2024 IECC Commercial Envelope (Course 583)

Colorado Chapter of ICC
Educational Institute 2025

March 7, 2025

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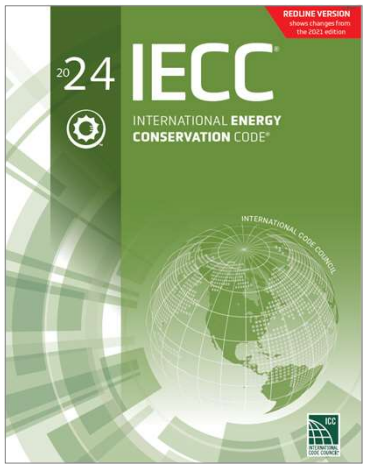
Course Outline

- Why is the building thermal envelope (BTE) important?
- PART A – Administrative & General
  - Construction Documents (C105)
  - Compliance Path (C401.2)
  - Building 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 – C402.4)
- PART C – Fenestration & Daylighting (C402.5)
- PART D – The Rest of the Story…
  - Component Performance Alternative (C402.1.4)
  - Air leakage (C402.6)
  - Additional Efficiency/Renewable/Load Mngmt "Credits" (C406)
  - Total Simulated Building (C407)
  - Existing Buildings – Envelope Alterations (C503.2)



We'll also note some key differences from 2021 IECC; also several section numbers have changed

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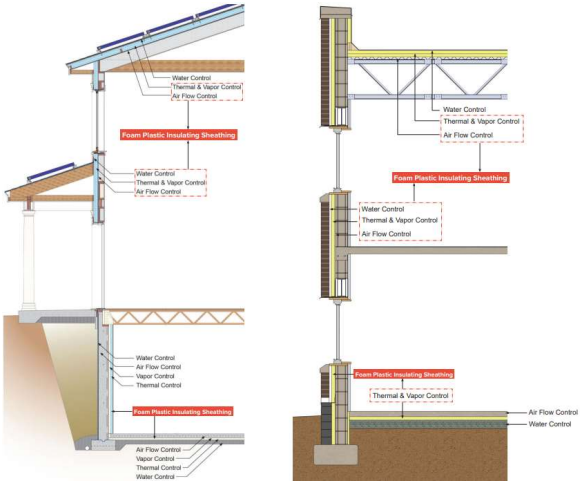
A. What is the building thermal envelope (BTE)?

- The BTE separates the indoor from the outdoor environment.
- The BTE is an integrated system which also supports the design and function of other building systems.

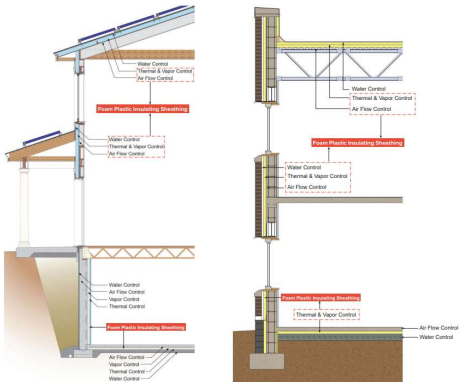
IECC Definition:

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.



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, its occupants, 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/handprint for the building.

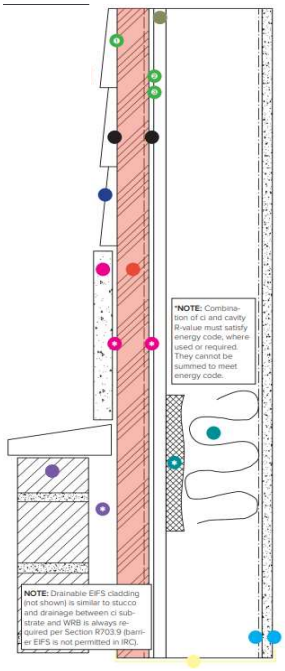


"Without a good building envelope, …HVAC system and design actions become more difficult and costly, and uncertain in their effectiveness [to control the indoor environment]."

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

Functions of the BTE

- In addition to fire safety, structural safety, sound control, 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]
- All functions must be satisfied at least to the minimum extent required by the building and energy code.
- Some "layers" or materials can perform multiple functions depending on design approach and material properties
- **FUN FACT:** 5 VR x 5 AB x 5 ci x 5 cavity x 6 WRB x 5 str shtg x 9 cladding = **168,750** possibilities to configure a wall! (and not all are equal, though most may be code compliant)



PART A: Administrative & General

- **Section C105 Construction Documents**
  - Requirements for preparation and submission of construction documents vary by local jurisdiction
- **C105.2 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

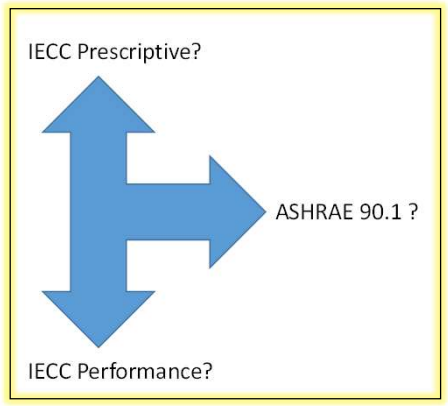
     NOTE: Not applicable where "straight-up" prescriptive compliance is followed.
  5. Air barrier and air sealing details, including location of air barrier
  6. Thermal bridges as identified in Section C402.7

     …
  14. Location of daylight zones on floor plans

NEW 2024

C401.2 Application

- **C401.2.1 International Energy Conservation Code**
  1. Prescriptive Compliance (Sections C402 – C406 and C408) or R406 for Group R-2 DU/SU's, **or**
  2. Simulated 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, a dated	
88	Energy conservation analysis/computations (e.g. ComCheck) statement of compliance per Part IV of the DPS Commercial E Code requirements document	

Declare the compliance path used.

More checklists for compliance:
https://energyoffice.colorado.gov/energy-code-adoption-toolkit
https://www.continuousinsulation.org/resources/plan-review-inspection-resources

IECC Section C107 Inspections

C107.2.2 Thermal envelope.
Inspections shall verify the correct type of insulation, *R*-values, location of insulation, *thermal bridge* mitigation, fenestration, *U*-factor, SHGC and VT, and that air leakage controls are installed, as required by the code, *approved* plans and specifications.

NEW inspection item added in 2024 (related to new Section C402.7 for thermal bridge prescriptive detailing requirements or other details as modeled in C407 compliance path)

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

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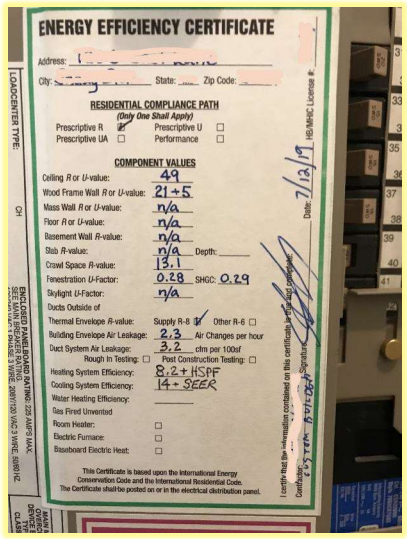
C401.3 Building Thermal Envelope Certificate

- 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/req'd)



ENERGY EFFICIENCY CERTIFICATE

Address:

City: 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: Custom

LOAD CENTER TYPE: CH

EMERGENCY PREPAREDNESS RATING: 225 AMPS MAX. SCCC RATING: 5 PHASE, 3 WIRE, 208/120 VAC 3 PHASE, 60Hz

MAIN BREAKER RATING: CLASS

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C301 Climate Zone & C302 Design Conditions

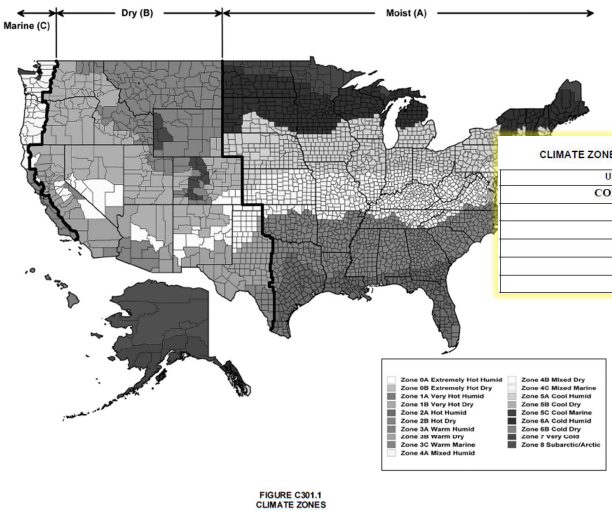

FIGURE C301.1
CLIMATE ZONES

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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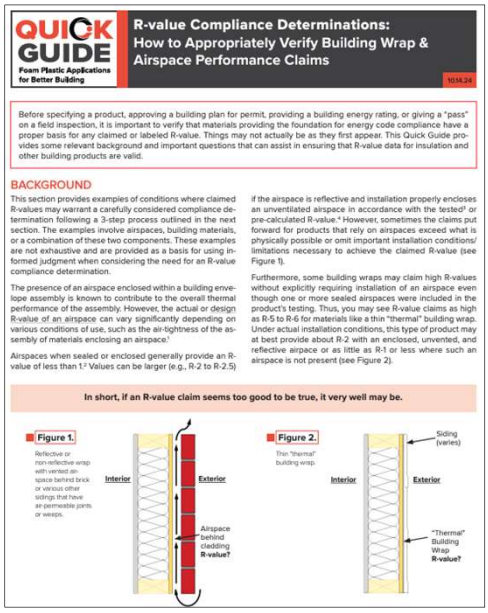
IECC on Product Labeling

(Testing, Labeling, Marking, Verification)

- **IECC C303.1 Identification**
  - Insulation materials must be identified in a manner to allow determination of compliance with the code.
  - RECOMMENDATION: Verify label (insulation mark) and, if necessary, also that product test data is certified by an *approved agency*
    - *NOTE: The code does not require an approved agency for R-value data; but it may be helpful for verification purposes where an R-value claim appears questionable.*



QUICK GUIDE
Foam Plastic Applications for Better Building

R-value Compliance Determinations: How to Appropriately Verify Building Wrap & Airspace Performance Claims

1014.24

Before specifying a product, approving a building plan for permit, providing a building energy rating, or giving a "pass" on a field inspection, it is important to verify that materials providing the foundation for energy code compliance have a proper basis for any claimed or labeled R-value. Things may not actually be as they first appear. This Quick Guide provides some relevant background and important questions that can assist in ensuring that R-value data for insulation and other building products are valid.

BACKGROUND

This section provides examples of conditions where claimed R-values may warrant a carefully considered compliance determination following a 3-step process outlined in the next section. The examples involve airspaces, building materials, or a combination of these two components. These examples are not exhaustive and are provided as a basis for using informed judgment when considering the need for an R-value compliance determination.

The presence of an airspace enclosed within a building envelope assembly is known to contribute to the overall thermal performance of the assembly. However, the actual or design R-value of an airspace can vary significantly depending on various conditions of use, such as the air-tightness of the assembly of materials enclosing an airspace.[1]

Airspaces when sealed or enclosed generally provide an R-value of less than 1.[2] Values can be larger (e.g., R-2 to R-2.5) if the airspace is reflective and installation properly encloses an unventilated airspace in accordance with the tested[3] or pre-calculated R-value.[4] However, sometimes the claims put forward for products that rely on airspaces exceed what is physically possible or omit important installation conditions/limitations necessary to achieve the claimed R-value (see Figure 1).

Furthermore, some building wraps may claim high R-values without explicitly requiring installation of an airspace even though one or more sealed airspaces were included in the product's testing. Thus, you may see R-value claims as high as R-5 to R-6 for materials like a thin "thermal" building wrap. Under actual installation conditions, this type of product may at best provide about R-2 with an enclosed, unvented, and reflective airpace or as little as R-1 or less where such an airspace is not present (see Figure 2).

In short, if an R-value claim seems too good to be true, it very well may be.

Figure 1.
Reflective or non-reflective wrap with vented airspace behind brick or various other sidings that have air-permeable joints or weeps.
Interior
Exterior
Airspace behind cladding R-value?

Figure 2.
Thin "thermal" building wrap.
Interior
Exterior
Siding (varies)
"Thermal" Building Wrap R-value?

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

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Insulation Material Requirements

- **IECC C303.1.1 Building thermal envelope insulation**
  - R-value mark on each piece or certification (including installation details of sprayed or blown-in insulation for R-value, 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)
- **IECC C303.1.2 Insulation mark installation**
  - The above information must be readily observable or certificate left on site immediately after installation (with same exception as above)
- **C303.1.3 Fenestration product rating**
  - Tom will cover this topic in greater detail later in Part C
- **IECC C303.1.4 Insulation product rating**
  - R-value determined in accordance with FTC R-value Rule and its referenced test methods (generally ASTM test standards)
  - For insulated siding, code requires ASTM C1363 testing

R-value mark on batt insulation

Installation Certificate

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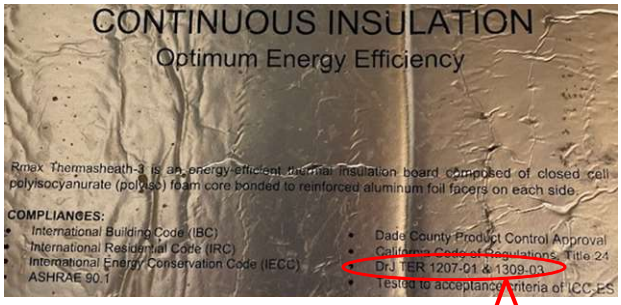
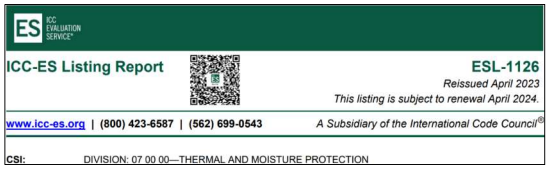
Example: IBC Product Labeling Foam Plastics

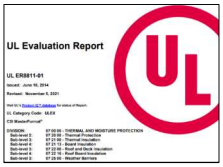
- **2024 IBC Section 2603.2 Labeling and identification.** Packages and containers of foam plastic insulation and foam plastic insulation components delivered to the job site shall bear the *label* of an *approved agency* showing the manufacturer's name, product listing, product identification and information sufficient to determine that the end use will comply with the code requirements.

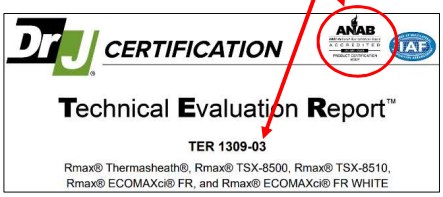
Example Product Marking/Label:



Examples of *approved agencies* & sources…



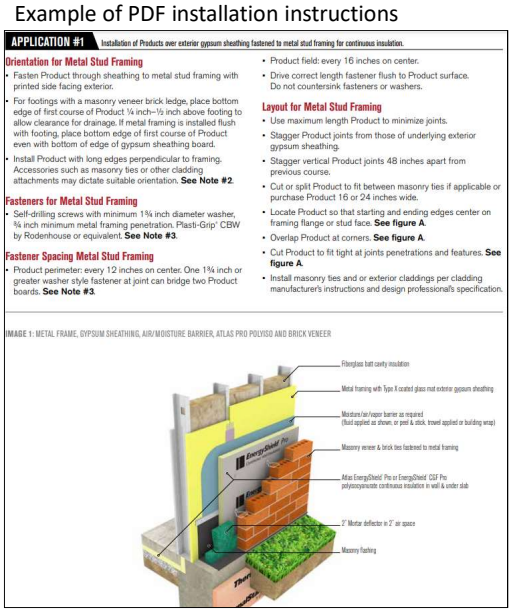




General Installation Requirements

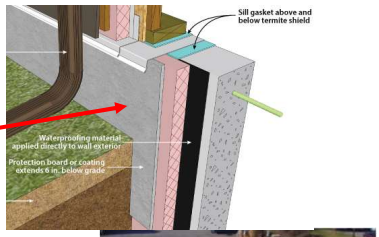
- **C303.2 Installation.** All materials, systems and equipment shall be installed in accordance with the manufacturer's installation instructions and the *International Building Code*.

Example of PDF installation instructions



General Installation Requirements

- 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
  - NOTE: Required to have min. 2 layers with joints staggered for above-deck roof insulation.



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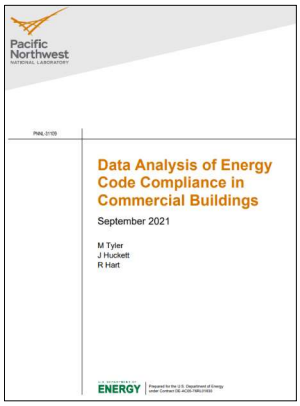
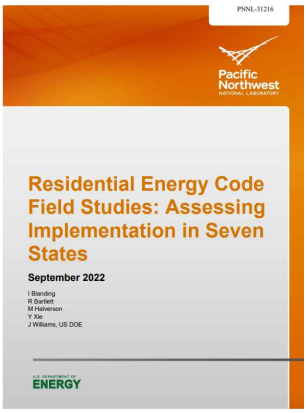
Hot Topics for Compliance and Enforcement

- 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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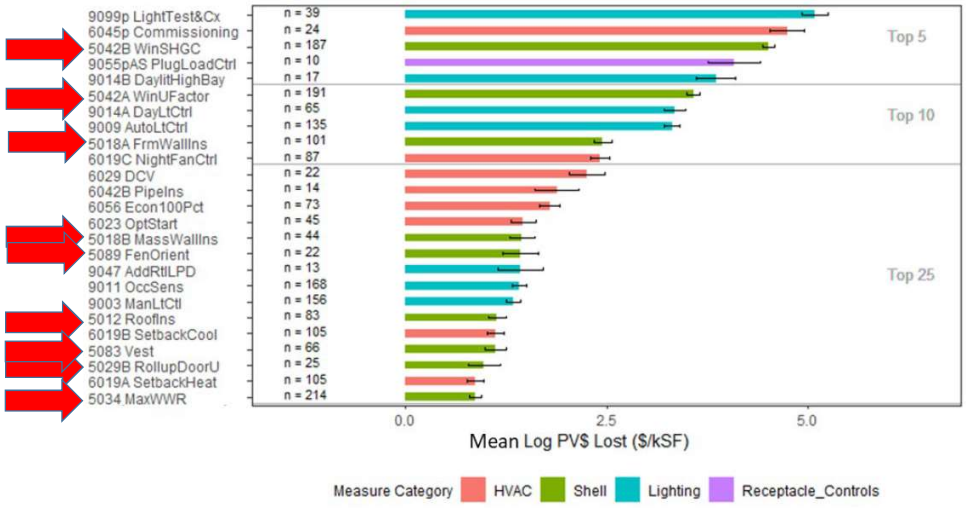
Commercial Building "Top 25" (All Measures)

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

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

Avg = 4.5ACH
Adequate ventilation?

Window compliance universally good

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

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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)

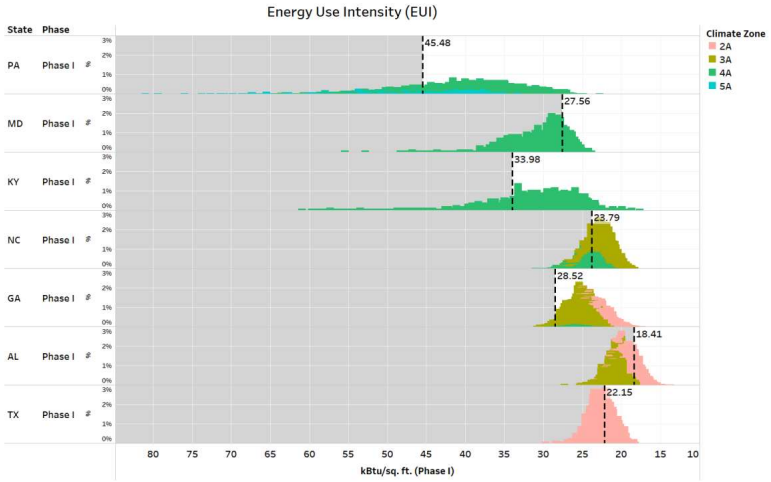

Figure 2.14 Comparison of Phase I Statewide EUIs

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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

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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!

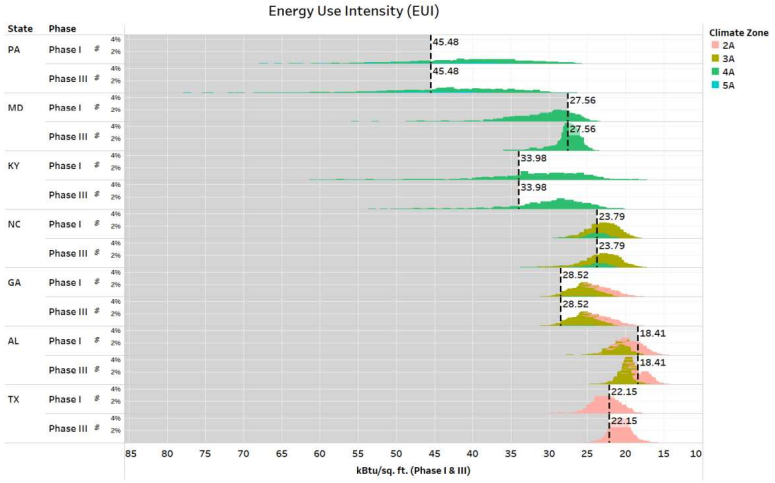

Figure 4.27. Comparison of Phase I and Phase III Statewide EUIs

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PART B: Building Envelope - Opaque Assemblies

- C402.1 General
- C402.2 Specific insulation and installation requirements
- C402.3/C402.4 Wall/Roof Solar Reflectance and Emittance

- To be addressed later:
  - Fenestration & Daylighting (C402.5)
  - Component Performance Method (C402.1.4)
  - Air leakage (C402.6)

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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. C402.1.2 (U-, C- and F-factor method),
     b. C402.1.3 (R-value method), or
     c. C402.1.4 (Component performance method)
  2. Wall solar reflectance and thermal *emittance* (C402.3)
  3. Roof solar reflectance and thermal *emittance* (C402.4)
  4. Fenestration (C402.5)
  5. Air leakage (C402.6)
  6. Thermal bridges in above-grade walls (C402.7)
  7. Cold-storage buildings, etc. (C403.12)

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

- **C402.1.1.1 Low-energy buildings.**
  - Low-energy building exemptions from C402 compliance:
    1. Peak design rate of energy usage < 3.4 Btu/h (10.7 W/m^2) or 1.0 W/ft^2 (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

- **402.1.1.2 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 C402.5.5 (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, C402.5.3 (fenestration U-factor), and C402.5.5 (doors).
3. Fenestration assemblies comply with Table C402.1.1.2. The U-factor for a roof shall be for the roof assembly or a roof that includes the assembly and an internal curtain system.*

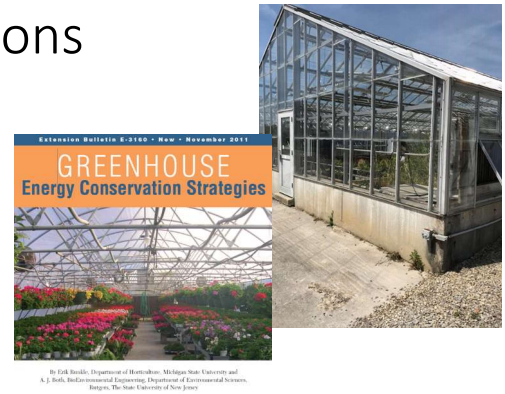

TABLE C402.1.1.2
FENESTRATION BTE MAXIMUM REQ'S

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

- **C402.1.1.3 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 ≤ 20,000 Btu/hr (6 kW) and setpoint ≤ 50 F
    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 – U-, C-, F-Factor Method

- **C402.1.2 Assembly U-factor, C-factor, or F-factor based method.**
  - BTE assemblies shall have a U-, C-, or F-factor not greater than that specified in Table C402.1.2 as indicated for "Group R" or "all other" occupancies.
  - 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")
    - Insulation component and location (e.g., cavity insulation and continuous insulation) and the degree of thermal bridging of cavity insulation

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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)].

per unit perimeter length of

***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 C402.1.2 – OPAQUE BTE MAX REQ'S, 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[c]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	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[e]	U-0.322[e]	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[e]	U-0.066[e]	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[e]	F-0.73[e]	F-0.73[e]	F-0.73[e]	F-0.73[e]	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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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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How to determine U-/C-/F- Factors?

C402.1.2.1 Methods of determining U-, C-, and F-factors. Where assembly *U-factors* , *C*-factors and *F*-factors and calculation procedures are established in **ANSI/ASHRAE/IES 90.1** Appendix A for opaque assemblies, such opaque assemblies shall be a compliance alternative provided they meet the criteria of **Table C402.1.2** and the construction, excluding cladding system on walls, complies with the applicable construction details from **ANSI/ASHRAE/IES 90.1** Appendix A. Where *U-factors* have been established by testing in accordance with **ASTM C1363**, such opaque assemblies shall be a compliance alternative provided they meet the criteria of **Table C402.1.2 ~~C402.1.4~~**. The *R-value* of *continuous insulation* shall be permitted to be added to or subtracted from the original tested design. Airspaces used for assembly evaluations shall comply with **Section C402.2.7**.

C402.1.2.1 compliments footnotes 'a' and 'b' in Table C402.1.2

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

- **Unpack C402.1.2.1 & Table C402.1.2 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 C402.1.2
- 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-15.8	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									

ASHRAE 90.1 Appendix A: Examples 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	[illegible]	[illegible]64	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.[illegible]	[illegible]043	**0.050**

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

- Example cold-formed steel frame wall calculation (2021 IECC - 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.

$$U = 1/[R_s + (ER)] \quad \textbf{(Equation 4-1)}$$

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)
3 1/2	16	13	0.46	5.98
		15	0.43	6.45
3 1/2	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 adds new Section C402.1.2.1.6 to reference AISI S250 standard. But it 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.

PENDING FOR ASHRAE 90.1-2025 / 2027 IECC: Improved calculation method based on steel framing as linear thermal bridges with ability to account for actual framing factor.

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

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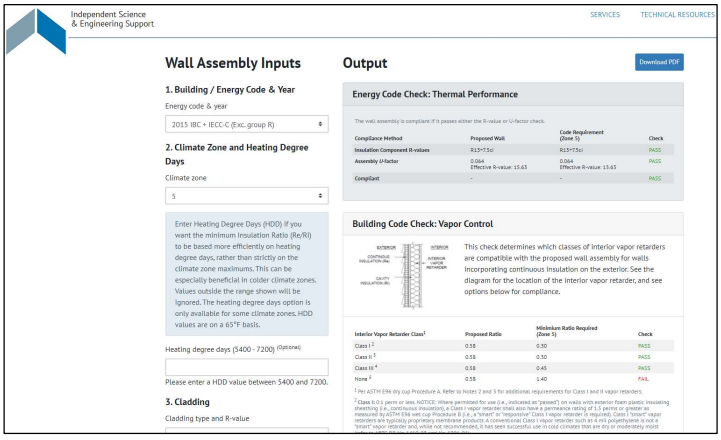
Opaque Envelope – U-, C-, F-Factor Method

- Live demo (or homework) 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							

Slab perimeter: "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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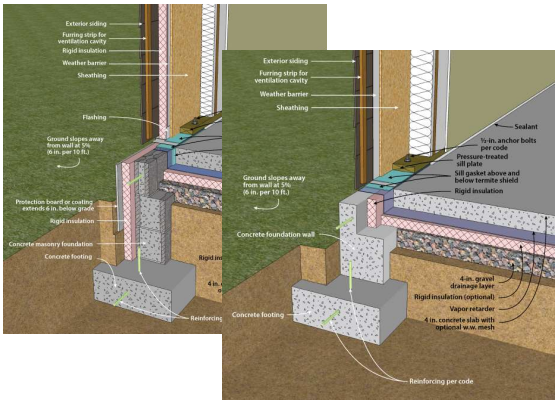
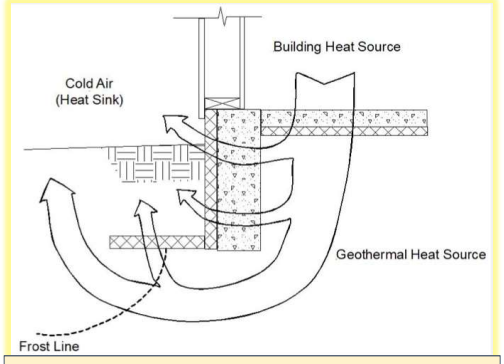
Opaque Envelope – U-, C-, F-Factor Method

- 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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Other Requirements for U-/C-/F-factors

- **C402.1.2.1.1 Tapered, above-deck insulation based on thickness**. For tapered, above-deck roof insulation, area-weighted U-factors of non-uniform insulation thickness shall be determined by an *approved* method.

  Exception: The area-weighted U-factor shall be permitted to be determined by using the inverse of the average R-value determined in accordance with the exception to Section C402.1.3.2.

  NOTE: $U_{assembly} = 1/R_{eff,assembly}$

  (In this case only, R_{eff} is taken as the average R-value of only the tapered, above-deck roof insulation components per C402.1.3.2, not the full roof assembly – close enough for this application and consistent with long-standing industry practice)

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Other Requirements for U-/C-/F-factors

- **C402.1.2.1.2 Suspended ceilings.** Insulation installed on suspended ceilings having removable ceiling tiles shall not be considered part of the assembly *U-factor* of the roof-ceiling construction.
- **C402.1.2.1.3 Concrete masonry units, integral insulation.** In determining compliance with Table C402.1.2, the U-factor of concrete masonry units with integral insulation shall be permitted to be used.
- **C402.1.2.1.4 Mass walls and floors.** Compliance with required maximum *U-factors* for mass walls and mass floors in accordance with Table C402.1.2 shall be permitted for assemblies complying with Section C402.1.3.4.

  NOTE: C402.1.3.4 defines minimum required weight/sqft and heat capacity to be considered a mass wall.

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Other Requirements for U-/C-/F-factors

- **C402.1.2.1.5 Area-weighted averaging of above-grade wall *U*-factors.** Where *above-grade walls* include more than one assembly type or a penetration of the opaque wall area, the area-weighted *U-factor* of the *above-grade wall* is permitted to be determined by an *approved* method.
- **C402.1.2.1.6 Cold-formed steel assemblies.** *U*-factors for building thermal envelopes containing cold-formed steel-framed ceilings and walls shall be permitted to be determined in accordance with **AISI S250** as modified herein.
  - 4 listed modifications or stipulations
  - These modifications do not address the U-factor under-estimation bias of AISI S250 mentioned earlier for walls that have more than just lay-out studs at specified spacing.
  - Local Amendment?: Suggest retaining 2021 IECC Section C402.1.4.2 (cavity correction factor procedure) or use pending improved calculation procedure in ASHRAE 90.1-2025 and 2027 IECC

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Other Requirements for U-/C-/F-factors

- **Section C402.1.2.1.7 Spandrel Panels**
  - Table of default U-factors for opaque assemblies within fenestration framing (i.e., spandrel panels)
  - U-factor for spandrel to be area-weighted into opaque wall U-factor (see C402.1.2.1.5)
  - The resulting area-weighted U-factor for the above-grade opaque wall is compared to maximum wall U-factor for opaque wall if complying prescriptively (not C402.1.4 or C407)
- **Section C402.1.2.1.8 Mechanical Equipment Penetrations**
  - Requires opaque above-grade wall U-factor to account for heat transfer through mechanical equipment penetrations where exceeding 1% of above-grade opaque wall area.
  - Use area-weighted U-factor approach per C402.1.2.1.5 or Section C402.1.4
  - Default U-0.5 (for area of equipment penetration)

TABLE C402.1.2.1.7
EFFECTIVE *U*-FACTORS FOR SPANDREL PANELSa

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

Opaque Envelope – R-value Method

- **C402.1.3 Insulation component R-value method.**
  - For opaque portions of the *BTE*, *R-values* for *cavity insulation* and *continuous insulation* shall not be less than that specified in Table C402.1.3.
  - Like U-factors, separate R-value criteria for "Group R" vs. "All other"
  - Just as with maximum U-/C-/F-factors, 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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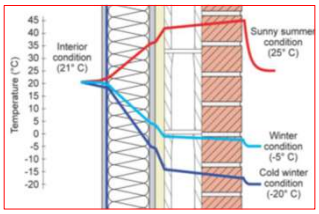
Opaque Envelope – R-value Method

***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 × ft^2 × °F/Btu) [(m^2 × 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-30 + 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-15.2ci	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 R20 + R3.8ci	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	R-7.5ci	R-7.5ci	R-7.5ci	R-10ci	R-10ci	R-15ci	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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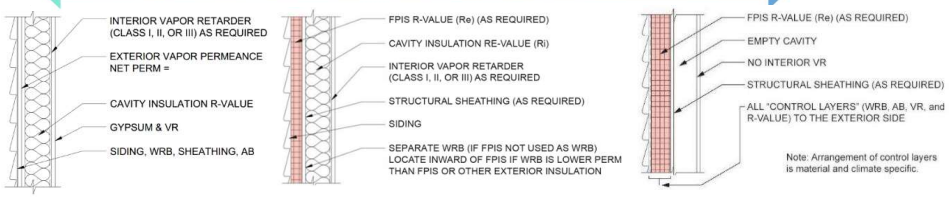
2024 IECC – added R-value options for light-frame walls

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[h,i]	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[h,i]	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

All options within each table cell have a U-factor equivalent to that required by Table C402.1.2.

1. Cover common stud depths (2x4 / 2x6)
2. Cover insulation location options (ci only, cavity+ci, and cavity only)

CAVITY INSULATION ONLY → CAVITY + CONTINUOUS HYBRID → CONTINUOUS ONLY



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Summary of IECC-C Prescriptive R-value & U-factor Requirements for Walls

2024 IECC-C - Tables C402.1.2 & C402.1.3 (prior - Tables C402.1.3 & C402.1.4)

Climate Zone	Building Use	Mass	Metal Framed			Wood Framed		
		2018/2021/2024 IECC	2018 IECC	2021 IECC	2024 IECC	2018 IECC	2021 IECC	2024 IECC
0 and 1	All other	R-5.7ci (U-0.151)	R13+5ci (U-0.077)	R13+5ci (U-0.077)	R0+10ci or R13+5ci or R20+3.8ci (U-0.077)	R13+3.8ci or R20 (U-0.064)	R13+3.8ci or R20 (U-0.064)	R0+12ci or R13+3.8ci or R20 (U-0.064)
	Group R							
2	All other							
	Group R	R-7.6ci (U-0.123)	R13+7.5ci (U-0.064)	R13+7.5ci (U-0.064)	R0+12.6ci or R13+7.5ci or R20+6.3ci (U-0.064)			
3	All other							
	Group R	R-9.5ci (U-0.104)						
4 Except Marine	All other							
	Group R	R-11.4ci (U-0.090)		R13+10ci (U-0.055)	R0+15.2ci or R13+10ci or R20+9ci (U-0.055)		R13+7.5ci or R20+3.8ci (U-0.051)	R0+16ci or R13+7.5ci or R20+3.8ci or R27 (U-0.051)
5 and Marine 4	All other					R13+7.5ci or R20+3.8ci (U-0.051)		
	Group R	R-13.3ci (U-0.080)						
6	All other			R13+12.5ci (U-0.049)	R0+17.3ci or R13+12.5ci or R20+11ci (U-0.049)			
	Group R	R-15.2ci (U-0.071)						
7	All other							
	Group R		R13+15.6ci (U-0.052)	R13+15.6ci (U-0.042)	R0+21ci or R13+15.6ci or R20+14.3ci (U-0.042)			
8	All other	R-25ci (U-0.037)	R13+7.5ci (U-0.064)	R13+18.8ci (U-0.037)	R0+24ci or R13+18.8ci or R20+17.5ci (U-0.037)	R13+15.6ci or R20+10ci (U-0.036)	R13+18.8ci (U-0.032)	R0+27.5ci or R13+18.8ci or R20+14ci (U-0.032)
	Group R		R13+17.5ci (U-0.045)					

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 not less than 32 inches on center vertically and not less than 48 inches or less on center horizontally, with ungrouted cores filled with materials having a maximum thermal conductivity of 0.44 Btu-in/h-ft2 °F.

d. Where heated slabs are below grade, below-grade walls shall comply with the R-value requirements for above-grade walls.

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 insulation components shall be installed in accordance with Section C402.2.4.

h. The first value is cavity insulation; the second value is continuous insulation…

i. Where the required R-value of Table C402.1.3 is met by using continuous insulation such that cavity insulation is not required, the R-value is applicable to any wall framing spacing.

LOTS OF FOOTNOTES!

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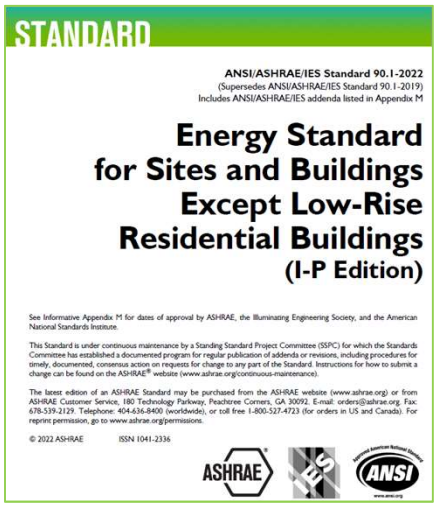
Opaque Envelope – R-value Method

- **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 "other" framing system is not known and this would affect the R-values and placement of insulation components required to meet the U-factor intent of code.


STANDARD

ANSI/ASHRAE/IES Standard 90.1-2022
(Supersedes ANSI/ASHRAE/IES Standard 90.1-2019)
Includes ANSI/ASHRAE/IES addenda listed in Appendix M

Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings (I-P Edition)

See Informative Appendix M for dates of approval by ASHRAE, the Illuminating Engineering Society, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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 ISSN 1041-2336

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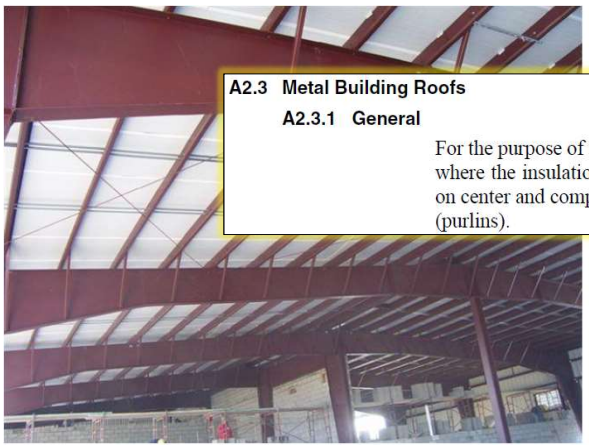
Opaque Envelope – R-value Method

- 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.

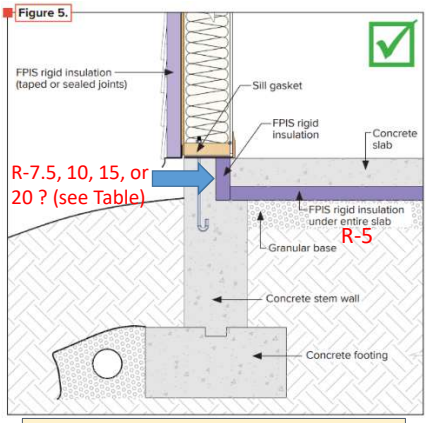
c. Advanced framing with insulated headers: Wood framing at 24 in. on center with cavities filled with 22.5 in. wide insulation for both 3.5 in. deep and 5.5 in. deep *wall* cavities. Double header cavities are insulated. Weighting factors are 78% insulated cavity, 18% studs, plates, and sills, and 4% 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 insulation components shall be installed in accordance with Section C402.2.4.
- 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 unheated and heated slab insulation in Section C402.2.4 (specific insulation and installation 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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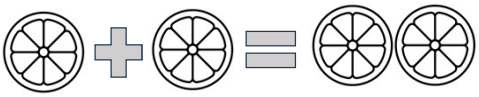
Opaque Envelope – R-value Method

- **C402.1.3.1 R-value of multi-layered insulation components**
  - 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't argue with figures. Two half nuthins is a whole nuthin'.
(Foghorn Leghorn, Warner Bros.)



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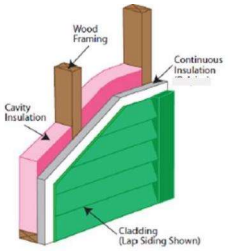
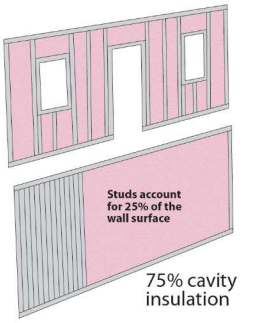
Opaque Envelope – R-value Method

- Example of an R-value summation non-compliance for a wood frame wall (e.g., R-20 + R-5ci ≠ R25) based on Parallel Path analysis for wood frame walls (shown earlier)

	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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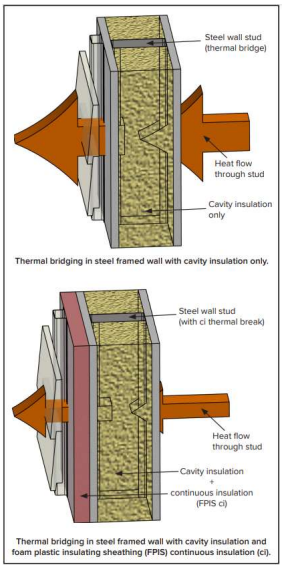
Opaque Envelope – R-value Method

- 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 a additional separate layer of cavity insulation and requires compliance through U-factor analysis of assembly (coming in ASHRAE 90.1-2025 Appendix A and proposed for 2027 IECC-C)

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 → 2024 IECC: R-0 + 15.2ci / R-13 + 10ci / R-20 + 9ci
      ("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

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

- **C402.1.3.2 Area-weighted averaging of R-values.**
  - Shall not be permitted for R-value compliance.
  - **Exception:** For tapered above-deck roof insulation, compliance with the R-values required in Table C402.1.3 shall be permitted to be demonstrated by multiplying the rated R-value per inch of the insulation material by the average thickness of roof insulation. The average thickness of roof insulation shall be equal to the total volume of the roof insulation divided by the area of the roof.
- This method is commonly used by tapered, above-deck roof industry and provided on shop drawings for roof insulation and drainage layout.
- As noted earlier in Section C402.1.2.1.1, this exception allows U-factor to be determined as the inverse of the area-averaged R-value of tapered roof insulation.

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Opaque Envelope – R-value Method

- **C402.1.3.3 Suspended ceilings.** Insulation installed on suspended ceilings having removable ceiling tiles shall not be considered part of the minimum thermal resistance (*R-value*) of roof insulation in roof-ceiling construction.
- **C402.1.3 Mass walls and mass floors.**
  - Mass walls and floors must meet minimum weight lbs/sqft (psf) or heat capacity requirements
  - Mass Walls: min. 35 psf, or 25 psf and max 120 pcf material, or heat capacity > 7 Btu/ft2 –F, or heat capacity > 5 Btu/ft2-F and max 120 pcf material.
  - Mass Floors: similar criteria
- *Where to find this data to determine if a mass wall (concrete, masonry, or wood/CLT) is a mass wall and can use the mass wall R-value or U-factors?* – see ASHRAE 90.1 Appendix A

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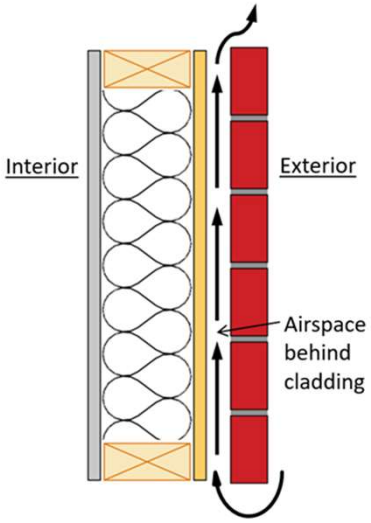
C402.2 Specific insulation and installation requirements



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

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Opaque Envelope – R-value Method

- **C402.1.5 Rooms containing fuel-burning appliances.**
  - Climate Zones 3-8
  - Combustion air provided through openings in exterior wall to a room or space containing a space-conditioning fuel-burning appliance
  - One of the following shall apply:
    1. The room or space is located outside the BTE, or
    2. The room or space is enclosed and isolated from the conditioned spaces inside the BTE. Such rooms shall comply with the following:
       - 2.1 Separation walls insulated as below grade walls per Table C402.1.3 or Table C402.1.2
       - 2.2 The walls, floors and ceilings shall be sealed in accordance with Section C402.6.1.2
       - 2.3 Doors fully gasketed.
       - 2.4 Heating/cooling system and water service piping shall be insulated per C403 and C404

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C402.2 Specific insulation and installation requirements

NEW 2024: Applies to both U-factor and R-value compliance, not just for R-values. Also, 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).

- C402.2.1 Roof-ceiling assembly
- C402.2.2 Above-grade walls
- C402.2.3 Floors over outdoor air or unconditioned space
- C402.2.4 Slabs-on-grade
- C402.2.5 Below-grade walls
- C402.2.6 Insulation of radiant heating systems
- C402.2.7 Airspaces

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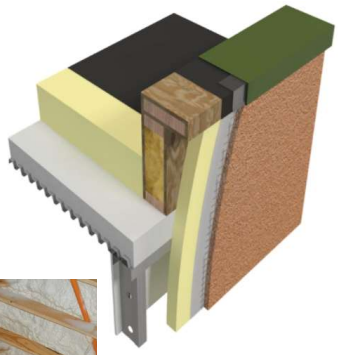
C402.2 Specific insulation and installation requirements

- **C402.2.1 Roof-ceiling construction**
  - Acknowledges insulation installed in multiple locations (between ceiling or roof framing, continuously above, below or within roof deck, or any approved combination).
  - Insulation above the roof deck shall comply with Sections C402.2.1.1 through C402.2.1.3.



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C402.2 Specific insulation and installation requirements

- **C402.2.1.1 Joints staggered.** Roof insulation located above the roof deck "shall be installed in not less than two layers and the edge joints between each layer shall be staggered, except were insulation tapers to the roof deck at gutter edge, roof drain, or scupper.
- **C402.2.1.2 Skylight curbs.** Must be insulated to the "level" of the above-deck roof insulation (R-value) 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
- **C402.2.1.3 Minimum thickness of tapered insulation.** The minimum thickness of tapered above-deck roof insulation at its lowest point, gutter edge, roof drain or scupper, shall not be less than 1 inch.

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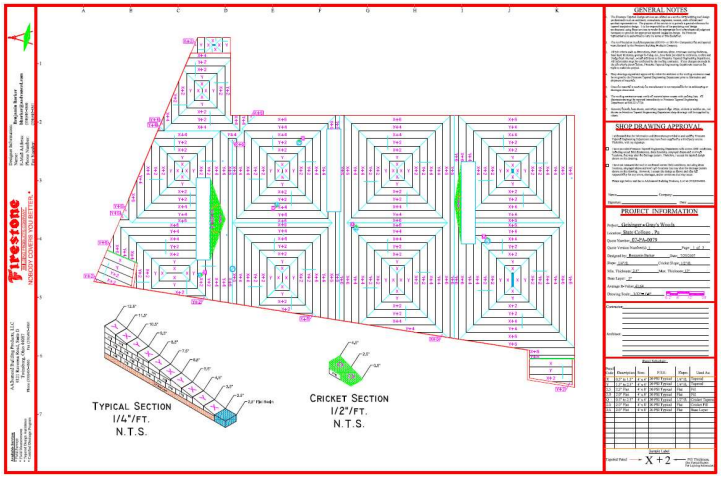
C402.2 Specific insulation and installation requirements

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



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C402.2 Specific insulation and installation requirements

- **C402.2.2 Above-grade walls**

Above-grade wall insulation materials shall be installed between the wall framing, be integral to the wall assembly, be continuous on the wall assembly, or be any combination of these insulation methods. Where *continuous insulation* is layered on the exterior side of a wall assembly, the joints shall be staggered.

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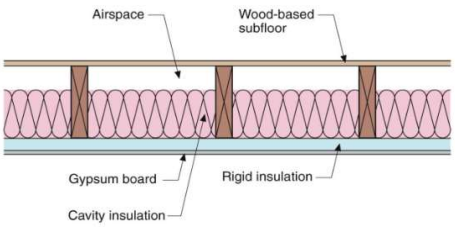
C402.2 Specific insulation and installation requirements

- **C402.2.3 Floors over outdoor air or unconditioned space.**
- Acknowledges installation "between floor framing, integral to the floor assembly, continuous on the floor assembly, or any combination of these insulation methods."
- Layered continuous insulation must have joints staggered.
- Cavity insulation or structural slab floor insulation shall be installed in permanent contact with the underside of subfloor decking or structural slabs.

EXCEPTION

Photo by Shaunna Mozingo



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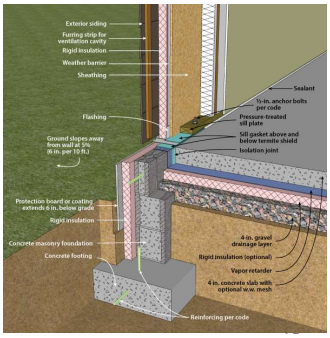
C402.2 Specific insulation and installation requirements

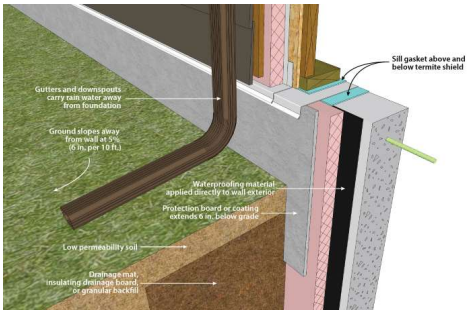
- **C402.2.4 Slabs-on-grade.** Where installed, the **perimeter insulation** for slab-on-grade shall be placed on the outside of the foundation or on the inside of the foundation wall. For installations complying with **Table C402.1.3**, the perimeter insulation shall extend downward from the top of 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. 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 (610 mm) below the finished exterior grade, perimeter insulation is not required.

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



C402.2 Specific insulation and installation requirements

- **C402.2.5 Below-grade walls.** Below-grade wall insulation shall be installed between framing members, be integral to the wall assembly, be continuous on the wall assembly, or be any combination of these insulation methods. For installations complying with **Section C401.2.1**, insulation 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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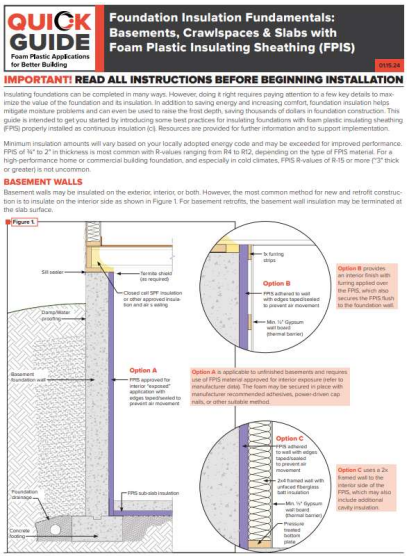
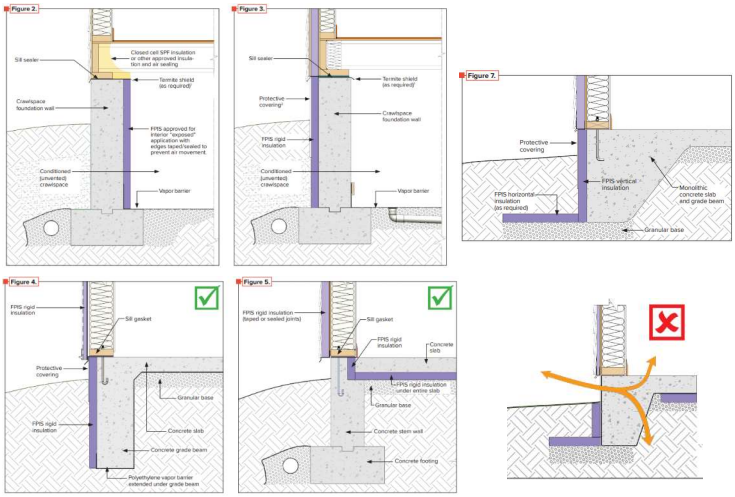
Foundation Insulation Fundamentals





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

C402.2 Specific insulation and installation 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~~. C402.1.2

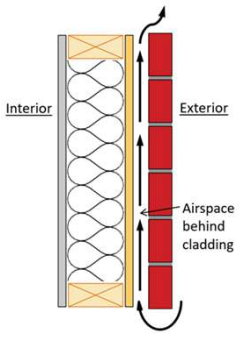
Exception: ~~Heated slabs on grade insulated in accordance with Section C402.2.4.~~

C402.2 Specific insulation and installation requirements

C402.2.7 Airspaces. Where the R-value of an airspace is used for compliance in accordance with Section C402.1, the airspace shall be enclosed in a cavity bounded on all sides by building components and constructed to minimize airflow into and out of the enclosed airspace. Airflow shall be deemed minimized where one of the following conditions occur:

1. The enclosed airspace is unventilated.
2. The enclosed airspace is bounded on at least one side by an anchored masonry veneer, construction in accordance with Chapter 14 of the IBC and vented by veneer weep holes located only at the bottom of the airspace and spaced not less than 15 on center with top of cavity airspace closed.

Exception: For ventilated cavities, the effect of the ventilation 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.

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C402.2 Specific insulation and installation 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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C402.4 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]

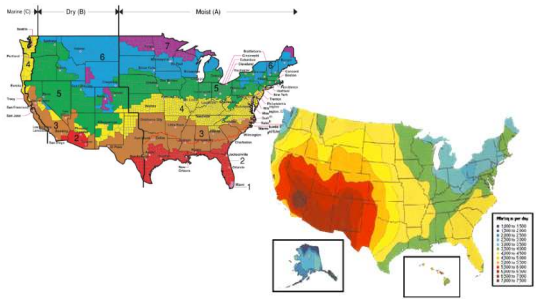
Three-year-aged solar reflectance index[b] of 55 and 3-year aged thermal emittance[c] of 0.75
Three-year-aged solar reflectance index[d] of 64

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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C402.4 Roof solar reflectance and thermal emittance

- Several exceptions…

NEW 2024: **Section C402.3 Above-grade wall solar reflectance** – Similar requirements added for above grade wall solar reflectance only 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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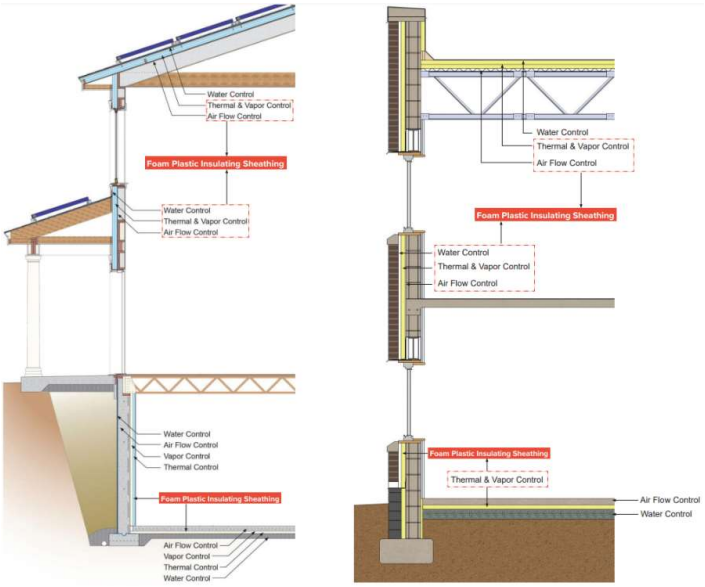
2024 IECC – New Thermal Bridging Requirements

- What?
- Why?
- How?



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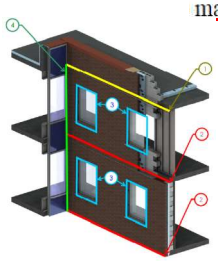
2021 IECC – wall definition included thermal bridging

- Again, definitions matter…

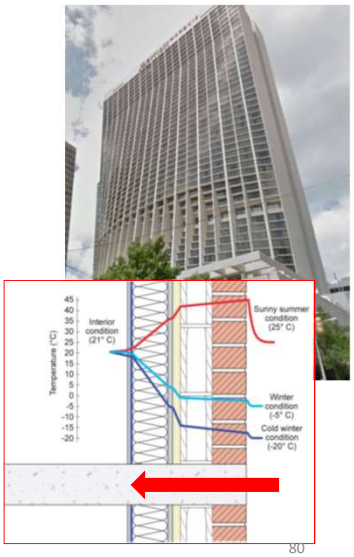
WALL, ABOVE-GRADE. A wall associated with the *building thermal envelope* that is more than 15 percent above grade and is on the exterior of the building or any wall that is associated with the *building thermal envelope* that is not on the exterior of the building. This includes, but is not limited 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: This 2021 definition change requires that 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.



80

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?

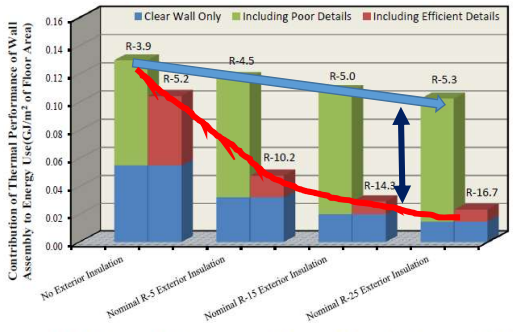


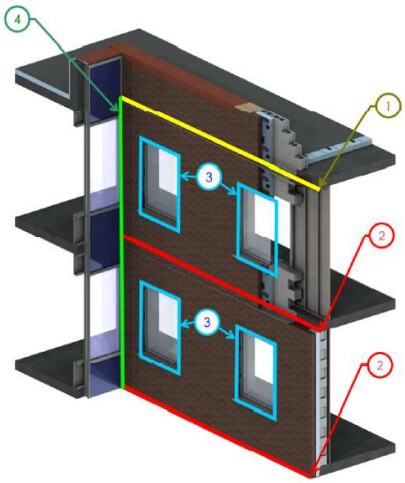
Figure 4.7: Additional building energy use based on thermal performance of the building wall assembly for varying amounts of nominal exterior insulation for a mid-rise MURB in Edmonton (overall assembly thermal resistance in $ft^2 \cdot °F \cdot h/Btu$ also given)

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

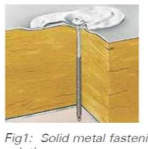


Fig1: Solid metal fastening solution

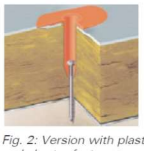
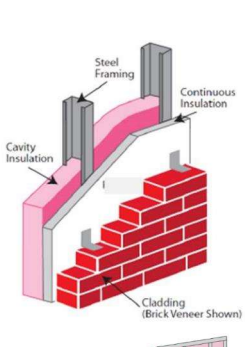
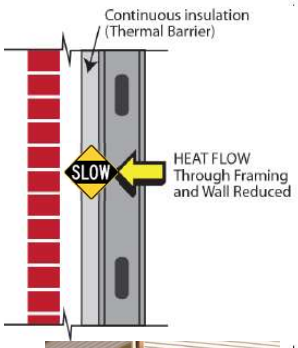
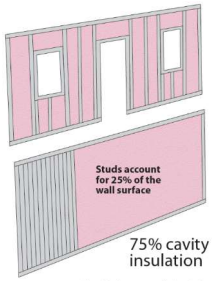


Fig. 2: Version with plastic sleeve and shorter fastener



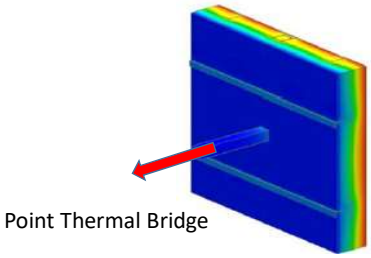




25% studs ("thermal bridges")

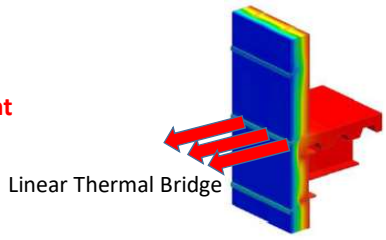
2024 IECC Definitions

- **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 Element

Source: Morrison Hershfield LTD
ASHRAE RP 1365



Linear Element

Source: Morrison Hershfield LTD
ASHRAE RP 1365

2024 IECC-C Code Provisions for Thermal Bridging

- **C105.2 Information on construction documents.**
  - Requires thermal bridges per C402.7 to be identified on plans
- **C402.7 Thermal bridges in above-grade walls.**
  - Provides prescriptive insulation & detailing solutions (with exemptions, exceptions, and design alternatives) for:
    - C402.7.1 Balconies and floor decks
    - C402.7.2 Cladding supports
    - C402.7.3 Structural beams and columns
    - C402.7.4 Vertical fenestration
    - C402.7.5 Parapets

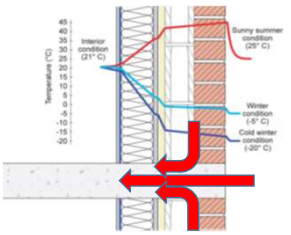
Similar thermal bridging provisions also in ASHRAE 90.1-2022

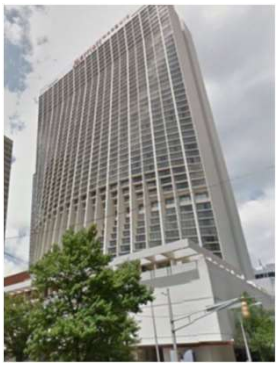
- **C402.1.2.1.8 Mechanical equipment penetrations** (discussed earlier)
- **C402.1.4 Component performance method** (includes thermal bridges in envelope trade-offs)
- **C407 / Table C407.4.1(1)** – includes thermal bridging in whole building simulation

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 C402.7.

  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

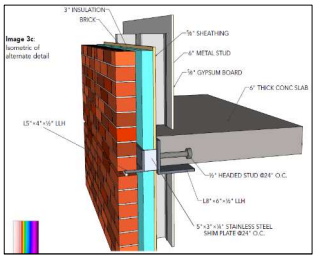
2024 IECC – Prescriptive TBM

- **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.

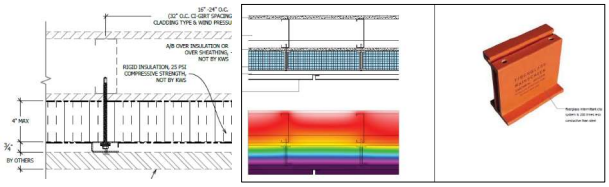
  Exceptions:

  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 2024 IBC Section 1404.5 (formerly 2603.12/.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.

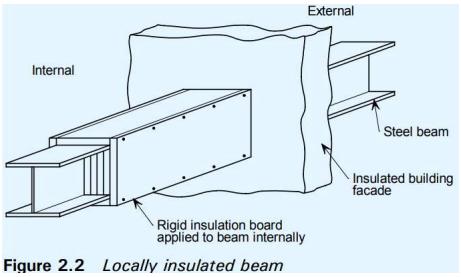
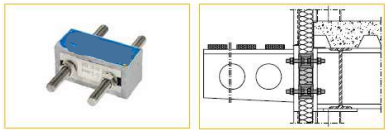


Figure 2.2 *Locally insulated beam*

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* .

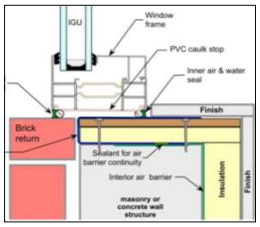
  3. The surface of the rough opening, not covered by the fenestration frame, shall be insulated with insulation of not less than R-3 material or covered with a wood buck that is not less than 1.5 inches (457 mm) thick.

  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*.

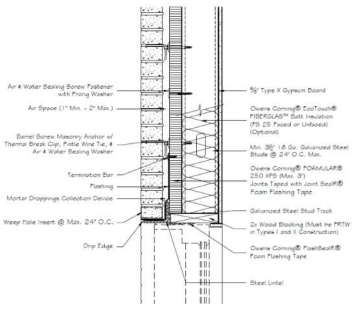
  Exceptions:

  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.



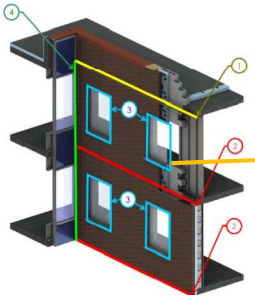
INSULATED WINDOW ROUGH OPENING DETAIL (USACE report)



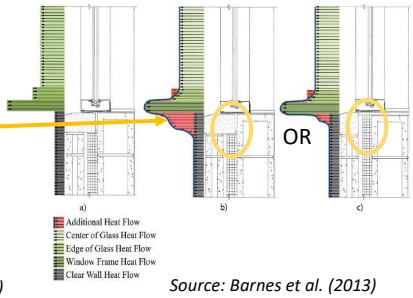
Source: Owens Corning, Enclosure Solutions NFPA 285 Guide, May 2019

Mitigating Thermal Bridging at Fenestration-Wall Interface

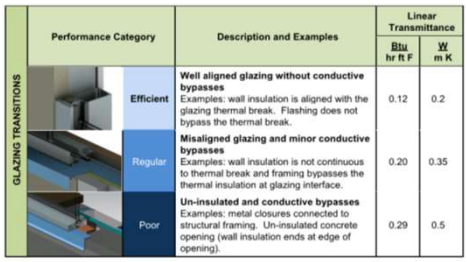
- Linear thermal bridge around perimeter of window opening
  - Not accounted for in window component U-factor
    (NFRC whole assembly U-factor does account for thermal bridging in the window frame, but not the surrounding materials.)
  - Not accounted for in wall clear-field assembly U-factor



Source: Morrison-Hershfield (2020)



Source: Barnes et al. (2013)

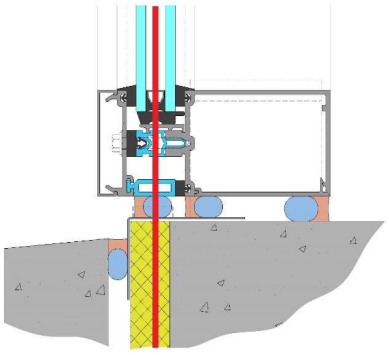


GLAZING TRANSITIONS	Performance Category	Description and Examples	Linear Transmittance Btu/hr ft F	Linear Transmittance W/m K
	Efficient	**Well aligned glazing without conductive bypasses** Examples: wall insulation is aligned with the glazing thermal break. Flashing does not bypass the thermal break.	0.12	0.2
	Regular	**Misaligned glazing and minor conductive bypasses** Examples: wall insulation is not continuous to thermal break and framing bypasses the thermal insulation at glazing interface.	0.20	0.35
	Poor	**Un-insulated and conductive bypasses** Examples: metal closures connected to structural framing. Un-insulated concrete opening (wall insulation ends at edge of opening).	0.29	0.5

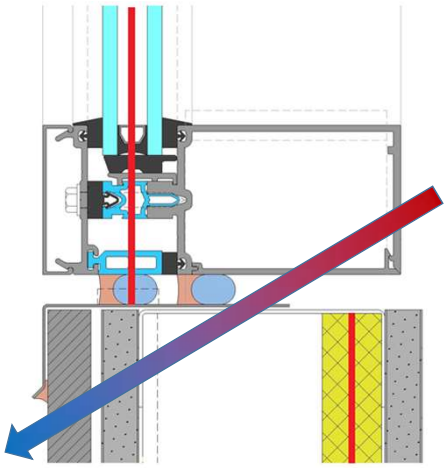
Source: Morrison-Hershfield (2020)

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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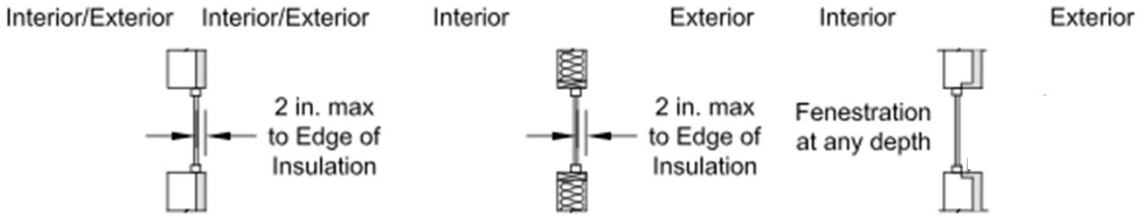
Mitigating Thermal Bridging at Fenestration-Wall Interface

- 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.

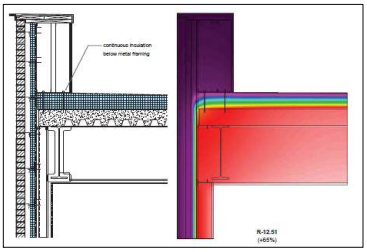
  2. Where continuous insulation is installed on the exterior side of the *above-grade wall* and the roof insulation is below the roof deck, the continuous insulation shall extend up the exterior side of the parapet to not less than the height of the top surface of the *roof assembly* .

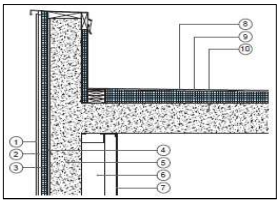
  3. Where continuous insulation is not installed on the exterior side of the *above-grade wall* and the roof is insulated with insulation entirely above deck, the wall cavity or integral insulation shall extend into the parapet up to the exterior face of the roof insulation or equivalent R-value insulation 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
(C402.5 and related)

(previously C402.4)

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Before we get into the detailed code requirements

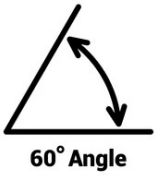
First, what is fenestration – and what is not – in the IECC?

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".

103

Fenestration Terminology - Low-E Coated Glass

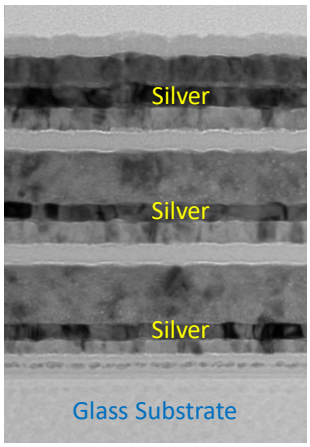
Besides computer chips, one of the first widespread uses of nanotechnology …

104

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

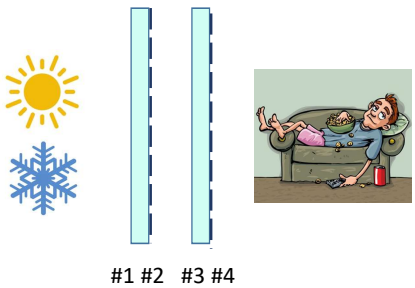


↕ 10 nm = 0.00000001 m

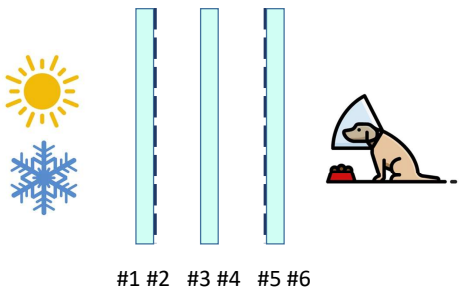
105

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

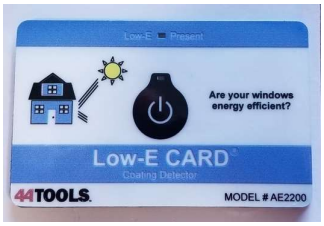


Low-e coating on just #2,
or both #2 and #5

106

Field Verification

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

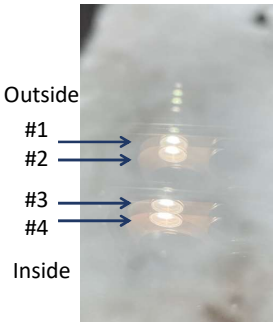


Easy and cheap
Can identify presence of low-e and which glass surface, although not what type of low-e.

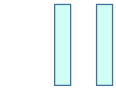
107

Field Verification

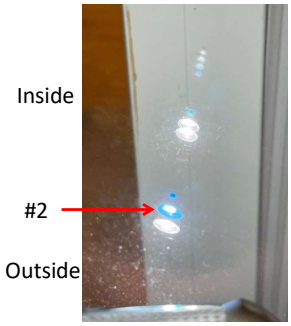
- With smart phone light, can see reflection from each glass surface … look for different color (blue, green, red) to identify low-e coating.



Double Clear

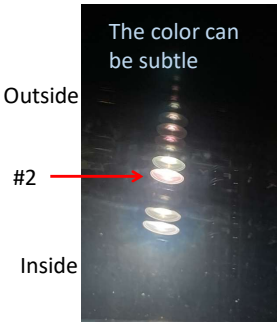


#1 #2 #3 #4



Double pane, low-e #2

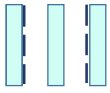
#1 #2 #3 #4



Double pane, low-e #2

#1 #2 #3 #4

Triple pane, low-e #2 + #5

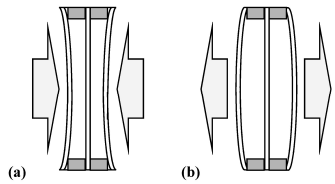


#1 #2 #3 #4 #5 #6

108

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 ”pre-equalized units” where the unit is manufactured with gas-fill for the proper final altitude.
  - Argon should be available for front range and up to 6500-7000 ft, and up to 12,000 ft with these pre-equalized units.
- 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.



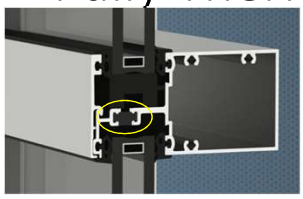
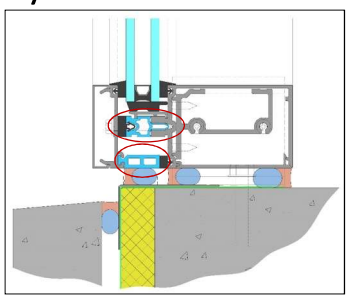
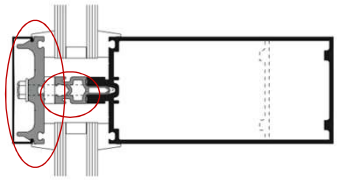
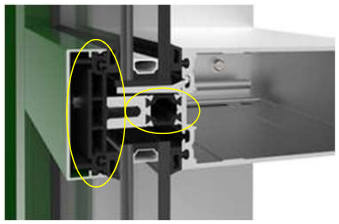
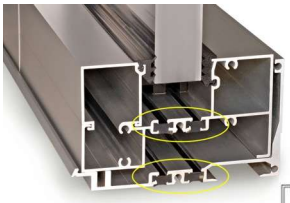
109

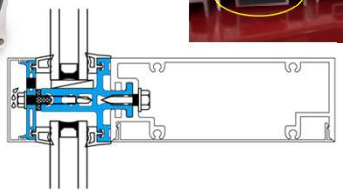
Fenestration Terminology – Thermally Broken Frames

- 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.

110

Fully Thermally Broken Frames




111

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.

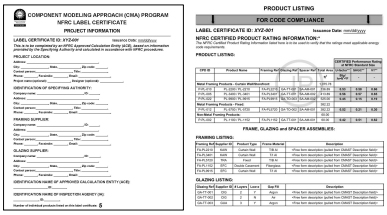
113

C303.1.3 Ratings for Fenestration Code Compliance

NFRC label

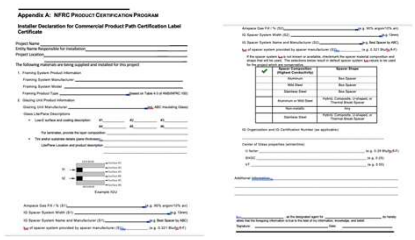
(primarily residential windows)

NFRC label certificate (CMA)



(commercial projects)

NFRC commercial product installer declaration



(commercial products)

- Unfortunately, current NFRC commercial program has not been widely used. (Cadmus report found < ½ % of projects use certified ratings.)
- NFRC is launching a new more streamlined rating method for commercial projects called the "Commercial Trendline Approach (CTA)".
- One "custom project" path with certificate for all products on a building, and one "product directory" path with ratings for individual products but with flexibility for combining different framing systems with different glazing options.

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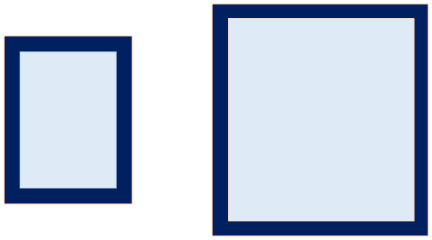
Fenestration Ratings – Size Matters

- 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.

115

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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C402.5 Fenestration Requirements - Area

Base level prescriptive maximums in C402.5.1:

- 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. (C402.5.1.1 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

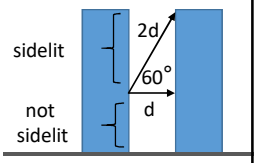
- Daylight responsive controls must be installed in the daylight zones.
- For increased vertical fenestration area,
  - At least 50% of net floor area must be in daylight zones for 1-2 story buildings.
  - At least 25% of net floor area must be in daylight zones for 3+ story buildings.
    (For this 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* …

120

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*. (C402.5.4 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.

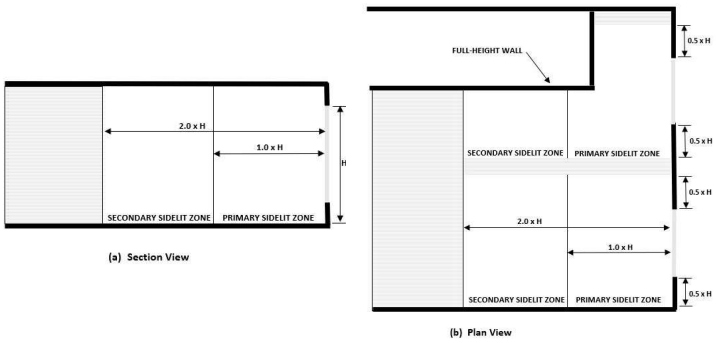
  (Still ok to have the above, just doesn't count as a sidelit daylight zone.)



121

Sidelit Daylight Zones

- 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 were cut in half, e.g. from 150 to 75 W in primary.

- Daylight controls required when > 75 W general lighting in primary zone, > 150 W general lighting in primary + secondary zone.
  New: exception for enclosed office spaces less than 250 square feet.
- Secondary zone not considered when determining if can use increased vertical fenestration area in section C402.5.1.1, only primary sidelit + toplit daylight zones.

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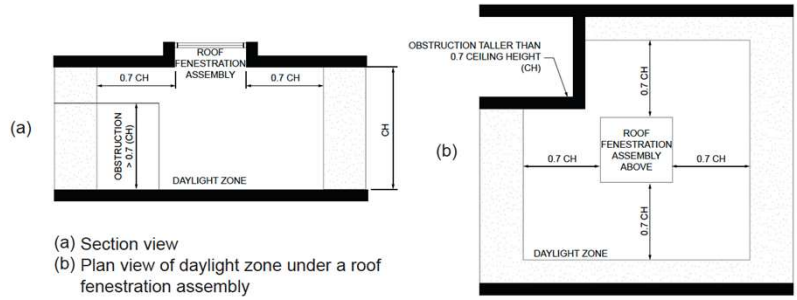
Toplit Daylight Zones

- 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

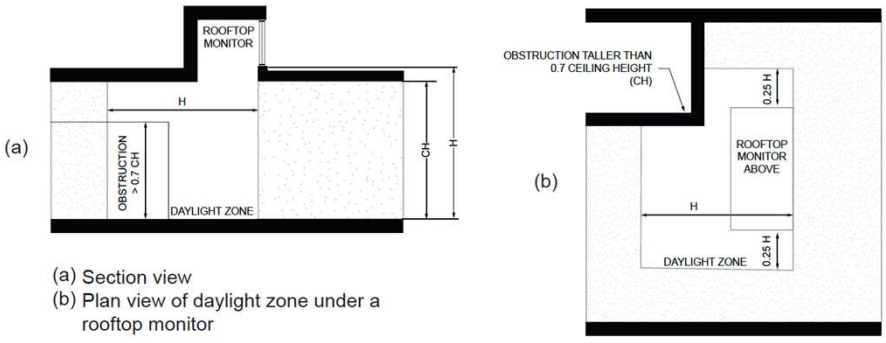
FIGURE C405.2.4.3
TOPLIT DAYLIGHT ZONE

- 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 > 75 W general lighting in toplit zone.
  (New for 2024 IECC – threshold cut in half.)

123

Other Daylight Zones Considerations – Rooftop Monitors

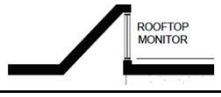
- Daylight zones under rooftop monitors are considered sidelit zones even though coming from above, because related to vertical fenestration.



(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

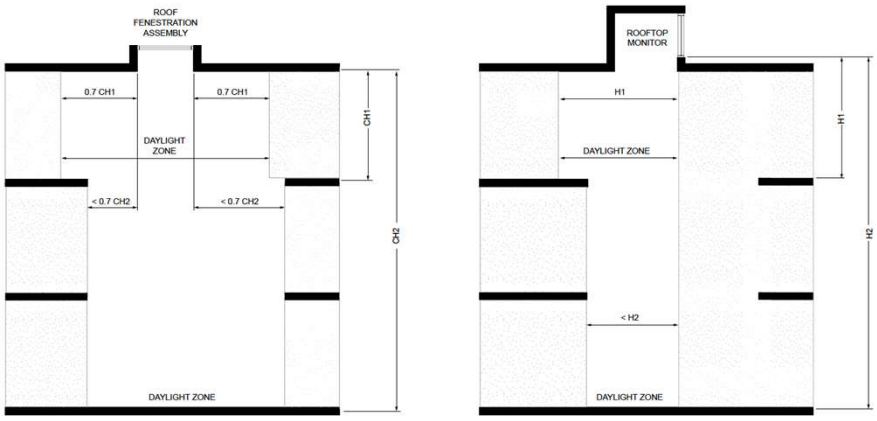
Same for rectangular or sloped rooftop monitors:



124

Other Daylight Zones Considerations - Atriums

- Multistory atriums handled based on top and bottom floors (not i



(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

- 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 C402.5.1.1 or C402.5.2.
  - 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 > 75 W in primary, > 150 W in primary + secondary, or > 75 W in toplit zones?
    - Note: C405.2.4 has certain exceptions for patient care, retail, small enclosed offices.

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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 functional testing as part of final commissioning (C408.3.1.3)

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Minimum Toplighting in Certain Spaces (C402.5.2)

- 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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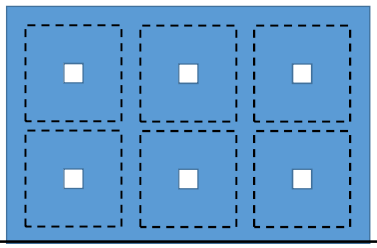
Minimum Toplighting in Certain Spaces (C402.5.2)

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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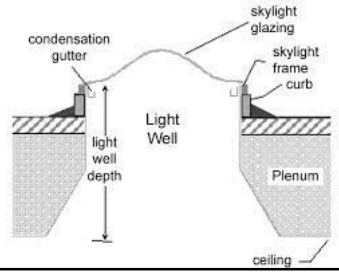
Minimum Toplighting in Certain Spaces (C402.5.2)

- 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 C402.1.4 Component Performance Alternative.
   - UA based trade-off that allows alterative U-factors and areas across the entire envelope (walls, roofs, floors, vertical fenestration, skylights). New: account for thermal bridging too.
   - 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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C402.5.3 Fenestration Requirements – U-factor

- Prescriptive maximum U-factor from Table C402.5

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 and 2022 values are the same

2024 IECC

Zone	4	5	6	7
Fixed vertical fenestration	**0.34**	**0.34**	0.34	**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 are like 2021 IECC, so not perfectly aligned with 2024 IECC

So what does this mean in terms of real windows?

C402.5.3 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 for 2025.

ROUGHLY what is needed to meet U-factor?

- **Zone 4-6:** Low-e double glazing, thermally broken frame and ***pick 3***:
  (used to be aboe to just pick 2)
  - 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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C402.5.3 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

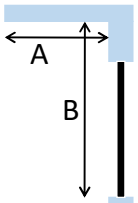

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Table C402.5 Prescriptive SHGC

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	

- For vertical fenestration, separate SHGC for fixed vs. operable products is listed, similar to U-factor.
- 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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C402.5.3 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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C402.5.3 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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C402.5.5 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 C402.5.

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C402.6.3 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 C402.1.4 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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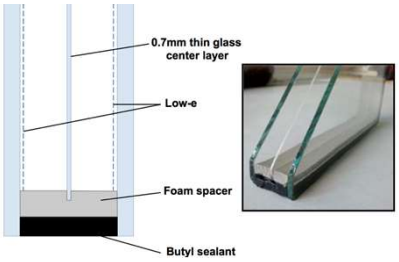
New fenestration technologies you may see

- Higher performance products and new technologies can get credit in:
  - C402.1.4 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)

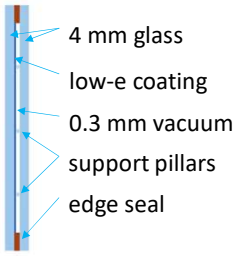
Thin triples with krypton

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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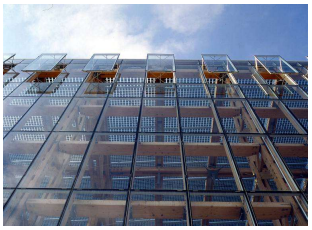
New fenestration technologies you may see

- 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 Method (C402.1.4)
- Air leakage (C402.6)
- Additional Efficiency, Renewable and Load Management Requirements / "Credits" (C406)
- Simulated Building Performance (C407)

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C402.1.4 Component Performance Method

"Envelope Trade-off Method"

C402.1.4 Component performance method. Building thermal envelope values and fenestration areas determined in accordance with Equation 4-1 shall be an alternative to compliance with the U-, F-, psi- and chi-, and C-factors in Tables C402.1.2, C402.1.2.1.7, C402.1.4 and C402.5 and the maximum allowable fenestration areas in Section C402.5.1. Fenestration shall meet the applicable SHGC requirements of Section C402.5.3.

$$A_P + B_P + C_P + T_P \leq A_T + B_T + C_T + T_T - V_F - V_S \quad \text{(Eq. 4-1)}$$

Subscripts: P = proposed, T = based on tabulated baseline values

- Provides a simplified building take-off and "math" approach to allow for trade-offs between BTE components
- Baseline performance is defined by maximum U-, F-, C-factor requirements in Table C402.1.2 (opaque assemblies), C402.1.2.1.7 (spandrels), C402.1.4 (thermal bridges), and Table C402.5 (fenestration)
- 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 4-1.
  - Also COMcheck is in progress to update to 2024 code and include new features for thermal bridges and spandrels.

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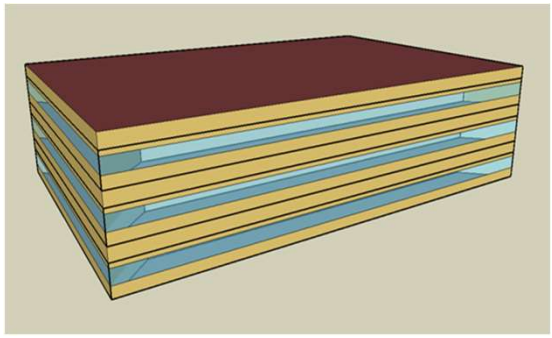
C402.1.4 Component Performance Method

- **Simple Office Building Example:**
- Climate Zone 4 A/B
- 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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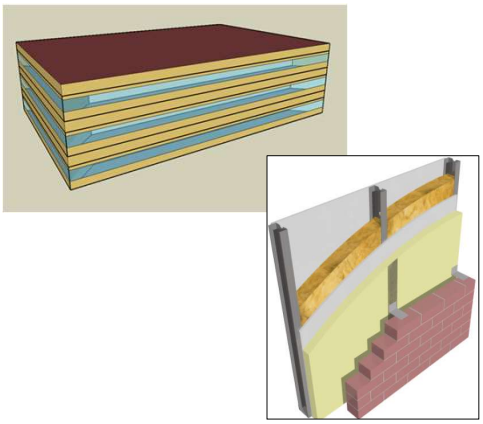
C402.1.4 Component Performance Method



- Determine A_P and A_T for **Walls**:
- Opaque Wall Area = 15,014 sqft
- U-factor Table = 0.055 (e.g., R13+10ci)
- U-factor Proposed = 0.064 (R13+7.5ci)
- A_P_wall = (0.064)(15,014 sqft) = **961**
- A_T_wall = (0.055)(15,014 sqft) = **826**
  - NOTE: The proposed wall UA is greater than than the UA based on tabulated max U-factors (less efficient); this will need to be offset by decreases in UA (more efficient) other components.

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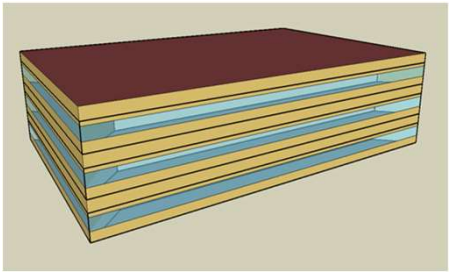
C402.1.4 Component Performance Method



- WHAT ABOUT WALL SPANDRELS?
  - If some or all of the spandrels are part of a fenestration system, then a separate A_P value would need to be determined for those wall spandrel portions using the default (table) U-factors in Table C402.1.2.1.7 for the proposed spandrel U-factor, unless other manufacturer/approved data is used. The Ap_wall and Ap_spandrel values would then be added together.
  - The At_wall value is unchanged as that is the baseline UA for the overall opaque wall area of the building.

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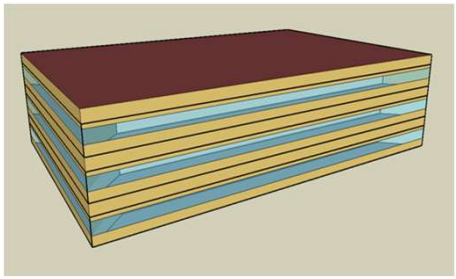
C402.1.4 Component Performance Method



- Determine A_P and A_T for **Fenestration**:
- Vertical fenestration area = 6,435 sqft
- 6,267 sqft fixed windows, 168 sqft glazed entrance doors, no skylights
- U-factor Table = 0.34 fixed windows, 0.63 entrance doors
- U-factor Proposed = 0.32 fixed windows, 0.77 entrance doors
- A_P_win = (0.32)(6267) = **2,005**
- A_T_win = (0.34)(6267) = **2,131**
- A_P_dr = (0.77)(168) = **129**
- A_T_dr = (0.63)(168) = **106**

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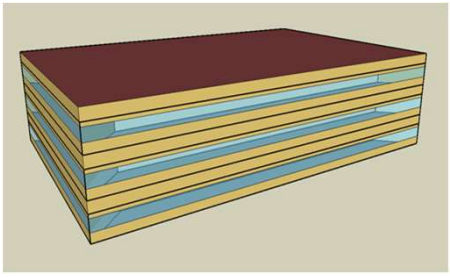
C402.1.4 Component Performance Method



- Determine V_F for excess vertical fenestration area
  - Fenestration/Glazing Area = 6,435 sqft
  - Glazing Area is 30%
  - Glazing area is less than or equal to the vertical glazing area allowed by Section C402.4.1
  - Therefore, **V_F = 0**
  - We'll do an example later with excess vertical glazing ($V_F > 0$)

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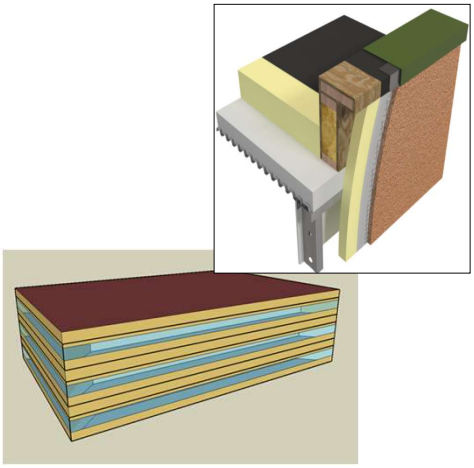
C402.1.4 Component Performance Method



- Determine A_P and A_T for **Roof**:
- Opaque Roof Area = 17,887 sqft
- U-factor Table = 0.032 (R-30ci)
- U-factor Proposed = 0.032 (R-30ci)
- A_P_roof = (0.032)(17,887) = **572**
- A_T_roof = (0.032)(17,887) = **572**

Determine A_P and A_T for **skylights**

- No skylights (or < 3% of roof area)
- A_P_skylgt = A_T_skylgt = **0**

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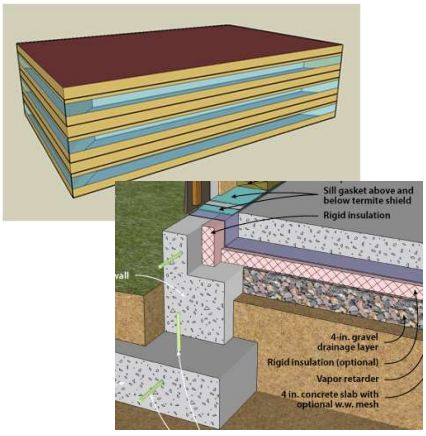
C402.1.4 Component Performance Method



- Determine B_P and B_T 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)
- B_P = 0.36(546 ft) = **197**
- B_T = 0.52(546 ft) = **284**

RECOMMENDATION: For more accurate F-factors and adjustments for slab edge height above- or below grade, refer to new Appendix RF in 2024 IECC-R. Not an issue if using COMcheck.

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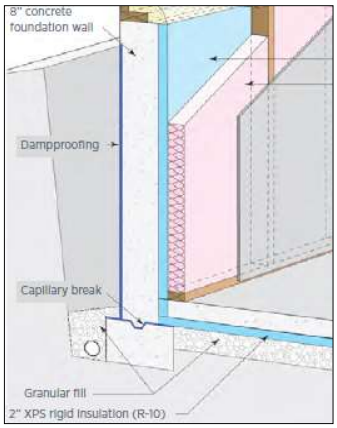
C402.1.4 Component Performance Method



- Determine C_P and C_T for **below-grade walls**:
  - No below-grade walls
  - **$C_P = C_T = 0$**

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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C402.1.4 Component Performance Method

- Tabulated values for thermal bridges (T_T)

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 NONCOMPLIANT WITH SECTION C402.7	
	Psi-Factor (Btu/h × ft × °F)	Chi-Factor (Btu/h × °F)	Psi-Factor (Btu/h × ft × °F)	Chi-Factor (Btu/h × °F)
C402.7.1 Balconies and floor 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

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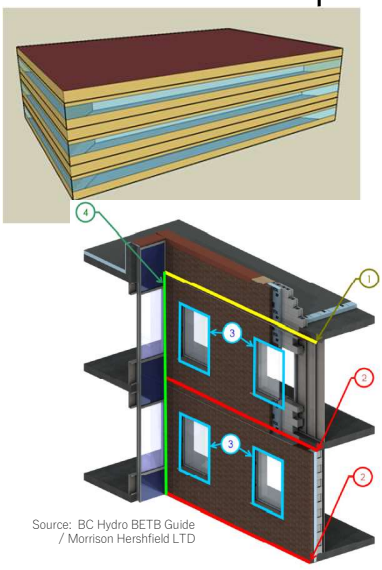
C402.1.4 Component Performance Method



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

- <u>Determine T_P and T_T for **thermal bridges**:</u>
- **Floor deck/edges,** length = 2 intermediate floors x {2(164 ft) + 2(109 ft)} = 1,092 ft
  - Psi-factor table = 0.2 (offset shelf angle per C402.7.1)
  - Psi-factor proposed = 0.2 (same)
  - T_P_fldeck = 0.2(1,092) = **218**
  - T_T_fldeck = 0.2(1,092) = **218**
- NOTE: Slab-on-grade floor edge addressed by F-factor (same as a Psi-factor)
- **Parapet,** length = 2(164 ft) + 2(109 ft) = 546 ft
  - Psi-factor table = 0.2 (insulated both sides)
  - Psi-factor proposed = 0.4 (insulated one side)
  - T_P_para = 0.4(546) = **218**
  - T_T_para = 0.2(546) = **109**

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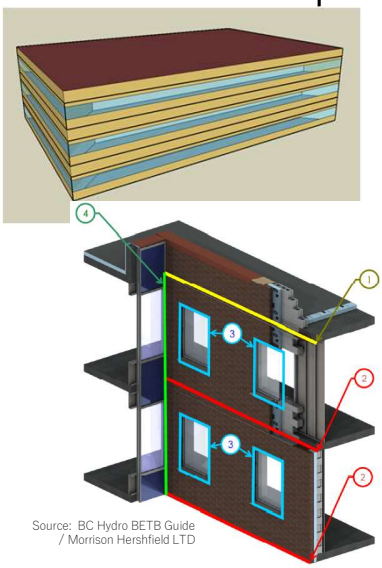
C402.1.4 Component Performance Method



Source: BC Hydro BETB Guide / Morrison Hershfield LTD

- Determine T_P and T_T for thermal bridges:
- No structural beam/column penetrations
  - Chi-factor table x count = T_T_beam/col = 0
  - Chi-factor proposed x count = T_T_beam/col = 0
- Window-wall intersection length = 6 x {2(164 ft) + 2(109 ft)} = 3,276 ft
  - Psi-factor table = 0.15 (per detail options in C402.7.4)
  - Psi-factor proposed = 0.10 (improved detail by thermal analysis, testing, or approved source)
  - T_P_win-wall = 0.10(3,276) = **328**
  - T_T_win-wall = 0.15(3,276) = **491**

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C402.1.4 Component Performance Method

- Now, sum and summarize all parameters:
  - ΣA_P = 961+2005+129+572 = **3,667** — R13+7.5ci walls, U-0.32 fixed windows, U-0.77 entrance door, & R-30ci roof insulation entirely above deck
  - ΣB_P = **197** — R-10ci, fully insulated slab (F-0.36)
  - ΣC_P = 0 — No below-grade walls
  - ΣT_P = 218+218+328 = **764** — Proposed thermal bridge details and associated Psi-/Chi- factors
  - ΣA_T = 826+2131+109+572 = **3,638** — Baseline using tabulated U-factors
  - ΣB_T = **284** — Baseline using tabulated F-factors
  - ΣC_T = 0 — No below-grade walls using tabulated C-factors
  - ΣT_T = 218+109+491 = **818** — Baseline using tabulated "compliant" thermal bridge Psi- / Chi-factors
  - V_F = 0 — Windows < 30% gross wall area (no excess area)
  - V_S = 0 — No skylights (thus, no excess skylight area)
- SOLVE:
- $A_P + B_P + C_P + T_P \leq A_T + B_T + C_T + T_T - V_F - V_S$ (Eq. 4-1)
- Proposed: 3,667 + 197 + 0 + 764 = **4,628** **vs.** Baseline: 3,638 + 284 + 0 + 818 = **4,740**
  - **Proposed < Baseline → OK – compliant!**

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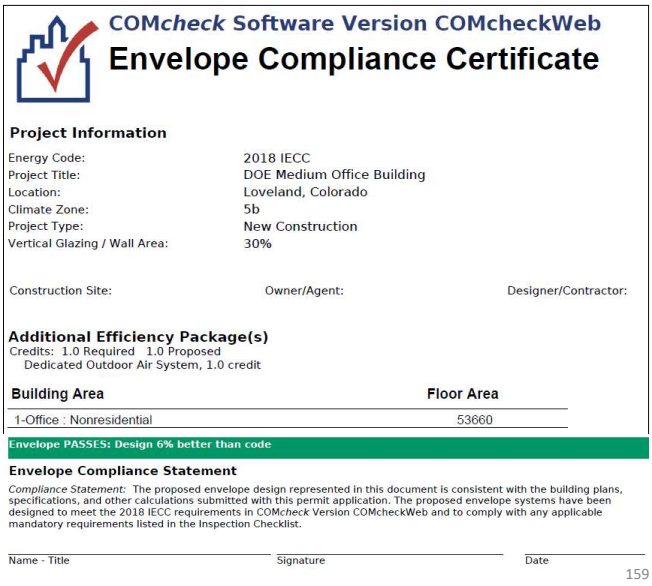
C402.1.4 Component Performance Method

- COMcheck as alternative to C402.1.4
- Automates envelope trade-offs
- Provides energy based trade-offs instead of heat transfer coefficient basis
- More accurate
- 2024 IECC version is pending and should include additional features for thermal bridges, etc.



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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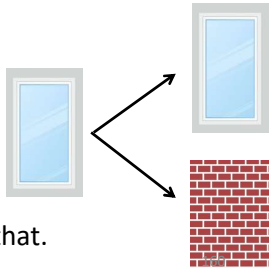
C402.1.4 Component Performance Method

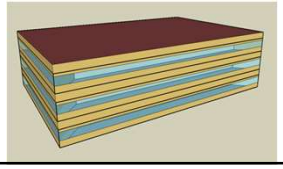
- How do you handle buildings that exceed baseline fenestration area in C402.4.1?
  - Max baseline vertical fenestration area
    = 30% of gross above-grade wall area
    = 40% if meet daylighting requirements in C402.4.1.1
  - Max baseline skylight area
    = 3% of gross roof area
    = 6% if meet daylighting requirements in C402.4.1.2
- COMcheck will handle it automatically.
- C402.1.4 handles excess area in terms V_F and V_S.
- 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.



C402.1.4 Component Performance Method

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 Ap term like before but with new areas and change roof to R-35ci (U-0.028) instead of R-30ci
  = 686 (walls) + 501 (roofs) + 3378 (windows) + 129 (doors) = 4694
- Do same for A_T terms like before but with new areas
  = 590 (walls) + 572 (roofs) + 3589 (windows) + 106 (doors) = 4857
- Bp (slabs) = 197, Cp (below-grade walls) = 0, V_S (excess skylights) = 0 same as before
- Tp (thermal bridging) = 764 is the same because linear window-wall length doesn't change in this simplified case, but would likely change in a real project.



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C402.1.4 Component Performance Method

Same example as before, but with 50% vertical fenestration.

- V_F term adjusts for the excess vertical fenestration area.
- Excess fenestration area compared to the wall it is replacing:
- R_F (excess area) = 10724 – 6435 = 4289 sqft based on 30% WWR
  For 40% with daylighting, it would be 10724 – 8579 = 2145
- S_F (average fenestration U-factor from table)
  = (0.34 × 10556 + 0.77 × 168)/10724 = 0.347
- T_F (average wall U-factor from table) = 0.055
- U_F = excess U for excess area = $S_F - T_F$ = 0.347 – 0.055 = 0.292
- $V_F = R_F \times U_F$ = 4289 × 0.292 = 1251

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C402.1.4 Component Performance Method

Same example as before, but with 50% vertical fenestration.

$A_P + B_P + C_P + T_P \leq A_T + B_T + C_T + T_T - V_F - V_S$ (Eq. 4-1)

- Proposed: 4,694 + 197 + 0 + 764 = **5,655** **vs.**
  Baseline: 4,857 + 284 + 0 + 818 – 1,215 - 0 = **4,707**
  - **Proposed > Baseline** → **fails**

- If add daylighting per C402.4.1.1, allowed more area so RF and VF are smaller.
  New baseline = 5,333. Compare 5,655 vs. 5,333.
  - **Closer, but proposed still > baseline** → **fails**

- If also use lower window 0.28 U-factor, new proposed = 5,233
  Compare 5,233 vs. 5,333
  - **proposed < baseline** → **passes!**

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C402.6 Air Leakage – building thermal envelope

- **C402.6 Air leakage.** Comply with all of the following (except CZ 2B):
- C402.6.1 Air barriers
  - C402.6.1.1 Air barrier design and documentation requirements
  - C402.6.1.2 Air barrier construction
- C402.6.2 Air leakage compliance
  - C402.6.2.1 Whole building test method and reporting
  - C402.6.2.2 Dwelling and sleeping unit enclosure method and reporting
- C402.6.3 Air leakage of fenestration and opaque doors
  Addressed in Tom's presentation
- Other related requirements (Sections C402.6.4 – C402.6.7) for access openings, vent dampers, vestibules, and loading dock weather seals

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C402.6 Air Leakage – building thermal envelope

- Major updates from 2021 IECC:
  - More sensible organization
  - Testing requirements and conditions clarified
  - Testing required for more building types/sizes/climate zones
  - Testing criteria made slightly more stringent (i.e., 0.35 cfm/ft^2 @ 75Pa instead of 0.40) for greater energy savings

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

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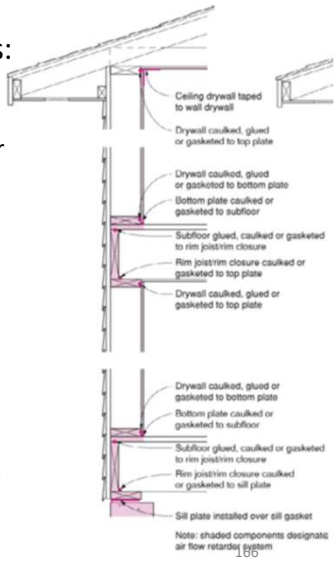
C402.6 Air Leakage – building thermal envelope

C402.6.1.1 Air barrier design and documentation requirements.

Design of the continuous air barrier shall be documented as follows:

1. Components and position of the AB shall be identified
2. Joints, interconnection and penetrations of AB shall be detailed.
3. Continuity of AB building element assemblies enclosing conditioned space (or separating from unconditioned space) shall be identified
4. Detail methods of sealing the AB (wrapping, caulking, gasketing, taping or other approved methods) at the following locations:
   1. Joints around fenestration/door frames
   2. Joints between building assemblies and components (e.g., walls-floors, wall-roof-parapet, etc.)
   3. Penetrations or attachment through the AB
   4. Building assemblies used as ducts or plenums
   5. Changes in AB materials and assemblies
5. Identify where testing will or will not be performed per Section C402.6.2 and, where not testing, provide a plan/schedule for periodic field inspections and corrective actions.



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C402.6 Air Leakage – building thermal envelope

- **C402.6.1.2 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 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 C402.6.1.2.1 (and other similar penetrating "objects" to maintain AB integrity).
5. Electric and communication boxes shall comply with C402.6.1.2.2

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C402.6 Air Leakage – building thermal envelope

- **C402.6.1.2.1 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
- **C402.6.1.2.2 Electrical and communication boxes**
- Shall comply with C402.6.1.2 or be air-sealed the air barrier penetrated and all concealed openings in the box sealed.
  - Air-sealed boxes shall be marked in accordance with NEMA OS4 and installed per manufacturer instructions

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C402.6 Air Leakage – building thermal envelope

- In 2021 IECC, air leakage testing requirements were confusing and difficult to determine when testing is required or not. One interpretation yields the following tabulation:

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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C402.6 Air Leakage – building thermal envelope

2024 IECC - Section C402.6.2 Air barrier compliance.

- Air leakage of the BTE shall be tested by an *approved* third party in accordance with Section C402.6.1
- Max air leakage rate reduced to 0.35 cfm/ft^2 @ 75 Pa where square footage is based on the above- and below-grade BTE surface area

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

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C402.6 Air Leakage – building thermal envelope

2024 IECC Section C402.6.2 Air barrier compliance.

- **Exceptions** (testing not required):
  - **Climate Zone 2B** exempted from testing or any air barrier installation and inspection requirement for all buildings.
  - **Buildings (other than Group I and R)** > 25,000 sf in CZ 0-4 that comply with periodic field inspection/verification of C402.6.2.3 are exempted from testing
  - **Group I-1 and R-2 buildings** are permitted to do dwelling/sleeping unit testing method (C402.6.2.2) at **ALR = 0.27 cfm/ft^2 @ 50 Pa** in lieu of whole building testing (C402.6.2.1)
  - **Allowance for "failed" test** where third party conducts diagnostic evaluation with visual inspection per ASTM E1186 and report specifying corrective action and retest showing ALR no greater than 0.45 cfm/ft^2@75Pa.

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

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C402.6 Air Leakage – building thermal envelope

C402.6.1.2 Whole building test method and reporting.

- Air leakage test method: ASTM E3158 (or equivalent approved method)
- A report documenting tested surface areas, floor area, air leakage by volume, stories above grade, and air leakage rates – submitted to code official and building owner
- Exceptions:
  - Buildings < 10,000 sqft permitted to be tested per ASTM E779, E3158, E1827 or equivalent approved method.
  - Buildings > 50,000 sqft shall be permitted to have portions tested with guidance regarding what portions require testing (i.e, story under roof, stories that have a building entrance, floor over unconditioned space, etc.)
    - Plus, remaining above-grade portions representing not less than 25% of the wall area enclosing the remaining condition space.

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C402.6 Air Leakage – building thermal envelope

C402.6.2.2 Dwelling and sleeping unit enclosure [test] method and reporting.

- Air leakage test methods: ASTM E779, E1827, or ANSI/RESNET/ICC 380
- Where multiple dwelling units or sleeping units or other spaces are contained within one building thermal envelope, each shall be considered an individual testing unit.
- Building air leakage shall be a weighted average of tested unit results
- Units shall be separately tested without simultaneously testing adjacent units
- Not less than 8 units tested or, where more than 8 units in a building the greater of 7 units or 20 percent of units shall be tested; three additional units shall be tested for each tested unit that exceeds the max leakage rate.
- Enclosed spaces (not dwelling/sleeping units) with at least one BTE exterior wall shall be tested per Section C402.6.2.1 with exceptions for certain floor areas not greater than 1,500 sqft where complying with C405.6.2.3 (inspection/verification) and either C402.6.2.3.1 (AB materials) or C402.6.2.3.2 (AB assemblies).

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C402.6 Air Leakage – building thermal envelope

- **C402.6.2.3 Building thermal envelope design and construction 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 C402.6.2.3.1 (AB materials) and C402.6.2.3.2 (AB assemblies) and make any necessary repairs
  3. A final inspection 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 identifies deficiencies and details of corrective measures applied.

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C402.6 Air Leakage – building thermal envelope

- **C402.6.2.3.1 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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C402.6 Air Leakage – building thermal envelope

- **C402.6.2.3.2 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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C402.6 Air Leakage – building thermal envelope

- **C402.6.3 Air leakage of fenestration and Opaque Doors.** Addressed by Tom
- **C402.6.4 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 by the IBC to comply with UL 1784

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C402.6 Air Leakage – building thermal envelope

- **C402.6.5 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.

- **C402.6.6 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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C402.6 Air Leakage – building thermal envelope

- **C402.6.6 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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C402.6 Air Leakage – building thermal envelope

- **C402.6.7 Loading dock weather seals.** Cargo door openings and loading door openings shall be equipped with weather seals that restrict *air leakage* and provide direct contact along the top and sides of vehicles that are parked in the doorway.

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C406 Additional Efficiency, Renewable and Load Management Requirements

- Completely overhauled in 2024 IECC and expanded to include load management measures
- Required credits vary by building occupancy group and climate zone (each credit point worth ~0.1% of whole building regulated energy use)
- Many more credit measures provided
- Six efficiency measures address building thermal envelope:
  - C405.2.1.1 Envelope performance (E01)
  - C406.2.1.2 UA reduction of 15% (E02, alternative to E01)
  - C406.2.1.3 Reduced air leakage by 10% (E03)
  - C406.2.1.4 Added roof insulation (E04) – can't combine with E01 or E02
  - C406.2.1.5 Added wall insulation (E05) – can't combine with E01 or E02
  - C406.2.1.6 Improve fenestration (E06) – can't combine with E01 or E02
- Credits award vary by building occupancy type and climate zone
- Some must be calculated (not selected from appropriate tables)

NOTE: Building Integrated PV is a part of on-site renewable energy credit - Addressed in Tom's presentation

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C406 Additional Efficiency, Renewable and Load Management Requirements

TABLE C406.1.1(1)
ENERGY CREDIT REQUIREMENTS BY BUILDING OCCUPANCY GROUP

BUILDING OCCUPANCY GROUP	CLIMATE ZONE																		
	0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
R-2, R-4 and I-1	65	66	67	77	80	86	80	81	90	86	90	90	86	90	90	70	89	80	78
I-2	43	42	38	37	36	38	32	32	30	36	36	35	43	43	44	46	47	50	53
R-1	63	62	66	65	70	71	77	80	84	81	83	88	85	86	90	83	87	87	85
B	62	62	64	66	66	65	64	64	68	70	72	74	71	73	77	71	74	74	71
A-2	70	70	72	72	75	75	70	73	82	69	74	78	67	72	78	60	67	57	51
M	80	79	83	79	81	84	67	74	87	80	66	65	79	62	50	75	67	75	58
E	56	57	55	58	58	57	59	62	59	61	66	62	64	67	67	65	67	63	58
S-1 and S-2	61	60	61	60	58	57	44	54	62	85	68	75	90	82	72	90	89	90	90
All other	31	31	31	32	32	33	30	32	36	35	35	35	37	36	36	36	37	36	34

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C406 Additional Efficiency, Renewable and Load Management Requirements

- Example table of credit value for selected measures

TABLE C406.2(1)
BASE ENERGY CREDITS FOR GROUP R-2, R-4 AND I-1 OCCUPANCIES[a]

ID	ENERGY CREDIT MEASURE	SECTION	CLIMATE ZONE																	
			0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
E01	Envelope performance	C406.2.1.1	Determined in accordance with Section C406.2.1.1																		
E02	UA reduction (15%)	C406.2.1.2	7	6	2	4	1	1	4	1	1	22	1	3	29	10	1	32	27	30	39
E03	Reduced air leakage	C406.2.1.3	15	10	12	8	6	16	13	5	1	7	7	9	65	16	11	73	43	52	26
E04	Add roof insulation	C406.2.1.4	1	1	1	1	1	1	4	3	1	5	3	4	6	5	4	7	7	6	8
E05	Add wall insulation	C406.2.1.5	10	10	6	8	5	6	8	4	1	8	3	4	11	7	3	14	12	13	13
E06	Improve fenestration	C406.2.1.6	7	7	4	6	9	11	13	3	1	22	5	10	27	18	7	41	33	22	21
H01	HVAC performance	C406.2.2.1	20	19	16	17	14	13	11	11	5	13	10	8	15	12	7	18	14	17	19
H02	Heating efficiency	C406.2.2.2	x	x	x	x	x	x	3	1	1	6	2	3	10	5	2	14	10	13	16
H03	Cooling efficiency	C406.2.2.3	7	6	4	4	3	3	1	1	1	1	1	1	1	1	x	x	x	x	x

Etc. Etc … many more measures

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Section C407 – Simulated Building Performance

- Simulated 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 Method, 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 requirements listed are C401.3 BTE certificate, C402.6 Air leakage, and a couple others (e.g., "joints staggered", "skylight curbs")
  2. Annual energy cost for the proposed design is less than the standard reference design (equivalent to a compliant prescriptive building, including adjustment to account for C406 credits required).
  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. C407.3 Documentation = compliance report, inspection checklist for the proposed design, modeling input and output reports, and documentation reduction in energy use (meaning imported energy use) associated with on-site renewable energy (which if used to trade-off building efficiency measures results in increased total building energy use).

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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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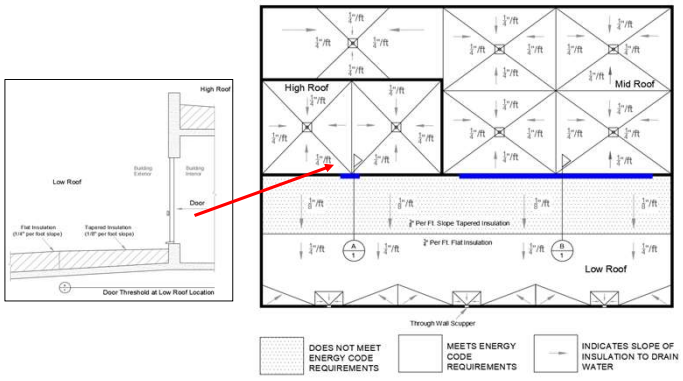
2024 C503.2.1 Roof, ceiling, and attic alterations

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

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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

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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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