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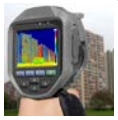
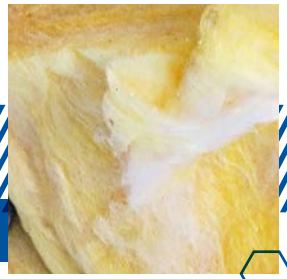
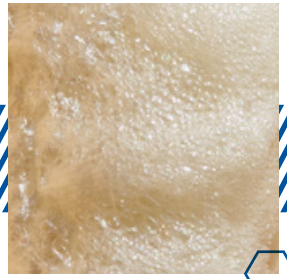


Insulation Fundamentals





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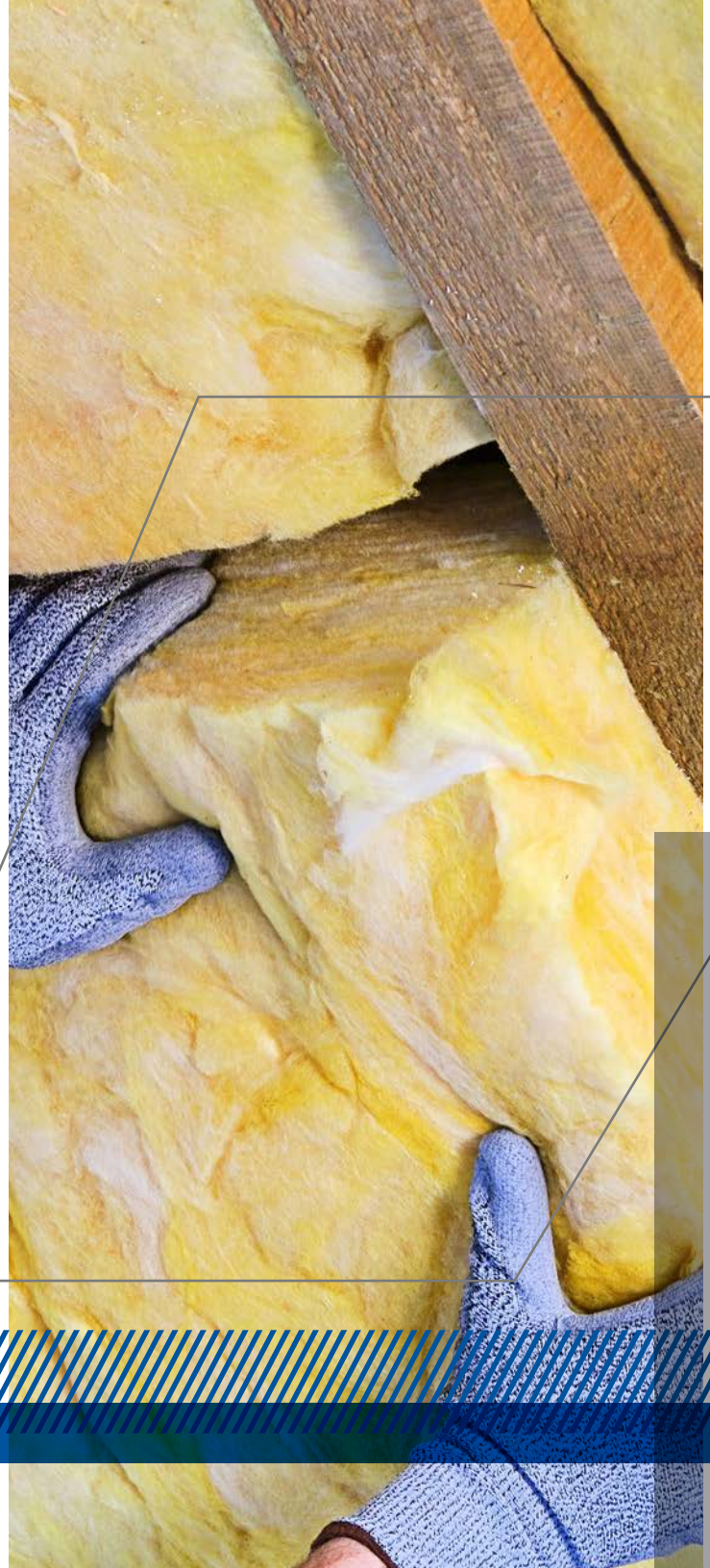

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WHAT IS INSULATION?

Rigid foam board insulation

Fiber insulation

Spray polyurethane foam insulation

Thermal Insulation: “Material that retards or prevents the progression or transmission of heat from one item or medium to another”

The Business Dictionary defines insulation as “Material that retards or prevents the progression or transmission of electricity, heat, moisture, shock, or sound from one item or medium to another”.

This e-book looks at insulation from the standpoint of thermal resistance, as well as the types of materials and methodologies that are employed for this purpose.

Above are a few types of insulation that will be reviewed. They have different properties and capabilities for utilization in specific areas of a structure.

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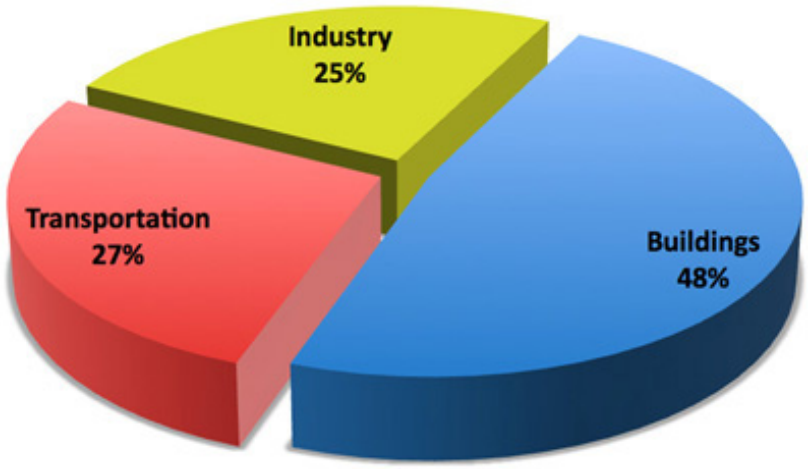
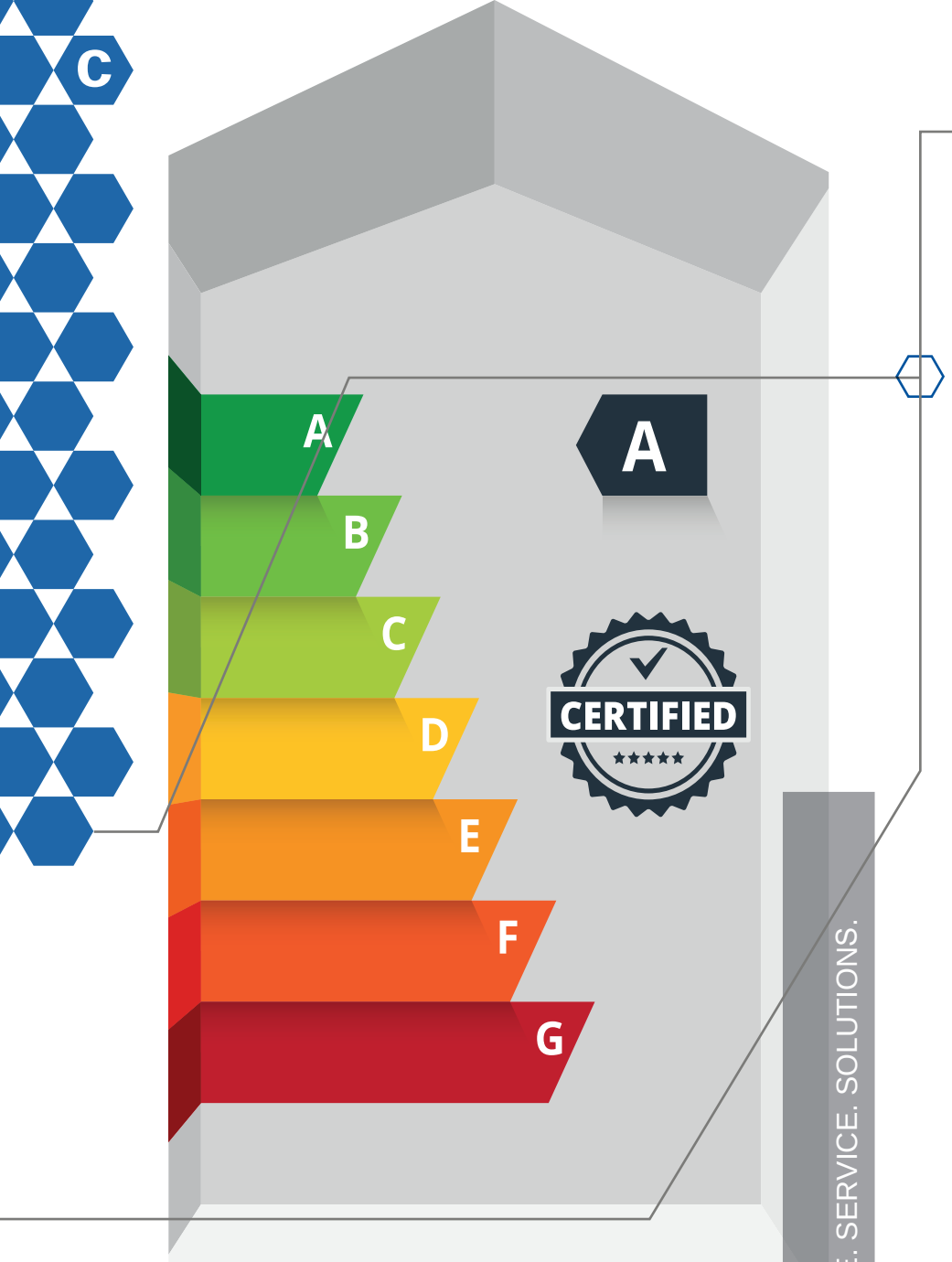


U.S. Energy use by sector

Why Insulation?
Buildings Account for Nearly Half of Total Energy Use in the USA!

- The commercial real estate industry spends approximately $24 billion annually on energy.
- Energy represents the single largest controllable operating expense for office buildings - typically a third of variable expenses

Source: www.boma.org BEEP (BOMA Energy Efficiency Program)



The Importance of Building Insulation

- Government and private initiatives call for aggressive reduction of building energy consumption
- Increased use of building insulation is a crucial part of meeting these objectives!
  - Buildings constructed to meet 2012 Energy Code are 30% more energy efficient compared to those built to meet 2006 Energy Code
  - Buildings constructed to meet 2015 Energy Code are 50% more energy efficient compared to those built to meet 2006 Energy Code

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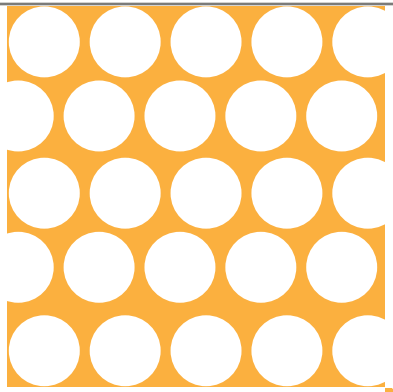
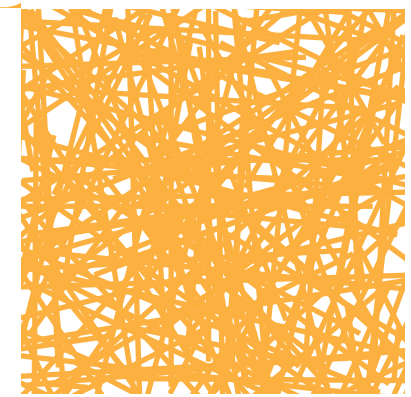


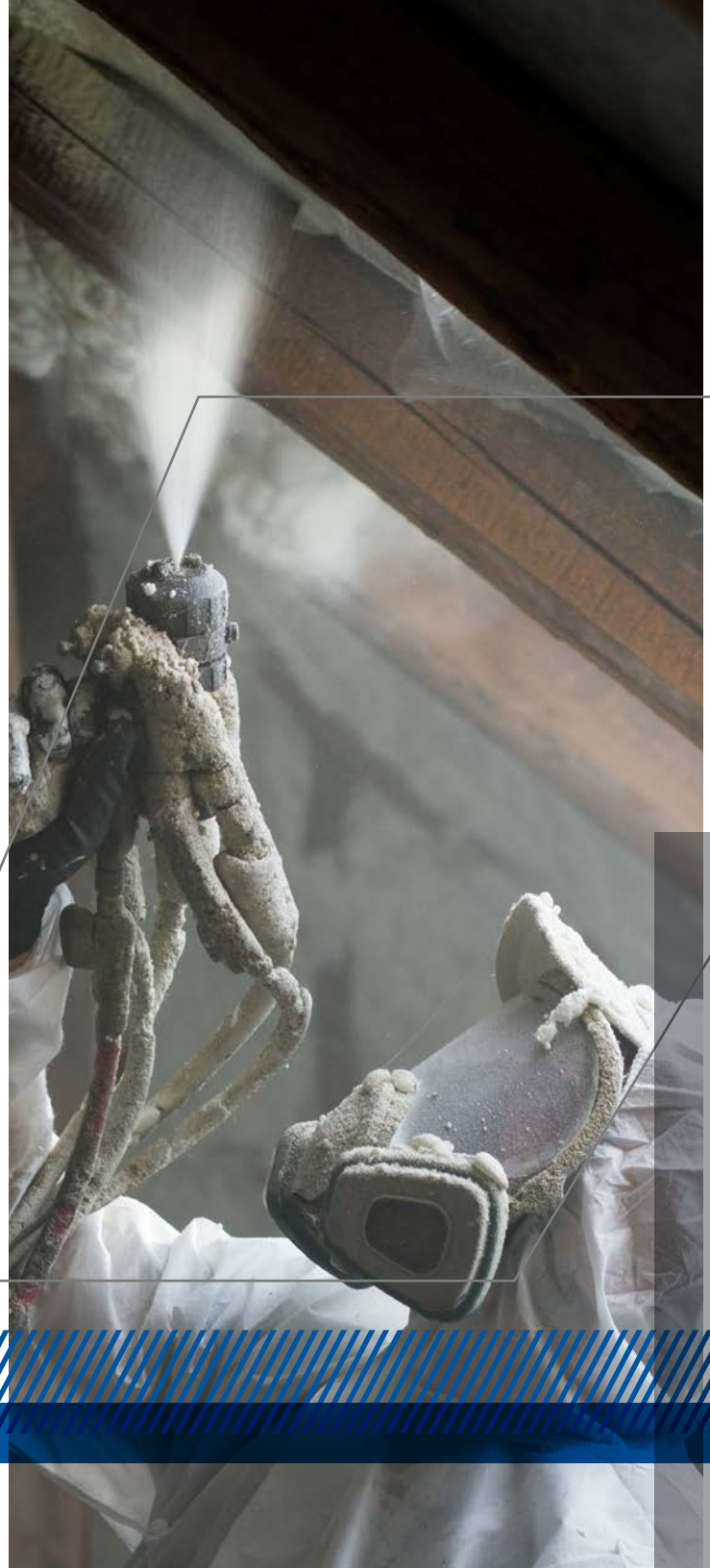
Foam



Fiber

How Insulation Works

- Gasses are much more insulating than solids
- Insulation contains trapped pockets of gas
- Foam insulation: works by trapping gas in cells; gas could be air or a more insulating gas (blowing agent)
- Fiber Insulation: Works by trapping air among the fibers



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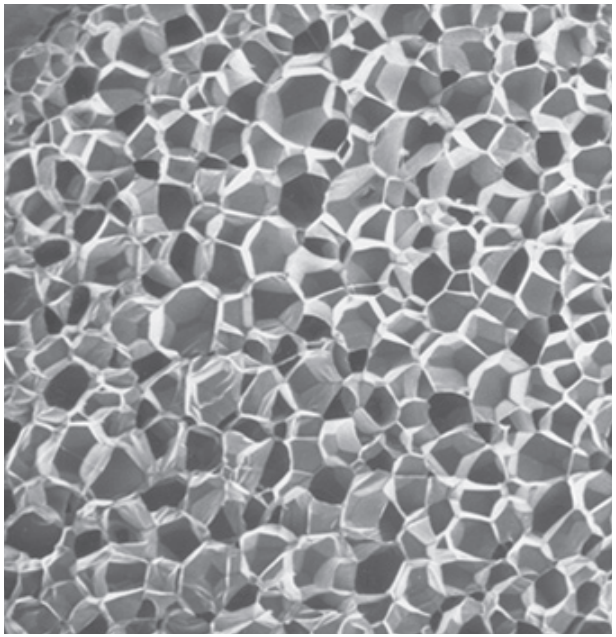


Closed cell foam, magnified photo

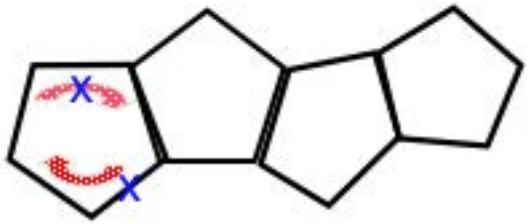
Closed Cell Foam - High Performance

Foam insulation in its closed cell form has excellent thermal resistance (R value) properties. The closed cell contains a blowing agent (trapped gas designed to impede heat flow).

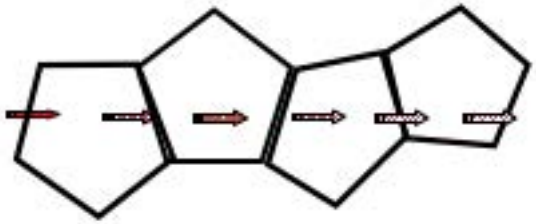
Many small cells (<~2 mm dia.) contribute to high performance.

Closed Cell Foam - High Performance

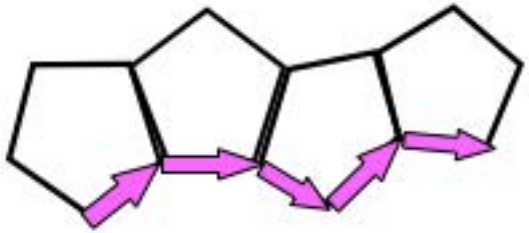
Composition provides very slow heat transfer in all three modes.



Convection : Convective heat transfer is negligible – The gas in each cell contains a very small volume, and it is at a uniform temperature.



Radiation : Radiant heat transfer is significantly slowed - must travel from "wall to wall" across each cell.



Conduction : Gas in each cell has very low thermal conductivity. Thermal conductivity occurs through cell walls – which provides a small area and a torturous path

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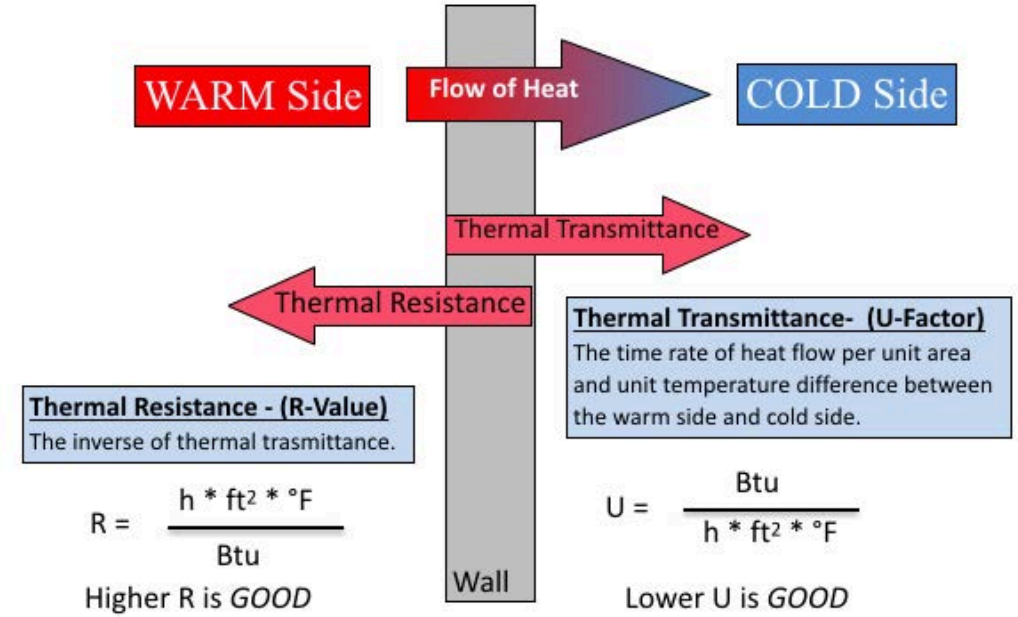
Theory and Terms of Insulation

NOTE: Btu = "British Thermal Unit". It is a unit of heat used in the U.S. Customary measurement system



Thermal Resistance - (R-Value)
The inverse of thermal trasmittance.

$$R = \frac{h * ft^2 * °F}{Btu}$$

Higher R is *GOOD*

Thermal Transmittance- (U-Factor)
The time rate of heat flow per unit area and unit temperature difference between the warm side and cold side.

$$U = \frac{Btu}{h * ft^2 * °F}$$

Lower U is *GOOD*

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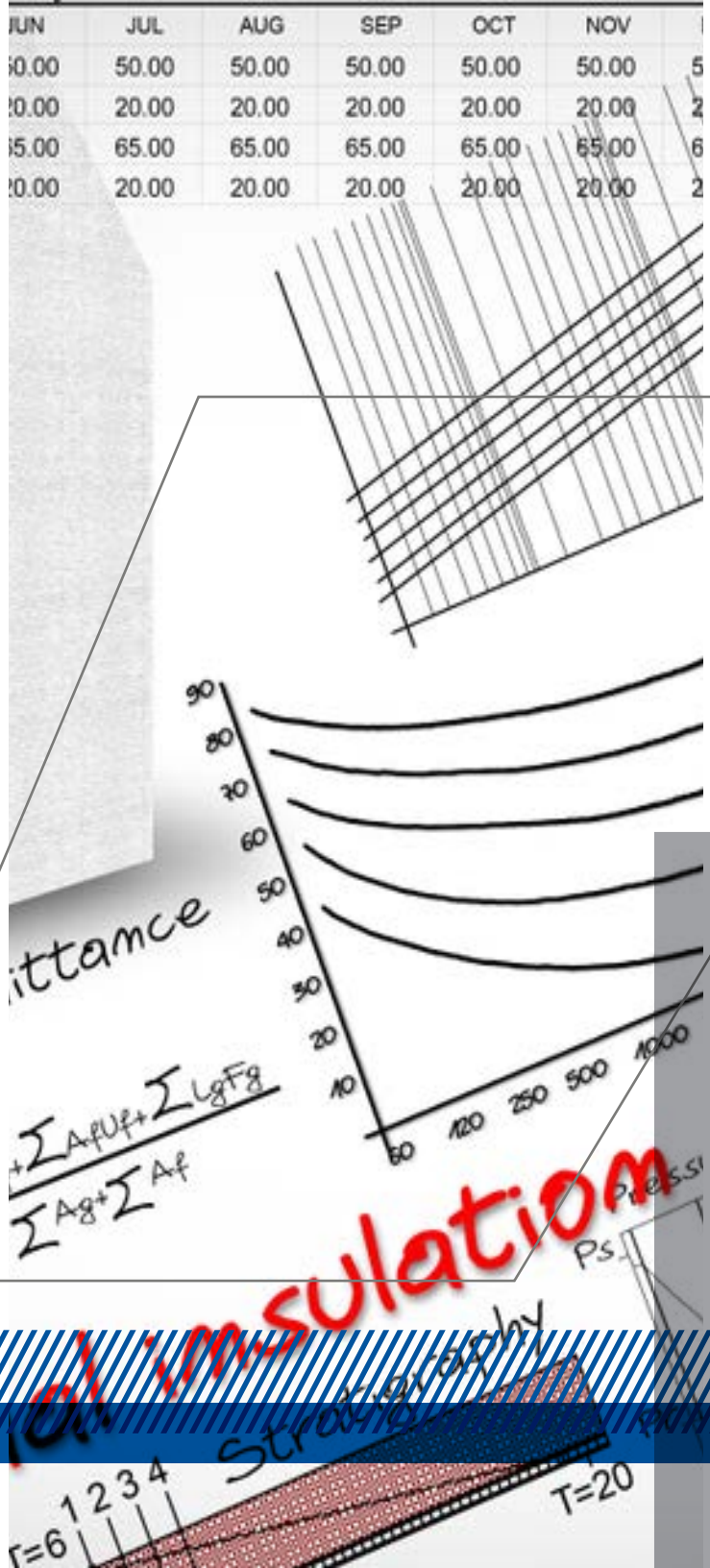

Higher R-Value = more insulation.

Value proposition of insulation is often expressed in $/R

Insulation R-Value

An insulating material's resistance to conductive heat flow is measured or rated in terms of its thermal resistance – it's R Value.

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R-Value of Common Types of Insulation

Insulation	R/ inch
20 psi Polyiso Board	5.6 to 6.5
2# CC Spray Polyurethane Foam	6.0 to 6.7
25 psi Extruded Polystyrene (XPS)	5.0 to 5.5
25 psi Expanded Polystyrene (EPS)	3.9 to 4.4
Mineral Wool	4.2
Fiber Glass	3.7

Measured to ASTM C 518 using 75°F Mean Temperature

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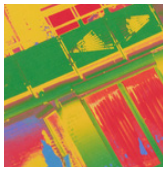

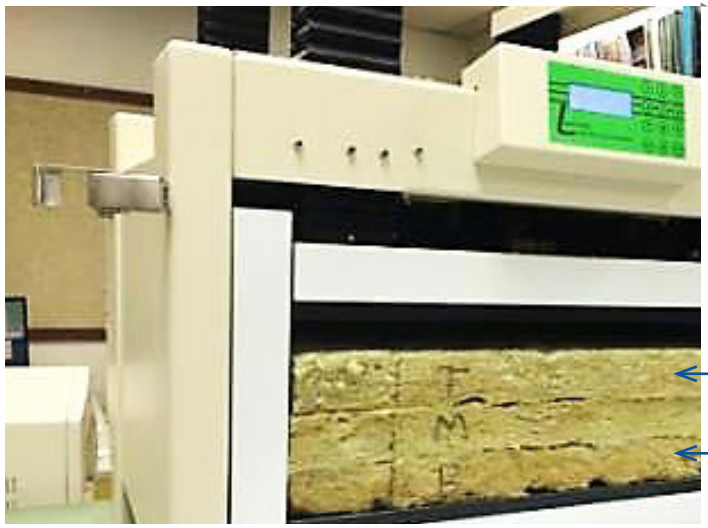

ASTM C 518

The Importance of Building Insulation

- ASTM C 518 is a test method for measuring R-Value in a laboratory
- Insulation sample sandwiched between hot plate and cold plate.
- Test measures heat flow through the insulation specimen
- Mean temperature is the average of the hot and cold plate temperatures (T1 and T2)
- Example: Hot Plate is 100°F, Cold Plate is 50°F, Mean Temp is 75°F
- Insulation material specifications provide additional requirements for R-value measurement
  – Sample pre-conditioning
  – Mean temperature to use
  – Temperature difference to use

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T2

Measuring R-Value of Insulation

- ASTM C 1289 Polyiso Foam
- ASTM C 578 Polystyrene Foam (XPS and EPS)
- ASTM C 1029 Spray Polyurethane Foam
- ASTM C 612 Mineral Fiber

Fiberglass Batts: Steel studs are bridging insulation. Batts are also wet from trapped condensation.

Polyiso foam board: Insulation is bridged with steel Z channels for attaching exterior panels.

Factors Affecting Insulation R-Value

- Insulation Type
- Amount (thickness) of Insulation
- Installation (continuity)
- Insulation Mean Temperature
- Aging
- Water Absorption
- Permeability to Air (wind washing)

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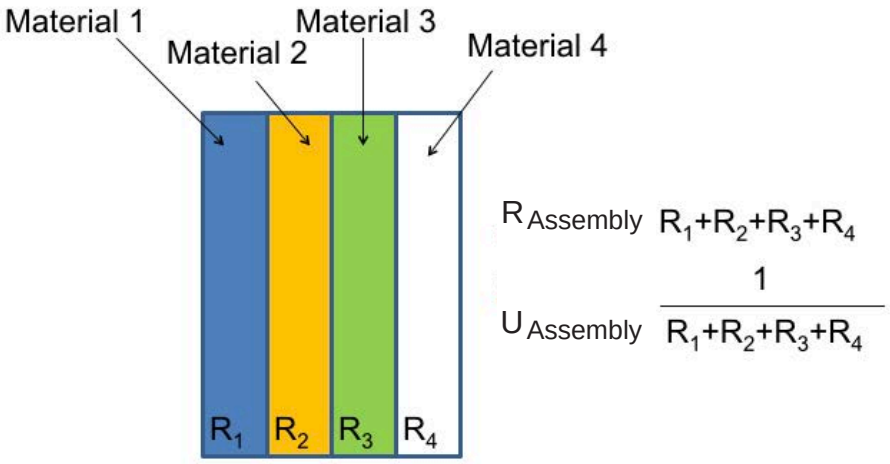

Measuring Wall Assembly Performance with R-Value vs. U-Factor

- Energy Code Gives Two Compliance Options:
  - Meet or exceed the minimum R value of insulation prescribed for that type of assembly and climate zone
  - Meet or go below the maximum assembly U Factor designated for that type of assembly and climate zone

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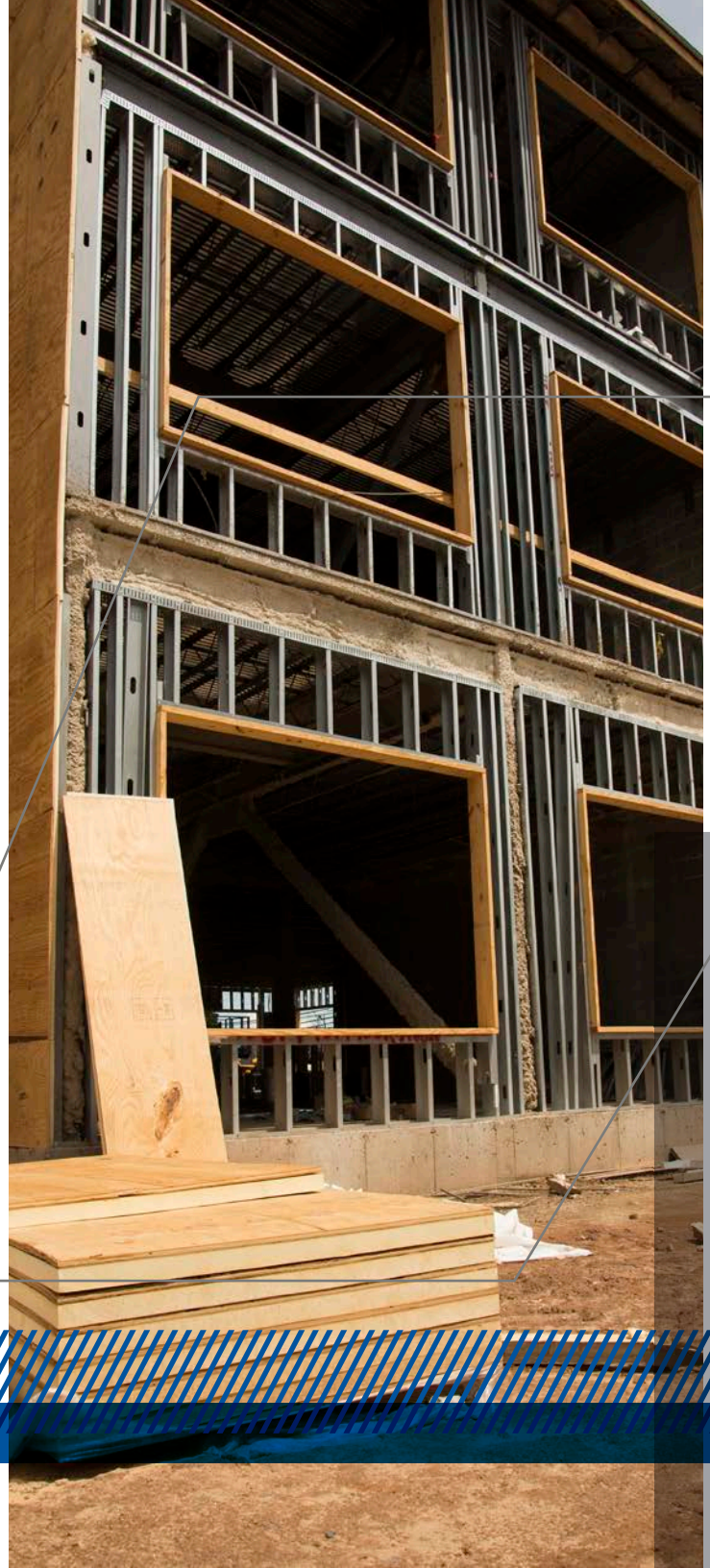
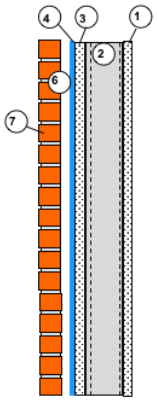
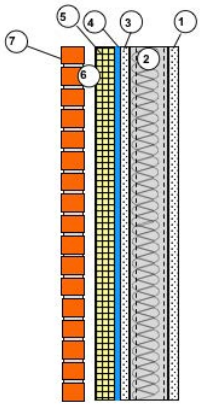




No insulation



1.5” Foil-Faced POLYISO
+ R-13 fiberglass batts in stud

	Component R-Value	Un-Insulated Wall	Insulated Wall
1	5/8” Interior Gyp	0.57	0.57
2	2X4 Steel Studs & Stud Cavity	2.84	6.00
3	5/8” Exterior Gyp	0.57	0.57
4	WRB/ air barrier	0.06	0.06
5	1.5” polyiso foam	N/A	10.0
6	1.5” air space	0.9	0.9
7	3.5” brick	0.6	0.6
	Assembly R-Value	5.54	20.76
	Assembly U-Factor	0.181	0.053

How insulation contributes to U-Factor

- In this example, adding insulation reduces wall assembly’s thermal transmittance more than 3X

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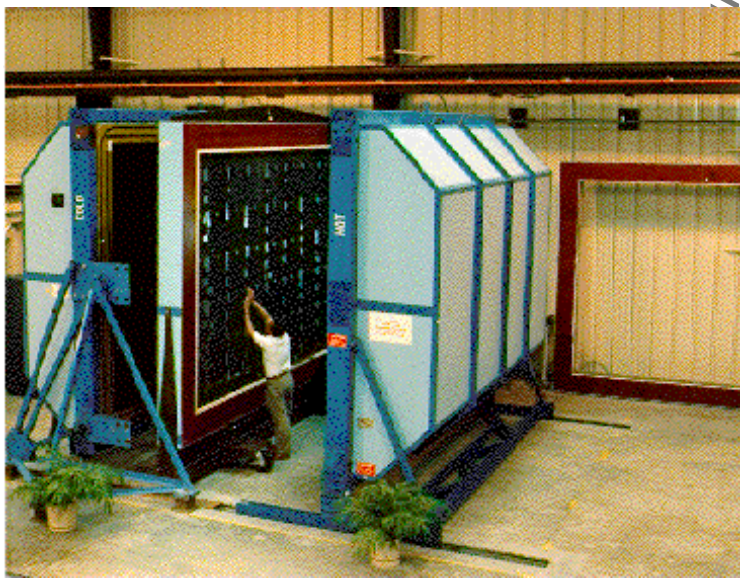

How U-Factor is Determined

- Measure U-Factor of the assembly in a laboratory using the "guarded hot box" test (ASTM C 1363)
  – or
- Use a standard assembly with published U-Factor in Model Codes
  – or
- Calculate U-Factor using published material properties in the assembly
  – or
- Complex, large assemblies, U-Factor can be estimated by using Thermal Modeling (Computer Software)

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COMMON TYPES OF INSULATION

Stud Cavity Applications

Cellulose

Spray Foam

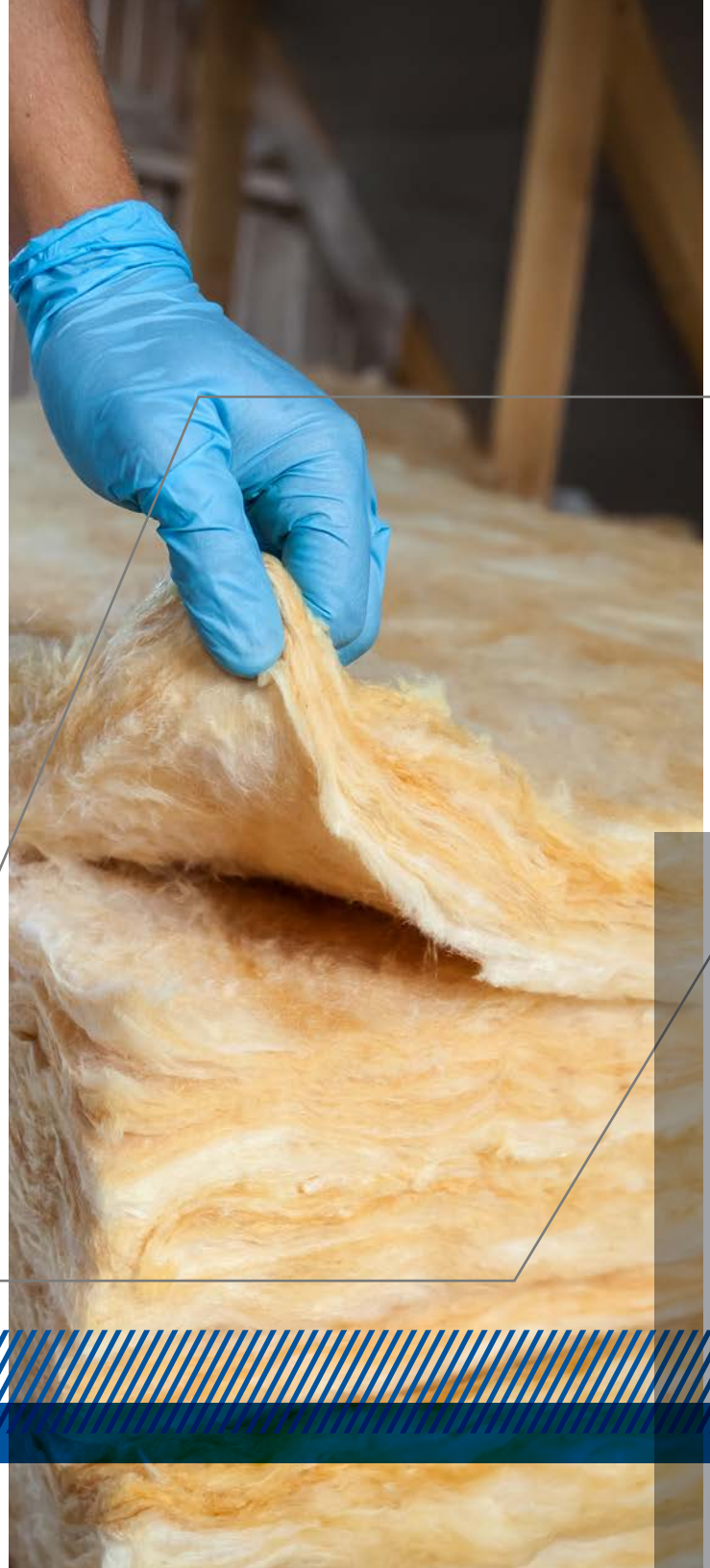
Fiberglass Batts

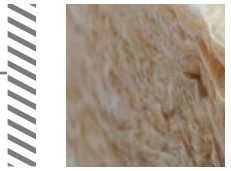
Standard Insulation is often referred to as cavity insulation. It is generally placed between rafters, underneath roof sheathing, and in between wall studs.

With the exception of closed-cell spray foam, the materials listed below are sensitive to moisture and lose their effectiveness in wet and damp environments.

Common Types of Cavity Insulation:

- Fiberglass batts or rolls
- Blown-In (loose) Cellulose
- Mineral Wool batts
- Spray Foam Insulation (open and closed cell)
- Natural Fiber Insulation (Cotton/Wool)





2X4 w/ R-15
U = 0.118

2X6 w/ R-21
U = 0.106

SOURCE: 2013 ASHRAE 90.1 Table A3.3.3.1

Desired Improvements in Energy Efficiency Cannot be Achieved with Stud Cavity Insulation

- Example - Steel Frame Walls, Studs 16” On Center
- 2X4 studs with max thickness glass fiber batt
  –vs.
- X6 studs with max thickness glass fiber batt
- Get only a 10% improvement in thermal performance of the assembly!!

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Stud Cavity Insulation - Loss of Effective R-Value from Thermal Bridging

Insulation placed between studs has a measurable loss of R-Value

Nominal Stud Size (a)	Space of Framing (in)	Cavity Insulation R-Value	Correction Factor	Effective Framing/ Cavity R-Values
2 X 4	16 o.c.	R-11 R-13 R-15	0.50 0.46 0.43	R-5.5 R-6.0 R-6.4
2 X 4	24 o.c.	R-11 R-13 R-15	0.60 0.55 0.52	R-6.6 R-7.2 R-7.8
2 X 6	16 o.c.	R-19 R-21	0.37 0.35	R-7.1 R-7.4
2 X 6	24 o.c.	R-19 R-21	0.45 0.43	R-8.6 R-9.0
2 X 8	16 o.c.	R-25	0.31	R-7.8
2 X 8	24 o.c.	R-25	0.38	R-9.6

Source: ASHRAE 90.1, 90.2

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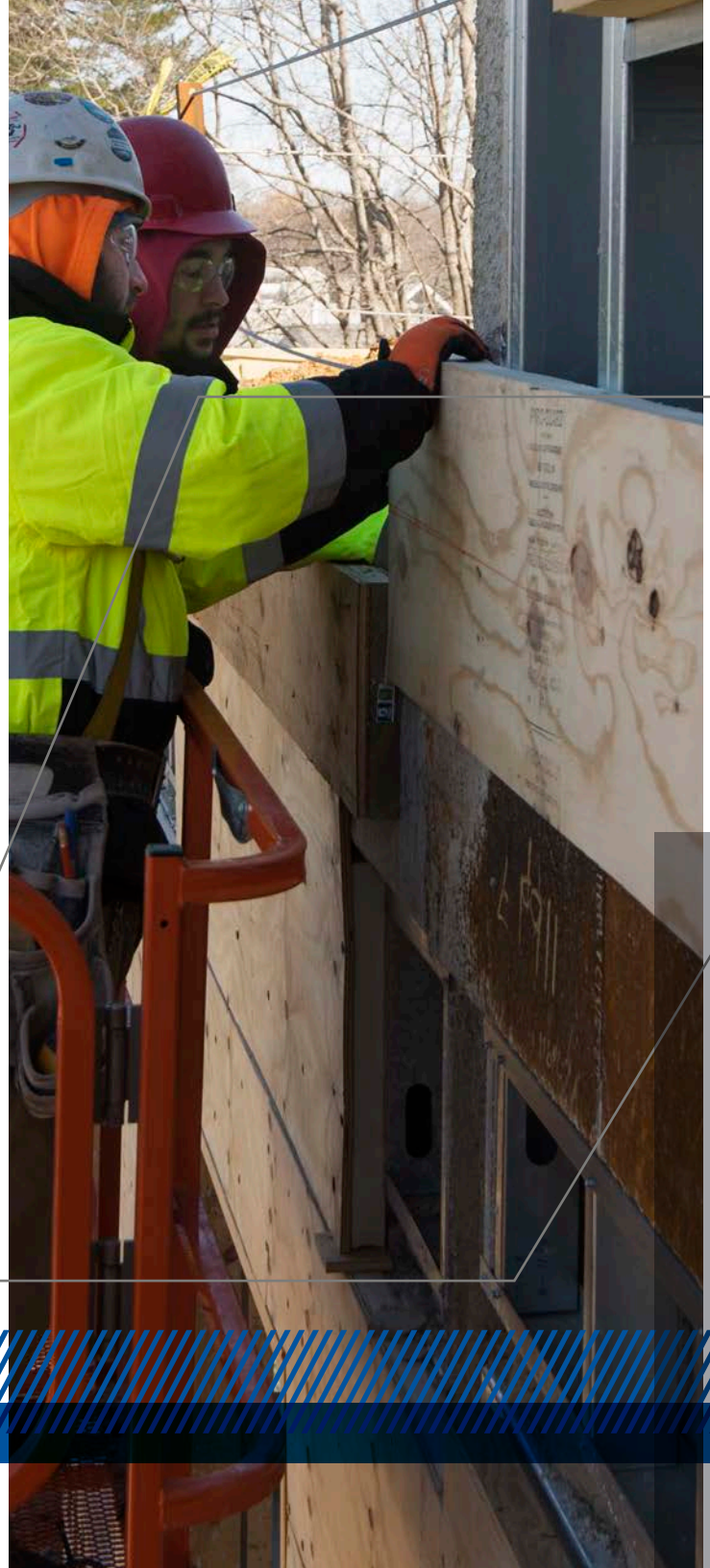

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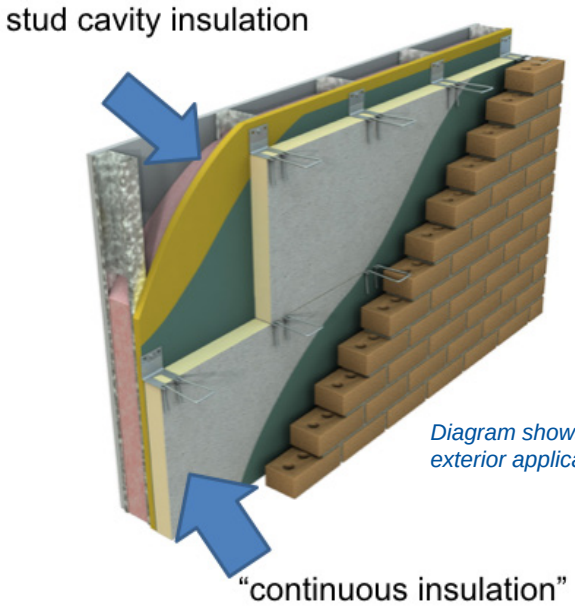
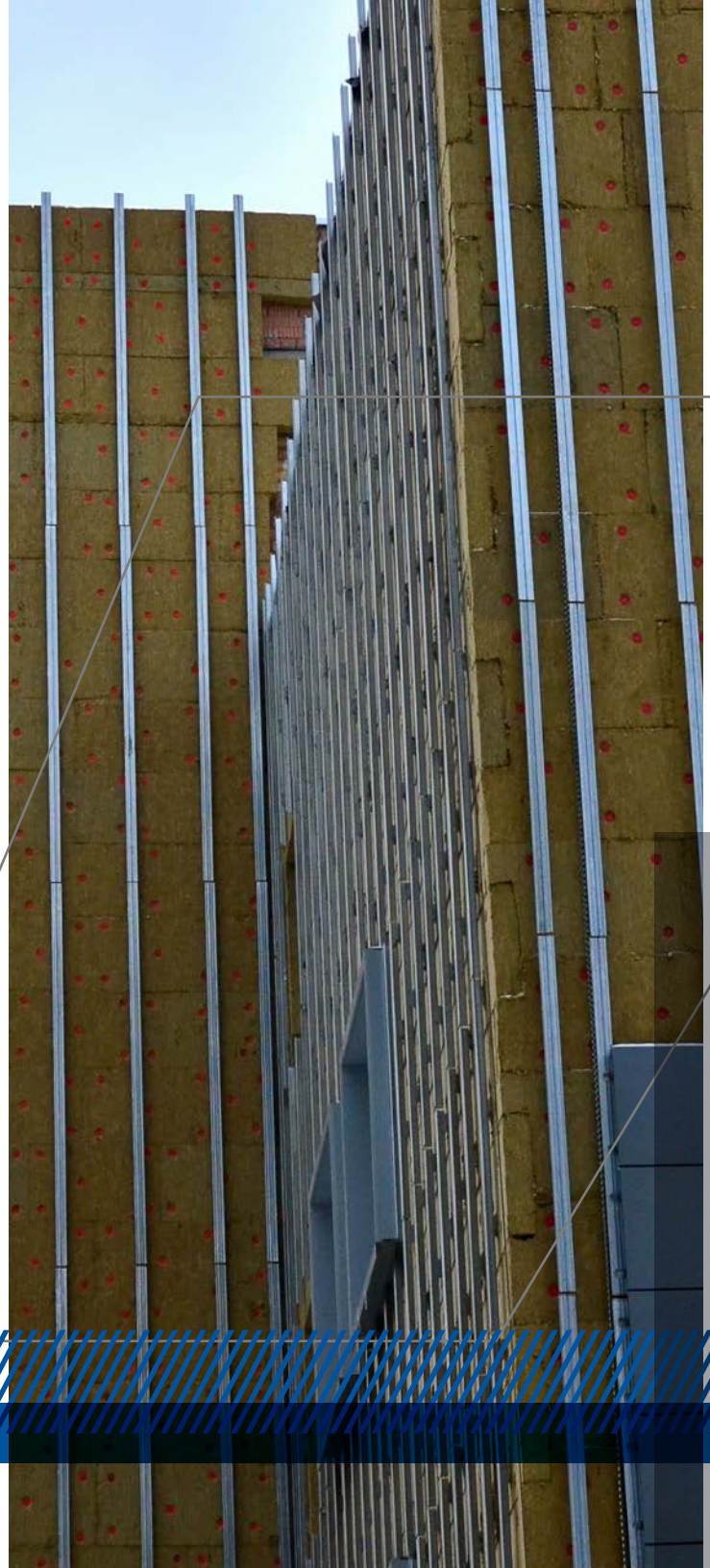
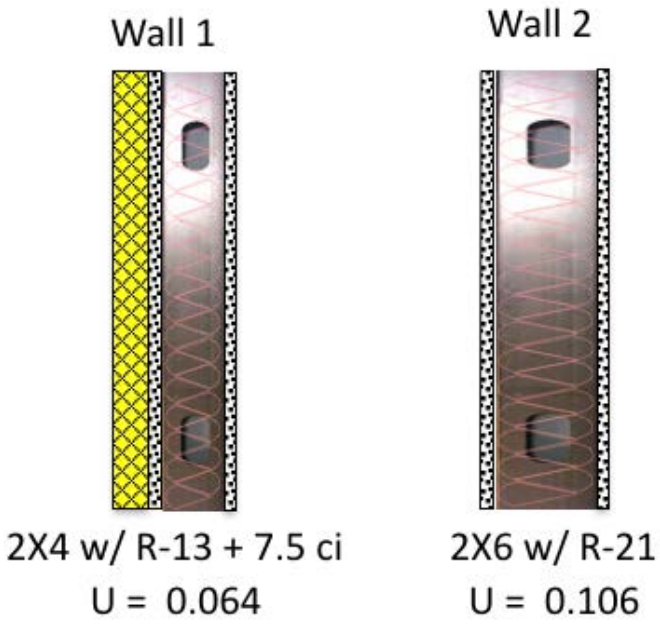


Diagram shows an exterior application

Improvements in Thermal Performance must come from Continuous Insulation "CI"

- Continuous Insulation (CI) consists of insulation installed continuously over all structural members with no thermal bridging, with the exception of fasteners, clips and service openings (windows, doors, mechanical/ electrical penetrations).
- "CI" has become a requirement in the latest Energy Codes
- Continuous Insulation can be installed on the exterior or interior side of the studs.





REF: 2013 ASHRAE 90.1 Table A3.3.3.1

Impact of Continuous Insulation

- Example - Steel Frame Walls:
- Wall 1: 2X4 studs 16” OC w/ R-13 glass batt + R 7.5 ci –VS.
- Wall 2: 2X6 studs 16” OC w/ R-21 glass batt
- Wall 1 performs 40% better!

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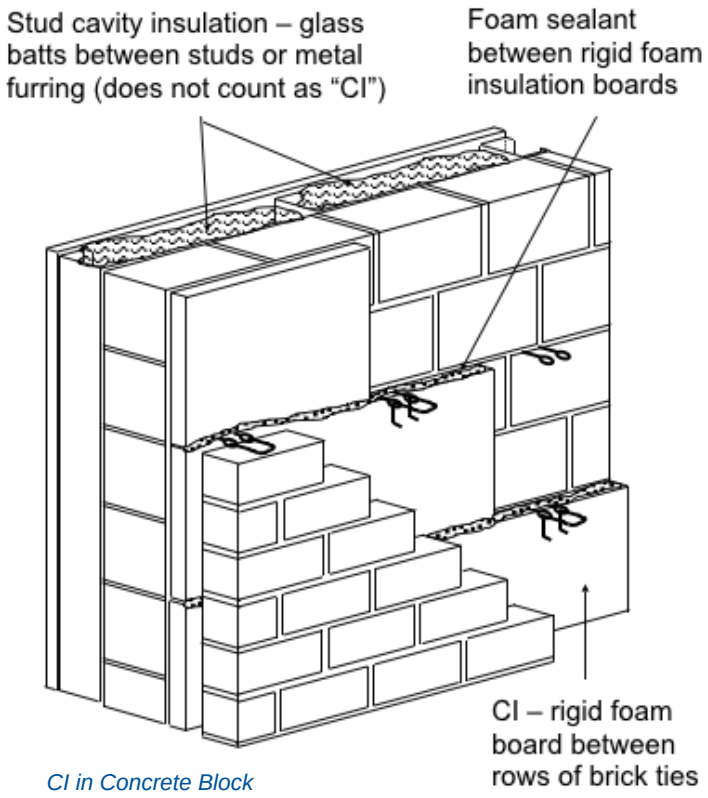
CI in Exterior Mass Walls (walls made of concrete block or concrete)



CI in Concrete Block Wall Assembly

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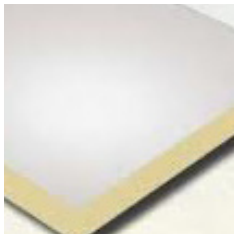
Mineral Fiber (aka mineral wool or rock wool)

Extruded Polystyrene Foam “XPS”



Polyisocyanurate Foam “Polyiso”

Expanded Polystyrene Foam “EPS”

Closed Cell Spray Polyurethane Foam “ SPF”

Materials Marketed as Continuous Insulation “CI”

- Often installed on exterior side of wall
- Can be installed outboard of the water resistive barrier
- Must resist moisture and temperature extremes

Fiber Insulation as CI

- Mineral fiber semi-rigid batts
- Typically more dense than mineral fiber for the stud cavity
- Marketed as “water repellent” and “non combustible”

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FOAM INSULATION CI

XPS

EPS

Polyiso

SPF

Foam vs. Fiber CI

Polyiso XPS

- Advantages
  - Higher insulating value (R) per inch
  - Very low water absorption
  - Not permeable to air
  - Lightweight
  - Can perform as air and water resistive barrier (WRB)
  - Provides a rigid, smooth plane for WRB and cladding installation
- Limitations
  - Combustible
  - Low vapor permeablity
  - Difficult to fit around complex projections

Mineral fiber semi-rigid batts

- Advantages
  - Non combustible
  - Vapor permeable
  - Good sound attenuation qualities
  - Can be friction fit around complex projections
- Limitations
  - Lower insulating value (R) per inch
  - Heavy, especially when wet
  - Permeable to air
  - High water absorption
  - Requires higher-cost hardware to install as CI

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Foam vs. Fiber CI : *Continued*

Polyiso XPS

- Limitations
  - Combustible
  - Low vapor permeablity
  - Difficult to fit around complex projections- complex projections

Mineral fiber semi-rigid batts

- Limitations
  - Lower insulating value (R) per inch
  - Heavy, especially when wet
  - Permeable to air
  - High water absorption
  - Requires higher-cost hardware to install as CI

Warm, dry block where CI on exterior has been installed.

Damp, cold block. (saturated with condensation of interior moisture). Occurs where exterior CI has not been installed yet.

Exterior CI Keeps Inboard Materials at Room Temperature

Photo of exterior CI installation in progress, shown from inside of building. Outdoors is cold, interior is warm and humid. CI allows block to warm, which prevents condensation and dries out dampness.

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High-Performing Exterior Walls Incorporate CI

Benefits:

- Improved thermal efficiency
- Improved moisture management
- Protection of underlying layers from temperature extremes

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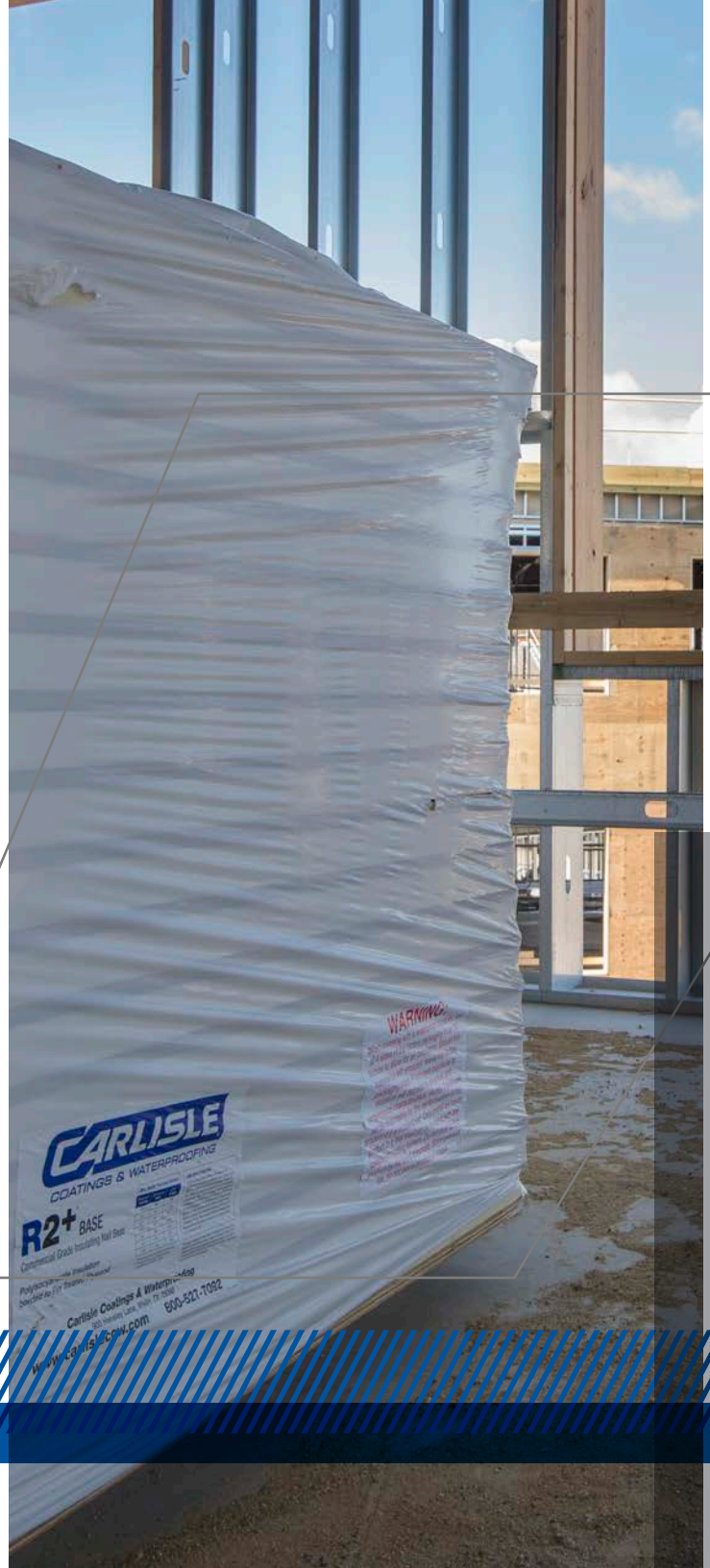

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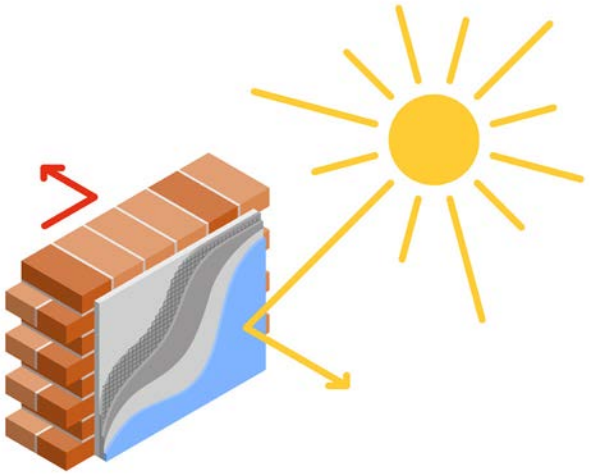
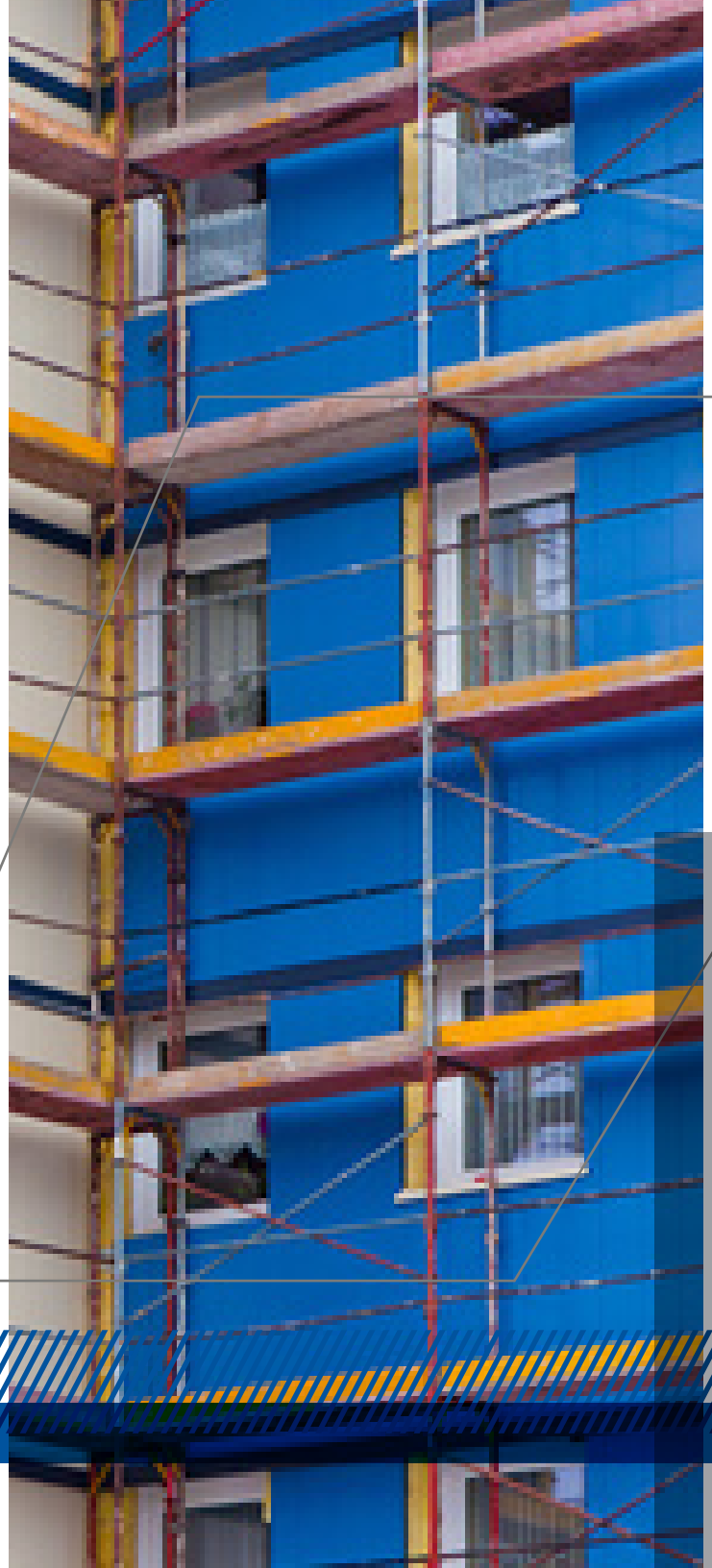


Thermal Insulation

High-Performing Exterior Walls Incorporate CI

Challenges:

- Exterior cladding and window installation through CI
- A drained and ventilated air space should be provided between exterior cladding and CI
- CI material properties and installation methods are essential for performance of the assembly



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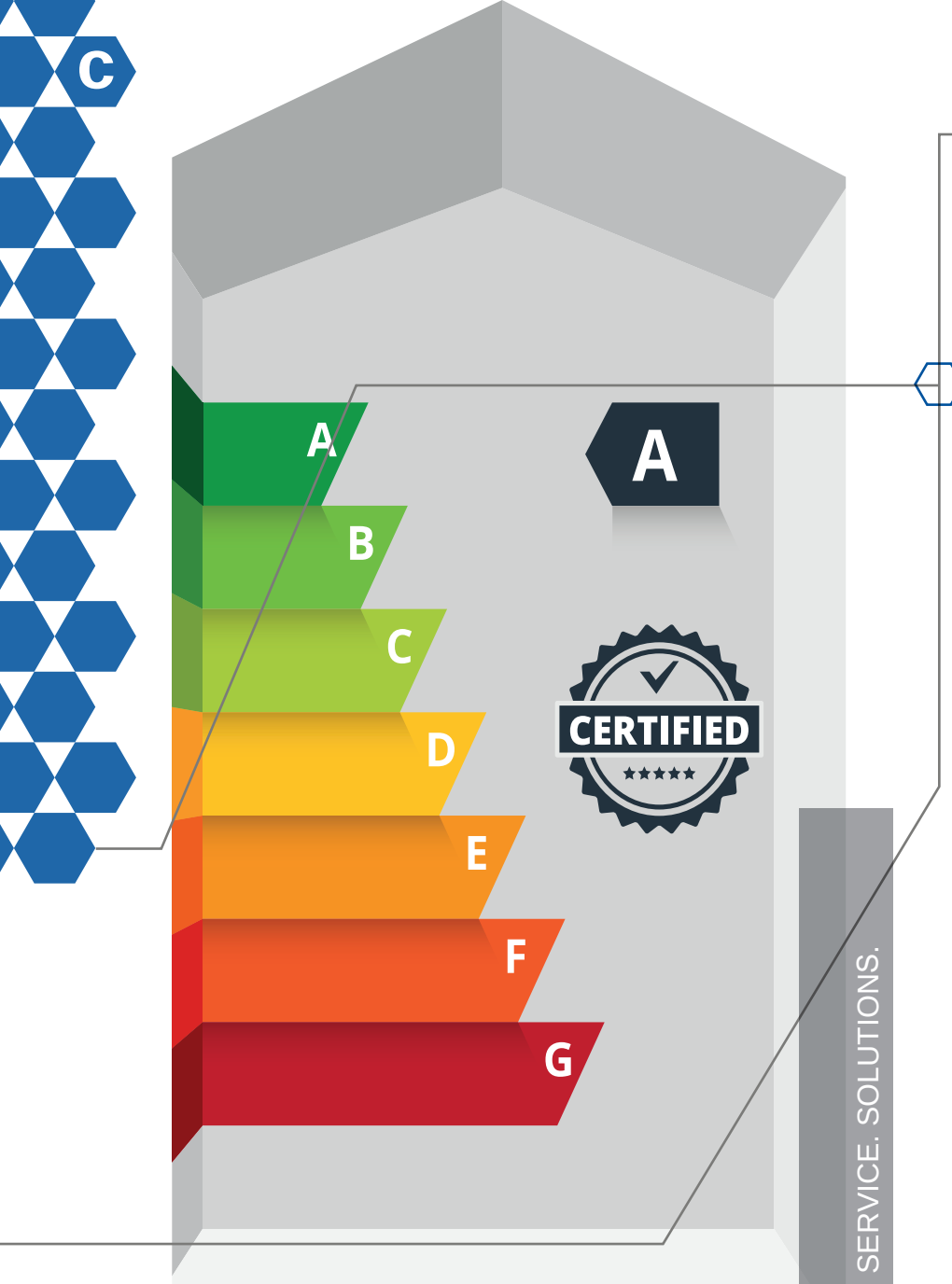
Model Energy Codes

- Local jurisdictions (state, county, city) typically adopt published “model codes” and enforce these requirements as minimum standards for building construction.



Energy Code Standards

- International Energy Conservation Code (IECC).
  – Versions in effect:
    – 2006 – 2012
    – 2009 – 2015
- American Society of Heating, Refrigerating and Air Conditioning (ASHRAE) Standard 90.1.
  – Versions in effect:
    – 2004 – 2010
    – 2007 – 2013
- Spec-Driven for higher performing buildings: ASHRAE Standard 189.1 (Standard for the Design of High-Performance Green Buildings)

Energy codes evolve

- Published model codes are updated every three years.
- Energy code compliance typically gives the option for compliance with the LATEST version of IECC OR ASHRAE 90.1

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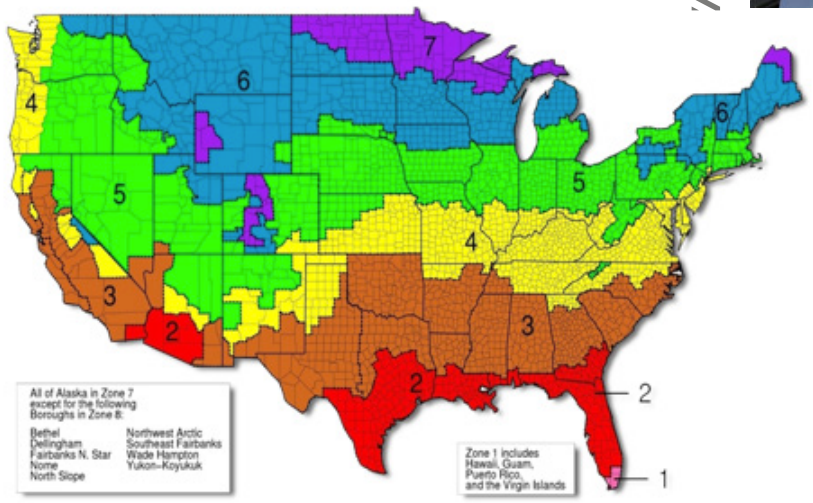

Heating Zone (Climate Zone) Map –
1 is warmest, 8 is coldest
The colder the climate, the more insulation is required

Continuous Insulation Code Requirement

The requirements for continuous insulation (CI) include:

- Climate-zone-specific and assembly-specific requirements for minimum insulation R-value OR maximum assembly U-Factor
- Wood stud exterior walls require a minimum R-Value prescribed with increased stud cavity insulation or a combination of stud cavity and continuous insulation
- Steel stud exterior walls require a minimum R-Value prescribed with a combination of stud cavity and continuous insulation.
- Mass walls (concrete block or concrete) require a minimum R-value prescribed with continuous insulation

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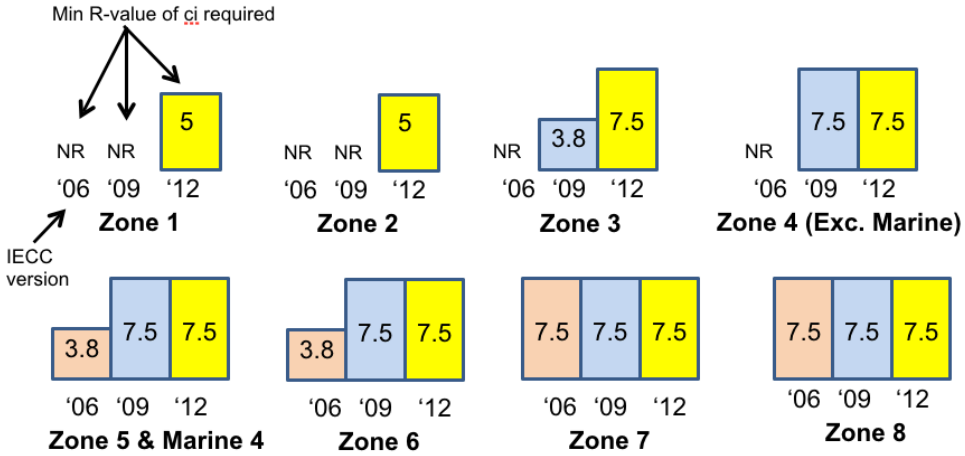
Example – IECC Requirements for “ci”, Non-Residential Steel Stud walls



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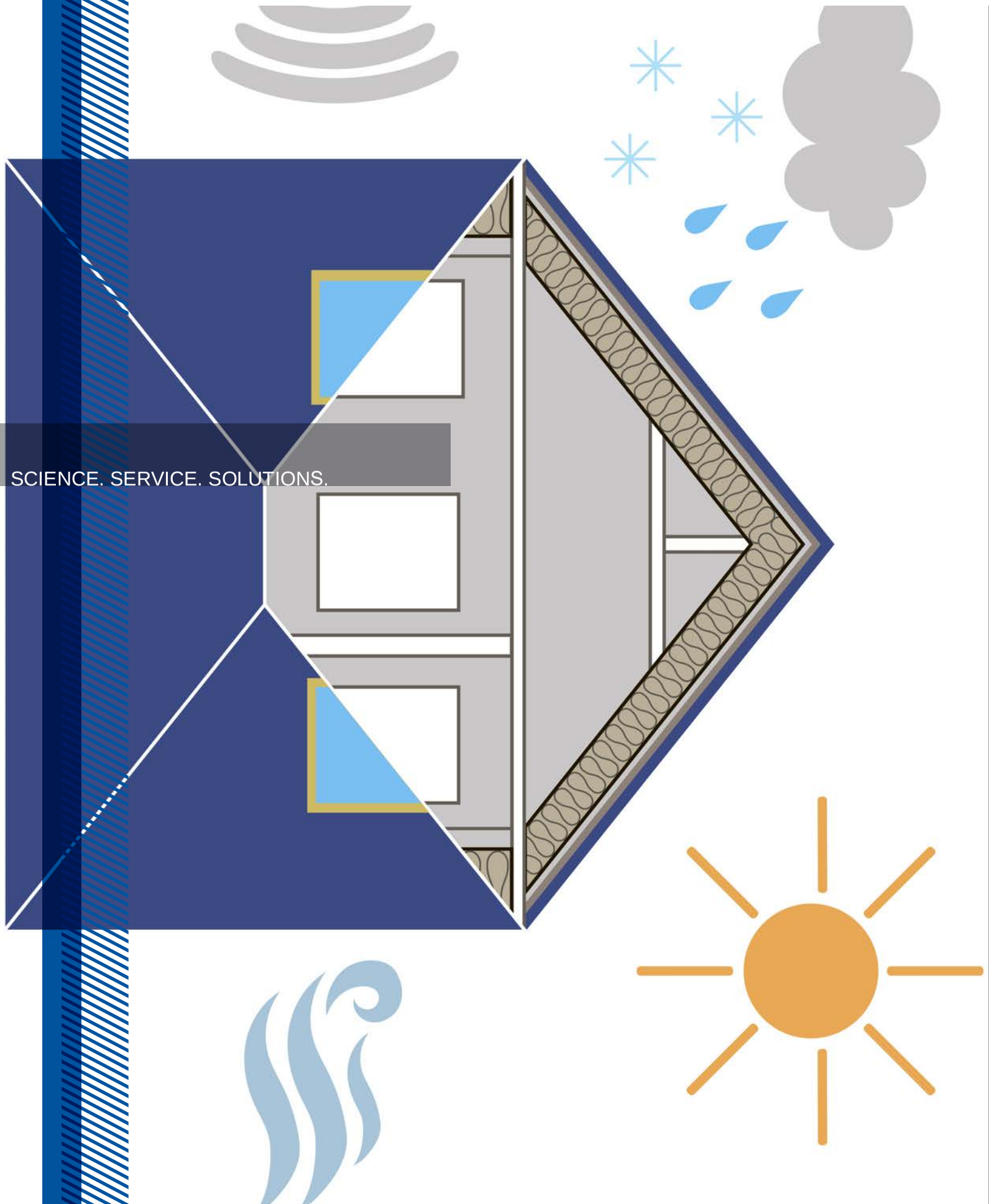
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