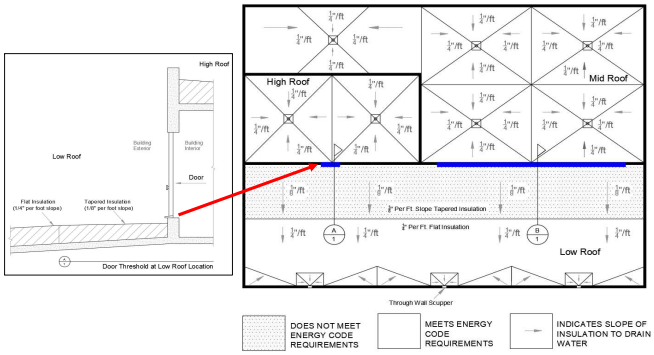
2024 C503.2.1 Roof, ceiling, and attic alterations

ROOF REPLACEMENT. An *alteration* that includes the removal of all existing layers of *roof assembly* materials down to the roof deck and installing replacement materials above the existing roof deck.

(IBC) 1512.2 Roof replacement. *Roof replacement* shall include the removal of all existing layers of *roof assembly* materials down to the *roof deck*.



Example roof replacement plan (above deck roof insulation) by RDP or *approved* third party to "minimize deviation" from insulation requirements (exception to meeting full insulation amount when limiting conditions cannot be otherwise reasonably addressed).

Images courtesy of PIMA: https://www.polyiso.org/

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Metal Building Retrofit with FPIS ci
(rated for interior exposure)

- Before

- After

2024 C503.2.4 Above-grade wall alterations

C503.2.4 Above-grade wall alterations. *Above-grade wall* alterations shall comply with the following:

1. Where wall cavities are exposed, the cavity shall be filled with *cavity insulation* complying with Section C303.1.4. New cavities created shall be insulated in accordance with Section C402.1 or an *approved* design that minimizes deviation from the insulation requirements.
2. Where *exterior wall* coverings and *fenestration* are added or replaced for the full extent of any *exterior wall* assembly on one or more elevations of the *building* , insulation shall be provided where required in accordance with one of the following:
    - 2.1 An R-value of continuous insulation not less than that designated in Table C402.1.3 for the applicable *above-grade wall* type and existing *cavity insulation* R-value, if any;
    - 2.2 An R-value of not less than that required to bring the *above-grade wall* into compliance with Table C402.1.2; or,
    - 2.3 An *approved* design that minimizes deviation from the insulation requirements of Section C402.1.
3. Where Items 1 and 2 apply, the insulation shall be provided in accordance with Section C402.1.

Where any of the above requirements are applicable, the *above-grade wall alteration* shall comply with Sections 1402.2 and 1404.3 of the *International Building Code*.

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Retrofit of above grade wall with FPIS ci

- Best if siding and window replacements done at same time
- Can be done with just siding replacement
  - Need to properly integrated wall WRB and flashing with windows and doors if they are not replaced.
  - https://www.pnnl.gov/projects/re-siding-ext-insulation
- For additional information on existing building retrofits, refer to: https://www.continuousinsulation.org/remodeling-energy-efficiency

https://basc.pnnl.gov/resource-guides/rigid-foam-insulation-existing-exterior-walls

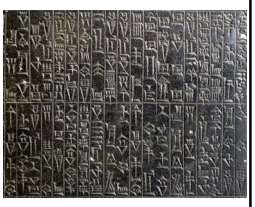
And to finish off, look how far we've come!

Code of Hammurabi 1760 B.C.

The first written building code:

229. If a builder builds a house for someone, and does not construct it properly, and the house which he built falls in and kills its owner, then that builder shall be put to death.

233. If a builder builds a house for someone, even though he has not yet completed it; if then the walls seem toppling, the builder must make the walls solid from his own means.



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Questions / Discussion

Thank You!

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