Low Slope Roofing Systems
The University of Wisconsin Madison
Madison, Wisconsin – November 28-29, 2023

Roof insulation

presented by

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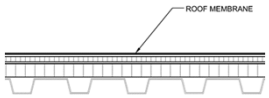
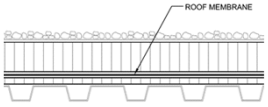
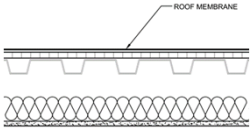
Roof assembly configurations



Conventional
Insulation above deck



Protected membrane
Insulation above membrane



Attic (or "other")
Insulation below deck

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Purpose(s) for insulation

Low-slope roof systems

- Thermal performance
- Condensation control
- Smooth substrate
- Deck stability
  - Reduce temperature variations
  - Control thermal expansion and contraction
- Fire resistance
- Roof slope
  - Above-deck tapered insulation

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Principles of thermal insulation

British thermal unit (Btu): the energy required to raise the temperature of 1 pound of water 1 degree Fahrenheit (F).

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Principles of thermal insulation

Thermal conductivity (k): the amount of heat is transmitted by conduction through 1 square foot of 1-inch-thick homogenous material in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the material.

$$k = Btu \bullet inch / ft^2 \bullet hr \bullet F$$

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Principles of thermal insulation

Thermal conductance (C): the amount of heat is transmitted by conduction through 1 square foot of a specified thickness of material in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the material.

$$C = Btu / ft^2 \bullet hr \bullet F$$

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Principles of thermal insulation

Thermal transmittance (U): the amount of heat is transmitted by conduction through 1 square foot of an assembly and its boundary layers in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the assembly.

$$U = Btu / ft^2 \bullet hr \bullet F$$

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R-values of boundary layer air films

Applicable to the inside and outside surfaces of assemblies

Surface	Condition	Resistance
Outside air film (f_o)	15 mph wind (winter) 7.5 mph wind (summer)	0.17 °F•ft²•h/Btu 0.25 °F•ft²•h/Btu
Inside air film (f_i)	Still air—horizontal surface[3] Heat flow upward (winter) Heat flow downward (summer)	 0.61 °F•ft²•h/Btu 0.92 °F•ft²•h/Btu

1. Values derived from Table 1, *2001 ASHRAE Handbook—Fundamentals*, page 25.4.
2. Surface air films exist on every surface. They are invisible layers of air that cling to the surface on a material and have some resistance to heat flow. Outside air films vary in thickness according to wind velocity; inside air films vary in effectiveness according to the direction of heat flow.
3. Inside air film values listed are for horizontal inside surfaces only. If the inside surface being evaluated is sloping or vertical, other thermal resistance values may apply; refer to Table 1, *2001 ASHRAE Handbook—Fundamentals*, page 25.4.

Figure 3-1: Thermal resistance values for air films

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Principles of thermal insulation

Thermal resistance: a relative measure of a material's or an assembly's resistance to heat flow; the reciprocal of the material's thermal conductance (C) or an assembly's thermal transmittance (U).

$$R = 1 / C \text{ or } R = 1 / U$$

R-values are readily additive (unlike k-values and C-values). Therefore $R_T = R_1 + R_2 + R_3 = \ldots$

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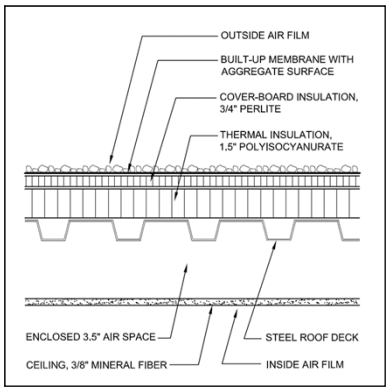
R-value calculations



Component	Heating Condition R-value	Cooling Condition R-value
Outside air film	0.17	0.25
Built-up membrane, aggregate surfaced	0.33	0.33
Insulation cover board, ¾-inch perlite board	2.08	2.08
Primary insulation, 1½-inch polyisocyanurate	7.50	8.40
Roof deck, steel	0.00	0.00
Enclosed air space, 3½ inches	0.93	1.24
Ceiling, ¾-inch mineral fiber	1.56	1.56
Inside air film	0.61	0.92
Total (R_T):	13.18	14.78

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R-values of enclosed spaces ("dead air")

Position of Air Space[3]	Condition[3]	Thickness of Air Space[4]	Thermal Resistance of Air Space[5]		
			Highly Reflective Roof Surface[6]	Moderately Reflective Roof Surface[7]	Non-Reflective Roof Surface[8]
Horizontal	Heat flow upward (winter)	0.75 inch 1.5 inches 3.5 inches	1.70°F•ft²•h/Btu 1.81°F•ft²•h/Btu 1.95°F•ft²•h/Btu	1.16°F•ft²•h/Btu 1.21°F•ft²•h/Btu 1.28°F•ft²•h/Btu	0.87°F•ft²•h/Btu 0.89°F•ft²•h/Btu 0.93°F•ft²•h/Btu
Horizontal	Heat flow downward (summer)	0.75 inch 1.5 inches 3.5 inches	2.41°F•ft²•h/Btu 3.27°F•ft²•h/Btu 4.09°F•ft²•h/Btu	1.45°F•ft²•h/Btu 1.73°F•ft²•h/Btu 1.93°F•ft²•h/Btu	1.02°F•ft²•h/Btu 1.15°F•ft²•h/Btu 1.24°F•ft²•h/Btu

1. Values derived from Tables 2 and 3, *2001 ASHRAE Handbook—Fundamentals*, pages 25.2 and 25.4.
2. Any air space where the air is not ventilated or otherwise allowed to freely move has some thermal resistance to heat flow. If the air space is ventilated or if the space is used as a plenum, the thermal resistance of the space and inside air film must be considered zero.
3. The thermal resistance values listed are for horizontal air spaces with the direction of heat flow either in an upward (winter) or downward (summer) direction. If the air space being evaluated is oriented in a sloping or vertical direction, other thermal resistance values may apply; refer to Tables 2 and 3, *2001 ASHRAE Handbook—Fundamentals*, pages 25.2 and 25.4.
4. Interpolation and moderate extrapolation for air spaces other than those listed is permissible.
5. Thermal resistance values based on 50 F mean temperature and 10 F temperature difference.
6. Values based on an Effective Emittance (ϵ_{eff}) of 0.20 with one surface with a reflectivity of 75-84 percent and the other surface with ϵ=0.90 (e.g., foil-surfaced modified bitumen membrane, mill finish aluminum panels).
7. Values based on an ϵ_{eff} of 0.50 with one surface with a reflectivity of 30-70 percent and the other surface with ϵ=0.90 (e.g., white membranes, smooth-surfaced membrane with a reflective coating).
8. Values based on an ϵ_{eff} of 0.82 with surfaces with a reflectivity of 5-15 percent (e.g., most aggregate-surfaced roofs, smooth-surfaced built-up roofs).

Figure 3-2: Thermal resistance values for enclosed air spaces

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Desirable properties for roof insulation

- Attachment capability
- Compatible with adhesives
- Compatible with other roof assembly components
- Compressive strength
- Dimensionally stable
- Fire resistant
- Impact resistance
- Moisture resistant
- Thermal resistant (low k-value or C-value/high R-value)
- Thermal resistance stability

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So, what is the "ideal" roof insulation?

There is no "ideal" roof insulation…

roof insulation selection and use is a compromise

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Roof insulation types

Rigid board insulation

- Cellular glass
- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)
- Faced gypsum
- Fiber-reinforced gypsum
- Mineral fiber (stone wool)
- Perlite
- Polyisocyanurate
- High-density polyisocyanurate
- Wood fiberboard
- Vacuum insulated panels

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Cellular glass

- Crushed glass and hydrogen sulfide gas heated to 950 F
- ASTM C552, Type IV
- 12” x 18”, 18” x 24” and 2’ x 4’
- 1½” to 6” and tapered
- R = 3.44 per inch

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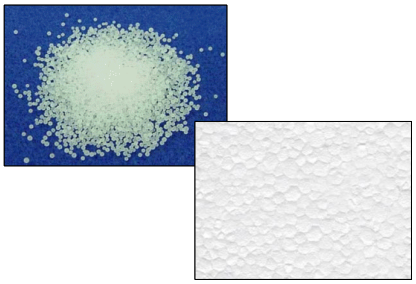
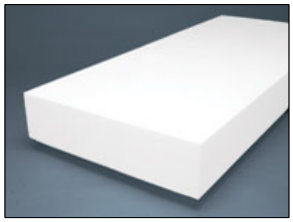
Expanded polystyrene (EPS)





- Polystyrene polymer, foaming agent and heat
- ASTM C578 (many types)
- 4’ x 4’ and 4’ and 8’
- ⅜” to 24”and tapered
- R = 3.1 to 4.3 per inch based upon density

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EPS types

ASTM C578, Type __

EPS type	Density, min. (pounds per cubic foot)	Compressive strength, min. (psi)	R-value
Type I*	0.90 (1.0 nominal)	10.0	3.6
Type II	1.35 (1.5 nominal)	15.0	4.0
Type VIII	1.15 (1.25 nominal)	13.0	3.8
Type IX	1.80 (2.0 nominal)	25.0	4.2
Type XI*	0.70 (0.75 nominal)	5.0	3.1
Type XIV	2.40 (2.5 nominal)	40.0	4.2
Type XV	2.85 (3.0 nominal)	60.0	4.3

* Type I and Type XI are generally not intended to be used in roofing applications

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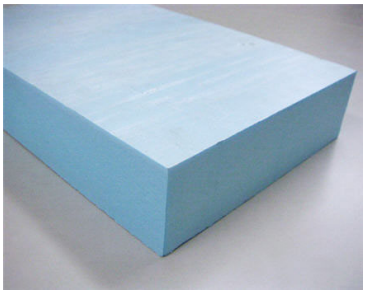
Extruded polystyrene (XPS)



- Polystyrene polymer is heated and extruded
- ASTM C578 (many types)
- 2’ x 4’ and 2’ x 8’
- 1”, 1½”, 2”, 2½”, 3” & 4”
- R = 4.6 to 5.0 per inch

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XPS types

ASTM C578, Type __

XPS type	Density, min. (pounds per cubic foot)	Compressive strength, min. (psi)	R-value
Type IV	1.45	25.0	5.0
Type V	3.00	100.0	5.0
Type VI	1.80	40.0	5.0
Type VII	2.20	60.0	5.0
Type X	1.30	15.0	5.0
Type XII*	1.20	15.0	4.6
Type XIII*	1.60	20.0	3.9

* Type XII and Type XIII are generally not intended to be used in roofing applications

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Faced gypsum

- Gypsum core between paper or fiberglass-mat facers
- ASTM C1396 (paper)
- ASTM C1177 (glass-mat)
- 4’ x 4’ and 4’ x 8’
- ¼”, ½” and ⅝” thick
- R = 1.12 per inch

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Fiber-reinforced gypsum

- Cellulose-fiber reinforced gypsum
- ASTM C1278
- 4’ x 4’ and 4’ x 8’
- ¼”, ⅜”, ½” and ⅝” thick
- R = 1.0 per inch

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Mineral fiber (stone wool)

- Rock, slag or glass heated and spun into fibers with a binding agent
- ASTM C726 or ASTM C612
- 4’ x 4’
- Up to 6” thick
- R = 4 per inch (10 pcf density)

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Perlite

- Expanded volcanic minerals, organic fibers and binders
- ASTM C728 (various types)
- 2’ x 4’ and 4’ x 4’
- ½”, ¾”, 1”, 1½”, 2” and tapered
- R = 2.78 per inch

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Perlite types

ASTM C728, Type __

- Type 1: Roof insulation board
- Type 2: Recover board
- Type 3: Recover board (higher physical properties)

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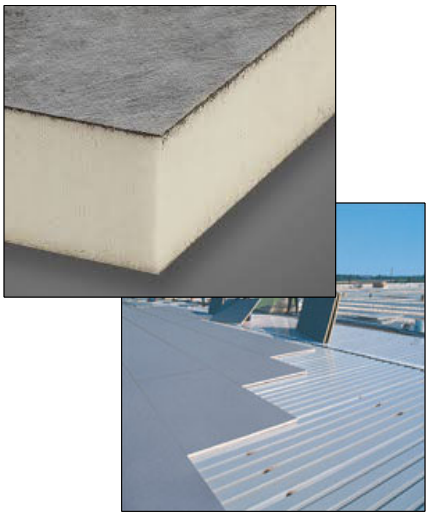
Polyisocyanurate



- Polyisocyanurate foam and facers
- ASTM C1289 (multiple types, grades and classes)
- 4’ x 4’ and 4’ x 8’
- Thicknesses range from 1” to 4”
- R = 5.0-6.0 per inch
- LTTR = 5.6 to 5.9 per inch

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Polyiso. type, grades and classes

ASTM C1289, Type II, Class __, Grade __

- Type II:
  - Class 1: organic/glass facer:
    - Grade 1: 16 psi (min.) compressive strength
    - Grade 2: 20 psi (min.) compressive strength
    - Grade 3: 25 psi (min.) compressive strength
  - Class 2: coated glass facer
  - Class 3: uncoated glass facer

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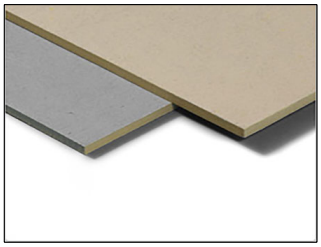
High density polyisocyanurate



- Polyisocyanurate foam and facers
- ASTM C1289, Type II, Class 4 (multiple grades)
- 4’ x 4’ and 4’ x 8’
- ¼” and ½” thick
- R = 1.0 for ¼” thick
  R = 2.0 for ½” thick

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HD polyiso. type, class and grades

ASTM C1289, Type III, Class 4, Grade __

- Type II:
  - Class 4: coated or uncoated glass mats:
    - Grade 1: 80 psi (min.) compressive strength
    - Grade 2: 110 psi (min.) compressive strength
    - Grade 3: 140 psi (min.) compressive strength

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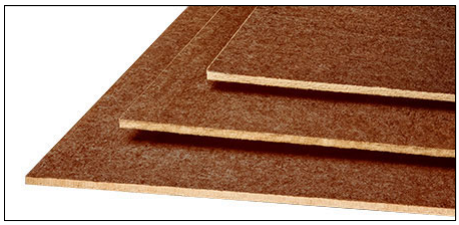
Wood fiberboard



- Wood or cane fibers and binders; may be coated
- ASTM C208, Type II (two grades)
- 2’ x 4’, 4’ x 4’ and 4’ x 8’
- ½”, 1” and 2’ thick
- R = 2.78 per inch

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Wood fiberboard grades

ASTM C208, Type II, Grade __

- ASTM C208, Type II:
  - Grade 1: For BUR and MB systems
  - Grade 2: For single-ply systems

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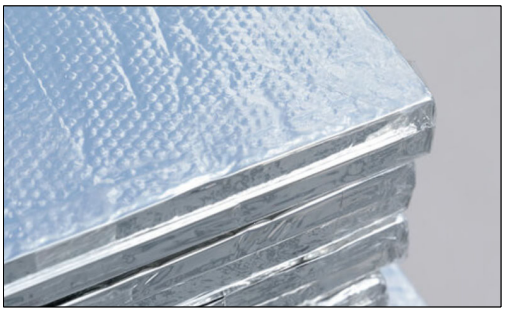
Vacuum insulated panels



- Microporous core, which is evacuated, encased and sealed in a thin, gas–tight, foil envelope
- ASTM C1484
- 2’ x 2’ and 2’ x 4’
- ¾- to about 2-inch thick
- R=28 per inch
- Cannot be cut or penetrated

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Added content

In-fill insulation

Vacuum insulated panels

Link to installation video

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Composite boards

- EPS and plywood/OSB
- Polyiso. and perlite, wood fiberboard, plywood/OSB or glass-mat-faced gypsum

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Board joints

Heat loss through gaps at the joints between insulation boards can represent up to a 10% reduction in effective R-value

A two-layer application rigid board insulation with staggered and offset board joints is recommended

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Mechanical fasteners

Mechanical fasteners through the cross-section of rigid board insulation can represent 3% to 8% losses in effective R-values.

Mechanically-attach the bottommost layer and adhere subsequent layers is preferred.

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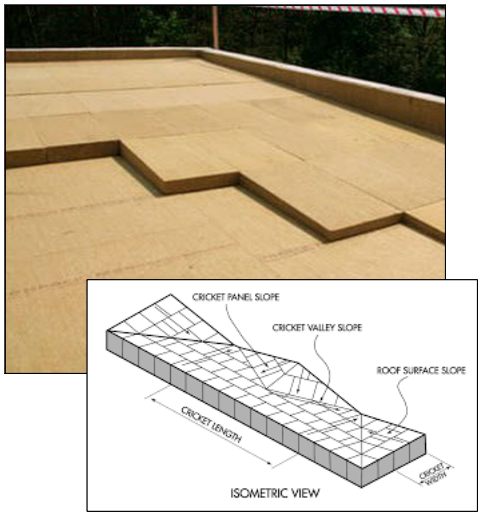
Tapered roof insulation



- Common materials:
  - EPS
  - XPS
  - Perlite
  - Polyisocyanurate
- Common slopes:
  - ⅛” per foot
  - ¼” per foot
  - ½” per foot

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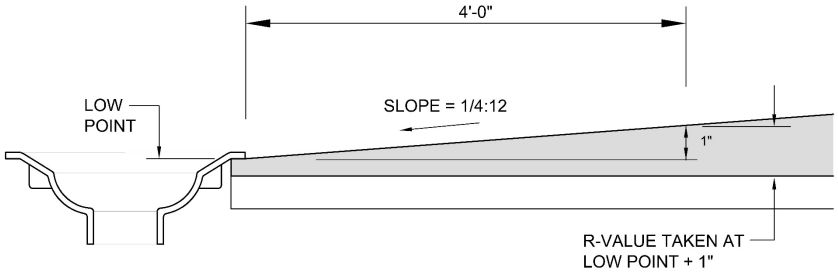
What is the R-value of tapered insulation…?

IBC 2018 and previous editions, Sec. C402.2-Roof Assembly , Exception 1 allows a 1-inch insulation thickness variation



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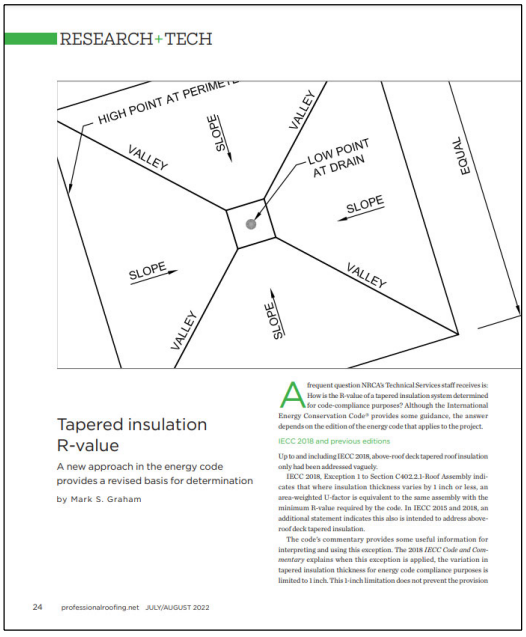
RESEARCH+TECH

HIGH POINT AT PERIMETER
VALLEY
SLOPE
VALLEY
LOW POINT AT DRAIN
SLOPE
SLOPE
VALLEY
VALLEY
SLOPE
EQUAL

Tapered insulation R-value

A new approach in the energy code provides a revised basis for determination

by Mark S. Graham

A frequent question NRCA's Technical Services staff receives is: How is the R-value of a tapered insulation system determined for code-compliance purposes? Although the International Energy Conservation Code® provides some guidance, the answer depends on the edition of the energy code that applies to the project.

IECC 2018 and previous editions

Up to and including IECC 2018, above-roof deck tapered roof insulation only had been addressed vaguely.

IECC 2018, Exception 1 to Section C402.2.1-Roof Assembly indicates that where insulation thickness varies by 1 inch or less, an area-weighted U-factor is equivalent to the same assembly with the minimum R-value required by the code. In IECC 2015 and 2018, an additional statement indicates this also is intended to address above-roof deck tapered insulation.

The code's commentary provides some useful information for interpreting and using this exception. The 2018 *IECC Code and Commentary* explains when this exception is applied, the variation in tapered insulation thickness for energy code compliance purposes is limited to 1 inch. This 1-inch limitation does not prevent the provision

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Tapered insulation R-value

Professional Roofing, July/August 2022

Link

Link to article applicable IECC 2018 and previous editions

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How much/what thickness of insulation is needed?

- Roof assembly's fire classification (Building Code)
- Energy Code's requirements

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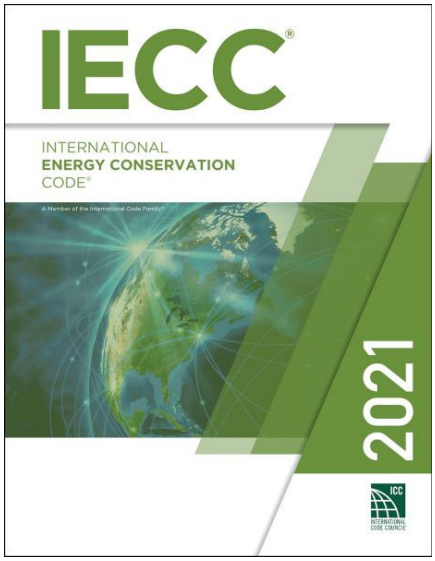

Roof requirements:

- Thermal efficiency
  - Multiple compliance paths
- Roof reflectivity (Commercial only)
- Air leakage
  - Multiple compliance paths

Separate requirements for Commercial (C) and Residential (R) buildings

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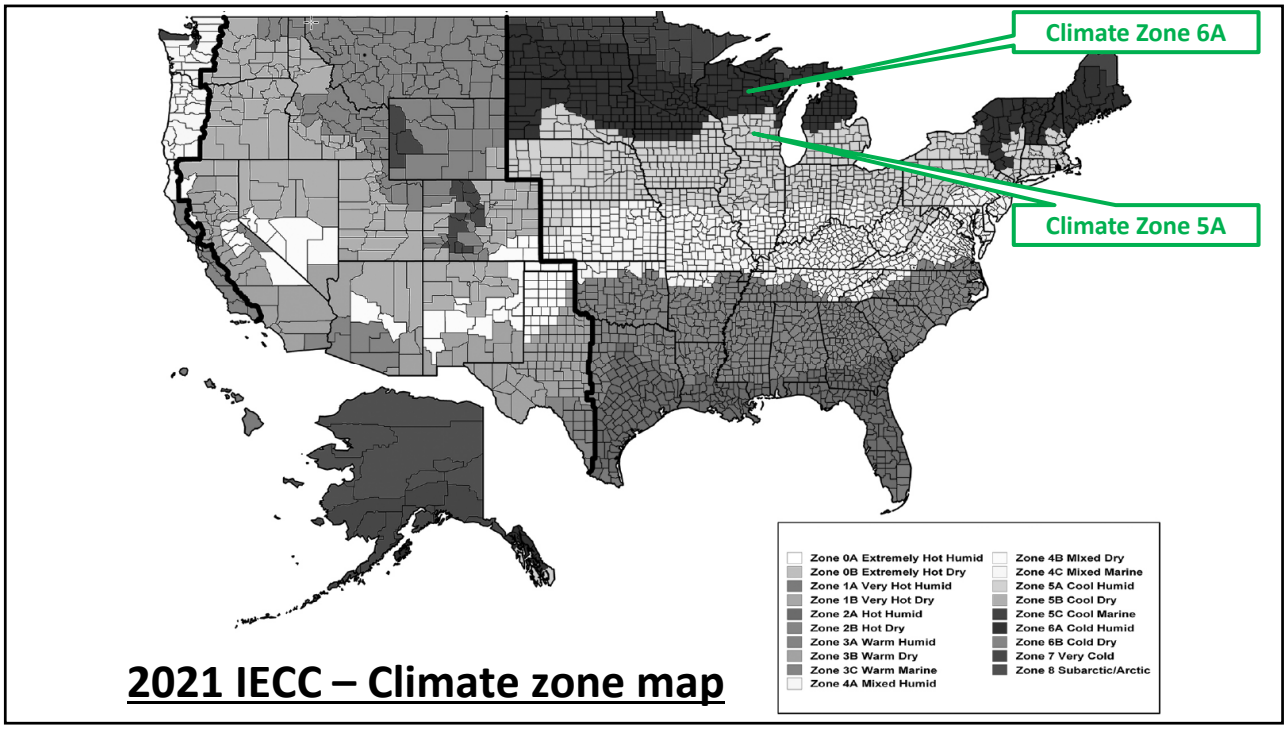

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TABLE C402.1.3
OPAQUE THERMAL ENVELOPE INSULATION COMPONENT MINIMUM REQUIREMENTS, *R*-VALUE METHOD[a]

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
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-7.5ci	R-13 + R-10ci	R-13 + R-10ci	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	NR	R-7.5ci	R-10ci	R-7.5ci	R-10ci	R-10ci	R-15ci	R-15ci	R-15ci	R-15ci
Floors																
Mass[e]	NR	NR	R-6.3ci	R-8.3ci	R-10ci	R-10ci	R-14.6ci	R-16.7ci	R-14.6ci	R-16.7ci	R-16.7ci	R-16.7ci	R-20.9ci	R-20.9ci	R-23ci	R-23ci
Joist/framing	R-13	R-13	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-38	R-38	R-38	R-38	R-38	R-38
Slab-on-grade floors																
Unheated slabs	NR	NR	NR	NR	NR	R-10 for 24" below	R-15 for 24" below	R-15 for 24" below	R-15 for 24" below	R-20 for 24" below	R-20 for 24" below	R-20 for 24" below	R-20 for 48" below	R-20 for 48" below	R-20 for 48" below	R-25 for 48" below
Heated slabs[g]	R-7.5 for 12" below+ R-5 full slab	R-7.5 for 12" below+ R-5 full slab	R-7.5 for 12" below+ R-5 full slab	R-7.5 for 12" below+ R-5 full slab	R-10 for 24" below+ R-5 full slab	R-10 for 24" below+ R-5 full slab	R-15 for 24" below+ R-5 full slab	R-15 for 24" below+ R-5 full slab	R-15 for 36" below+ R-5 full slab	R-15 for 36" below+ R-5 full slab	R-15 for 36" below+ R-5 full slab	R-20 for 48" below+ R-5 full slab	R-20 for 48" below+ R-5 full slab	R-20 for 48" below+ R-5 full slab	R-20 for 48" below+ R-5 full slab	R-20 for 48" below+ R-5 full slab

For SI: 1 inch = 25.4 mm, 1 pound per square foot = 4.88 kg/m², 1 pound per cubic foot = 16 kg/m³.
ci = Continuous Insulation, NR = No Requirement, LS = Liner System.
a. Assembly descriptions can be found in ANSI/ASHRAE/IESNA 90.1 Appendix A.
b. Where using *R*-value compliance method, a thermal spacer block shall be provided, otherwise use the *U*-factor compliance method in Table C402.1.4.
c. R-5.7ci is allowed to be substituted with concrete block walls complying with ASTM C90, ungrouted or partially grouted at 32 inches or less on center vertically and 48 inches or less on center horizontally, with ungrouted cores filled with materials having a maximum thermal conductivity of 0.44 Btu-in/h-ft² °F.
d. Where heated slabs are below grade, below-grade walls shall comply with the exterior insulation requirements for heated slabs.
e. "Mass floors" shall be in accordance with Section C402.2.3.
f. "Mass walls" shall be in accordance with Section C402.2.2.
g. The first value is for perimeter insulation and the second value is for full, under-slab insulation. Perimeter insulation is not required to extend below the bottom of the slab.

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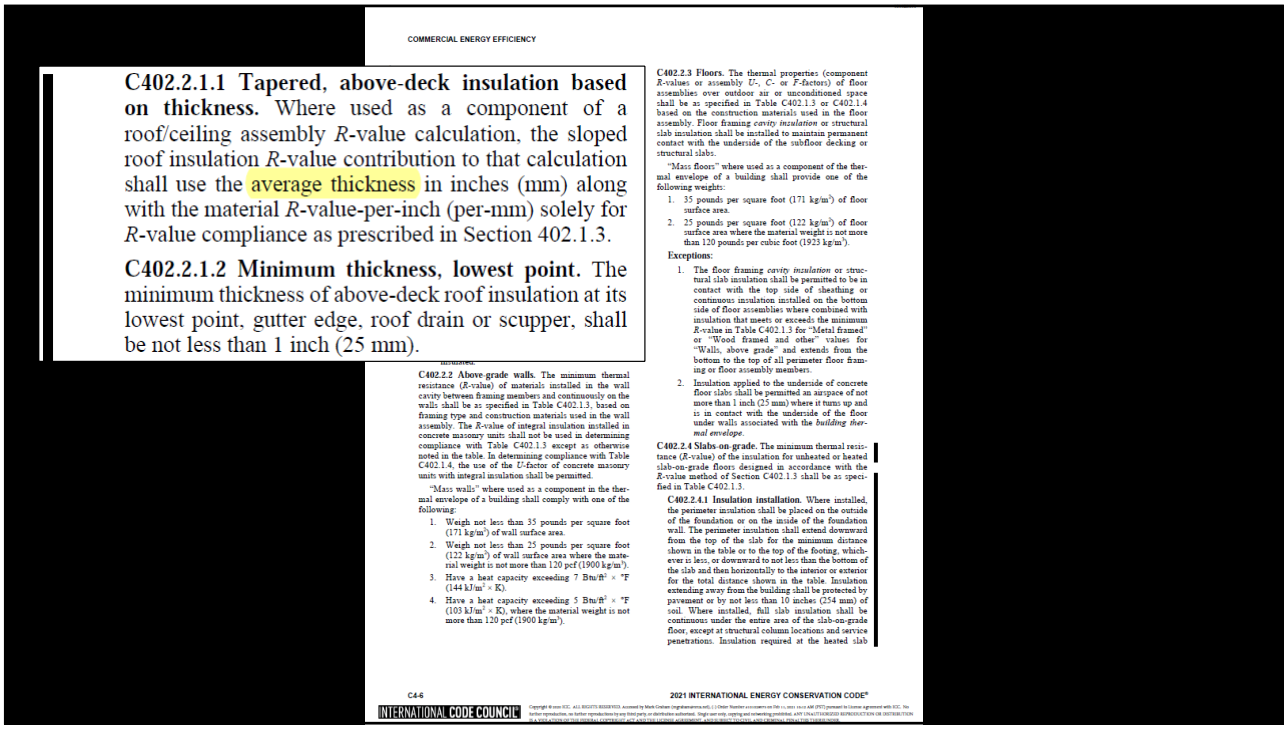
C402.2.1.1 Tapered, above-deck insulation based on thickness. Where used as a component of a roof/ceiling assembly *R*-value calculation, the sloped roof insulation *R*-value contribution to that calculation shall use the average thickness in inches (mm) along with the material *R*-value-per-inch (per-mm) solely for *R*-value compliance as prescribed in Section 402.1.3.

C402.2.1.2 Minimum thickness, lowest point. The minimum thickness of above-deck roof insulation at its lowest point, gutter edge, roof drain or scupper, shall be not less than 1 inch (25 mm).


COMMERCIAL ENERGY EFFICIENCY

C402.2.2 Above-grade walls. The minimum thermal resistance (*R*-value) of materials installed in the wall cavity between framing members and continuously on the walls shall be as specified in Table C402.1.3, based on framing type and construction materials used in the wall assembly. The *R*-value of integral insulation installed in concrete masonry units shall not be used in determining compliance with Table C402.1.3 except as otherwise noted in the table. In determining compliance with Table C402.1.4, the use of the *U*-factor of concrete masonry units with integral insulation shall be permitted.

"Mass walls" where used as a component in the thermal envelope of a building shall comply with one of the following:

1. Weigh not less than 35 pounds per square foot (171 kg/m²) of wall surface area.
2. Weigh not less than 25 pounds per square foot (122 kg/m²) of wall surface area where the material weight is not more than 120 pcf (1900 kg/m³).
3. Have a heat capacity exceeding 7 Btu/ft² × °F (144 kJ/m² × K).
4. Have a heat capacity exceeding 5 Btu/ft² × °F (103 kJ/m² × K), where the material weight is not more than 120 pcf (1900 kg/m³).

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

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

1. 35 pounds per square foot (171 kg/m²) of floor surface area.
2. 25 pounds per square foot (122 kg/m²) of floor surface area where the material weight is not more than 120 pounds per cubic foot (1923 kg/m³).

Exceptions:

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

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

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

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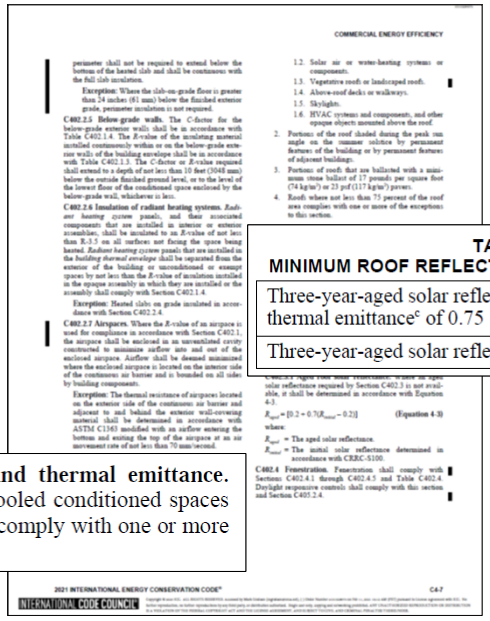
ICC 2021 Commercial – Roof Reflectivity

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.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perimeter shall not be required to extend below the bottom of the heated slab and shall be continuous with the full slab insulation.

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

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

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

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

C402.2.7 Airspaces. Where the *R*-value of an airspace is used for compliance in accordance with Section C402.1.1, the airspace shall be enclosed in an unventilated cavity constructed to minimize airflow into and out of the enclosed airspace. Airflow shall be deemed minimized where the enclosed airspace is located on the interior side of the continuous air barrier and is bounded on all sides by building components.

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

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/m²) or 23 psf (117 kg/m²) pavers.
4. Roofs where not less than 75 percent of the roof area complies with one or more of the exceptions to this section.

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

where:

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

C402.4 Fenestration. Fenestration shall comply with Sections C402.4.1 through C402.4.5 and Table C402.4. Daylight responsive controls shall comply with this section and Section C405.2.4.

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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

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Definitions

Solar reflectance: The fraction of solar flux reflected by a surface expressed within the range of 0.00 and 1.00.

Thermal emittance: The ratio of radiant heat flux emitted by a surface to that emitted by a black body radiator at the same temperature expressed within a range of 0.00 to 1.00.

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Definitions – cont.

Solar reflectance index (SRI): The relative steady-state surface temperature of a surface with respect to the standard white (SRI = 100) and standard black (SRI = 0) under standard solar and ambient conditions.

--ASTM E 1980

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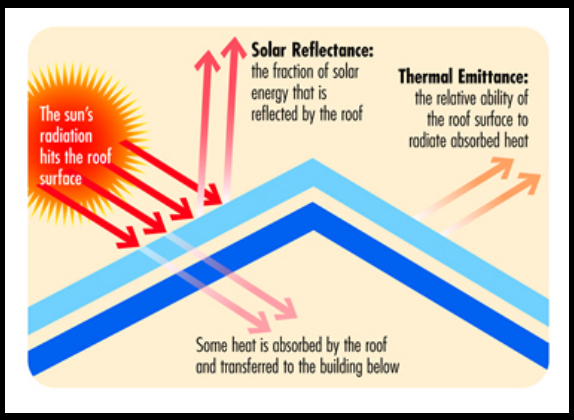

Courtesy of the Cool Roofs Rating Council

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IECC 2021 Sec. C402.5-Air Leakage-Thermal envelope

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.

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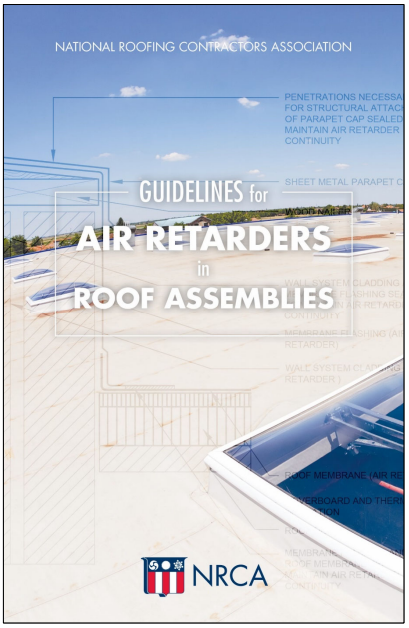

Guidelines for Air Retarders in Roof Assemblies

- Ch. 1: IECC and ASHRAE
- Ch. 2: Industry research
- Ch. 3: Recommendations

Link

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Wisconsin has some notable modifications in their adoption of their Energy Code

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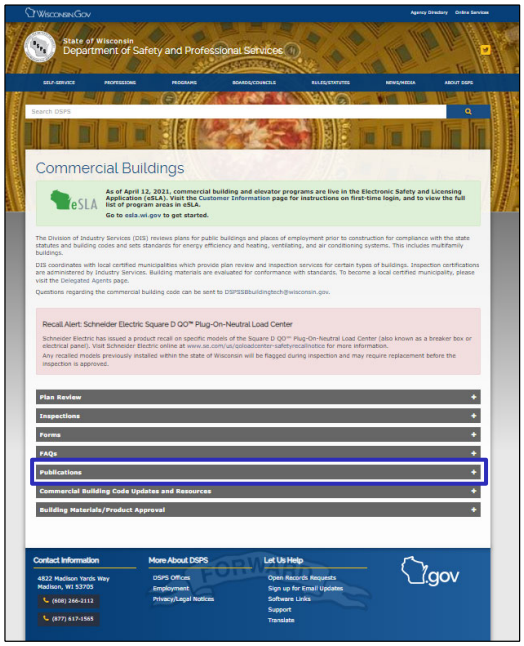

State of Wisconsin
Dept. of Safety and Professional Service
dsps.wi.gov

Link

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Insert pages for May 1, 2018 Wisconsin Commercial Building Code, SPS 361 – SPS 366, into the International Energy Conservation Code, 2015 Edition

Wisconsin Department of Safety and Professional Services- Division of Industry Services

IECC Chapter 5, Insert 5A[CE], Page 1 of 2
Insert between pages C-94 and C-95

SPS 363.0502 Additions.

(1) OPAQUE ASSEMBLIES. Substitute 2009 IECC Table 502.2 (1) for 2015 IECC Table C402.1.3 and renumber Table C402.1.3.

(2) OPAQUE ELEMENT MAXIMUM U–FACTORS. Substitute 2009 IECC Table 502.1.2 for 2015 IECC Table C402.1.4 and renumber Table C402.1.4.

(3) AIR LEAKAGE. Substitute the wording from 2009 IECC sections 402.4.1, 402.4.2, 402.4.2.1 and 402.4.2.2 for IECC section C402.5, C402.5.1, C402.5.1.1, and C402.5.2.

(4) AIR BARRIER AND INSULATION INSPECTION COMPONENT TABLE. Substitute 2009 IECC Table 402.4.2 for IECC Table C402.5.1.2, C402.5.1.2.1, and C402.5.1.2.2.

Link to IECC insert pages
Wisc. Commercial Building Code

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Comparison of IECC's various editions

Commercial Buildings (Insulation component R-value-based method)

Climate Zone	IECC 2003	IECC 2006	IECC 2009	IECC 2012*	IECC 2015*	IECC 2018*
1	R-12 ci	R-15 ci	R-15 ci	R-20 ci	R-20 ci	R-20 ci
2	R-14 ci		R-20ci		R-25 ci	R-25 ci
3	R-10 ci					
4	R-12 ci			R-25 ci	R-30 ci	R-30 ci
5	R-15 ci	R-20 ci				
6	R-11 ci					
7	R-15 ci	R-25 ci	R-25 ci	R-30 ci	R-35 ci	R-35 ci
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* Applies to roof replacement projects
ci = continuous insulation

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Questions

Codes and standards

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