Energy Boot Camp for Builders

Building Science and Changes to the Montana Energy Code

December 2013
Presented by Dale Horton, Architect
National Center for Appropriate Technology
## Organization of 2012 IECC

<table>
<thead>
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<th>Chapter</th>
<th>Commercial Section</th>
<th>Residential Section</th>
</tr>
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<tr>
<td>5</td>
<td>Referenced Standards</td>
<td>5</td>
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</tbody>
</table>
...sufficient clarity to indicate the location, nature and extent of work proposed,...
Construction Documents - Details Shall Include...

- Insulation materials and R-value
- Fenestration U-factors and SHGCs
- Mechanical system design criteria
- Mechanical and service water heating system and equipment types, sizes and efficiencies
- Equipment and system controls
- Fan motor HP and controls
- Duct sealing, duct and pipe insulation
- Lighting fixture schedule with wattage and control narrative
- Air sealing details
Climate Specific Requirements

Table R301.1
**Cut to the Chase** - Major Changes

- More efficient windows (U-0.33 to U-0.32)
- More efficient skylights (U-0.60 to U-0.55)
- More efficient crawlspace walls (R-10/19 to R-15/19)
- Mandatory whole-house pressure test (1 yr transition)
- Mandatory thermal envelope tightness checklist
- More stringent duct leakage test
- Mandatory mechanical ventilation
- 75% high efficacy lamps mandatory
- RESCheck will now be "better than code" (it had been "easier than code")
**Cut to the Chase** – **Major Non-changes**

- Wall insulation requirement unchanged (IECC requires added R5 insulation sheathing)*
- Maximum House Air Tightness (4 ACH50)*
- Retains prohibition on envelope-equipment trade-offs
- May use building cavities as return ducts*
- DHW distribution pipe requirements – minimal changes*

* - Montana Amendments
Compliance Paths

Mandatory +
Prescriptive R-Values

Mandatory +
Prescriptive U-Factors

Mandatory +
Prescriptive Total UA

Mandatory +
Performance

Mandatory +
Above-code Program
## Compliance Paths

<table>
<thead>
<tr>
<th>Compliance Paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory + Prescriptive R-Values</td>
</tr>
<tr>
<td>Mandatory + Prescriptive U-Factors</td>
</tr>
<tr>
<td>Mandatory + Prescriptive Total UA</td>
</tr>
<tr>
<td>Mandatory + Performance</td>
</tr>
<tr>
<td>Mandatory + Above-code Program</td>
</tr>
</tbody>
</table>

**R402 & R405**

**Simplicity**

**Ease of Use**

**Greater Flexibility**
Compliance Paths

- Mandatory + Prescriptive R-Values
- Mandatory + Prescriptive U-Factors
- Mandatory + Prescriptive Total UA
- Mandatory + Performance
- Mandatory + Above-code Program

Table R402.1.1: Insulation and Fenestration Requirements by Component

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Fenestration U-Factor*</th>
<th>Skylight U-Factor</th>
<th>Glazed Fenestration SHGC*</th>
<th>Ceiling R-Value</th>
<th>Wood Frame Wall R-Value</th>
<th>Masonry Wall R-Value</th>
<th>Floor R-Value</th>
<th>Basement Wall R-Value</th>
<th>Slab R-Value &amp; Depth</th>
<th>Crawl Space Wall R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NR</td>
<td>0.75</td>
<td>0.25</td>
<td>30</td>
<td>13</td>
<td>3/4</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.40</td>
<td>0.65</td>
<td>0.25</td>
<td>38</td>
<td>13</td>
<td>4/6</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.55</td>
<td>0.25</td>
<td>38</td>
<td>20 or 13+5*</td>
<td>8/13</td>
<td>19</td>
<td>5/13i</td>
<td>0</td>
<td>5/13</td>
</tr>
<tr>
<td>4 except Marine</td>
<td>0.35</td>
<td>0.55</td>
<td>0.40</td>
<td>49</td>
<td>20 or 13+5*</td>
<td>8/13</td>
<td>19</td>
<td>10/13</td>
<td>10, 2 ft</td>
<td>10/13</td>
</tr>
<tr>
<td>5 and Marine 4</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20 or 13+5*</td>
<td>13/17</td>
<td>30</td>
<td>15/19</td>
<td>10, 2 ft</td>
<td>15/19</td>
</tr>
<tr>
<td>6</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20+5 or 13+10*</td>
<td>15/20</td>
<td>30</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
<tr>
<td>7 and 8</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20+5 or 13+10*</td>
<td>19/21</td>
<td>38</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
</tbody>
</table>

Note: For SI: 1 foot = 304.8 mm.

- R-values are minimums. U-factors and SHGC are maximums. When insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed R-value of the insulation shall not be less than the R-value specified in the table.
- The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration. Exception: Skylights may be excluded from glazed fenestration SHGC requirements in Climate Zones 1 through 3 where the SHGC for such skylights does not exceed 0.30.
- “15/10” means R-15 continuous insulation on the interior or exterior of the home or R-10 cavity insulation at the interior of the basement wall. “15/10” shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. “10/13” means R-10 insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.
- R-5 shall be added to the required slab edge R-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in Climate Zones 1 through 3 for heated slabs.
- There are no SHGC requirements in the Marine Zone.
- Or insulation sufficient to fill the framing cavity, R-10 minimum.
- First value is cavity insulation, second is continuous insulation at or insulated siding, so “13+5” means R-13 cavity insulation plus R-5 continuous insulation or insulated siding. If structural sheathing covers 40 percent or less of the exterior, continuous insulation R-value shall be permitted to be reduced by no more than R-3 in the locations where structural sheathing is used to maintain a consistent total sheathing thickness.
- The second R-value applies when more than half the insulation is on the interior of the mass wall.
Compliance Paths

Mandatory + Prescriptive R-Values

Mandatory + Prescriptive U-Factors

Mandatory + Prescriptive Total UA

Mandatory + Performance

Mandatory + Above-code Program

R402.1.3

TABLE R402.1.3 EQUIVALENT U-FACTORS

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>PENETRATION U-FACTOR</th>
<th>SKYLIGHT U-FACTOR</th>
<th>CEILING U-FACTOR</th>
<th>FRAME WALL U-FACTOR</th>
<th>MASS WALL U-FACTOR</th>
<th>FLOOR U-FACTOR</th>
<th>BASEMENT WALL U-FACTOR</th>
<th>CRAWL SPACE WALL U-FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50</td>
<td>0.75</td>
<td>0.035</td>
<td>0.082</td>
<td>0.197</td>
<td>0.064</td>
<td>0.360</td>
<td>0.477</td>
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<td>2</td>
<td>0.40</td>
<td>0.65</td>
<td>0.030</td>
<td>0.082</td>
<td>0.165</td>
<td>0.064</td>
<td>0.360</td>
<td>0.477</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.55</td>
<td>0.030</td>
<td>0.057</td>
<td>0.098</td>
<td>0.047</td>
<td>0.091*</td>
<td>0.136</td>
</tr>
<tr>
<td>4 except Marine</td>
<td>0.35</td>
<td>0.55</td>
<td>0.026</td>
<td>0.057</td>
<td>0.098</td>
<td>0.047</td>
<td>0.059</td>
<td>0.065</td>
</tr>
<tr>
<td>5 and Marine 4</td>
<td>0.32</td>
<td>0.55</td>
<td>0.026</td>
<td>0.057</td>
<td>0.098</td>
<td>0.047</td>
<td>0.059</td>
<td>0.065</td>
</tr>
<tr>
<td>6</td>
<td>0.32</td>
<td>0.55</td>
<td>0.026</td>
<td>0.048</td>
<td>0.060</td>
<td>0.033</td>
<td>0.050</td>
<td>0.065</td>
</tr>
<tr>
<td>7 and 8</td>
<td>0.32</td>
<td>0.55</td>
<td>0.026</td>
<td>0.048</td>
<td>0.057</td>
<td>0.033</td>
<td>0.050</td>
<td>0.065</td>
</tr>
</tbody>
</table>

a. Nonfenestration U-factors shall be obtained from measurement, calculation or an approved source.
b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in Climate Zone 1, 0.14 in Climate Zone 2, 0.12 in Climate Zone 3, 0.087 in Climate Zone 4 except Marine, 0.065 in Climate Zone 5 and Marine 4, and 0.057 in Climate Zones 6 through 8.
c. Basement wall U-factor of 0.360 in warm-humid locations as defined by Figure R301.1 and Table R301.1.

R-value Cavity
- Inside air film: 0.68
- Gypsum board: 0.45
- Cavity insulation: 21
- 5.5” Stud: 6.8
- Exterior sheathing: 0.5
- Exterior siding: 1.0
- Outside Air Film: 0.17
- Total R-value: 23.8

R-value Stud
- Inside air film: 0.68
- Gypsum board: 0.45
- Cavity insulation: 21
- 5.5” Stud: 6.8
- Exterior sheathing: 0.5
- Exterior siding: 1.0
- Outside Air Film: 0.17
- Total R-value: 9.68
Compliance Paths

Mandatory + Prescriptive R-Values

Mandatory + Prescriptive U-Factors

Mandatory + Prescriptive Total UA

Mandatory + Performance

Mandatory + Above-code Program

\[ U = (A_1 \text{fraction} \times U_1) + (A_2 \text{fraction} \times U_2) + ... \]
Compliance Paths

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Prescriptive R-Values</td>
</tr>
<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Prescriptive U-Factors</td>
</tr>
<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Prescriptive Total UA</td>
</tr>
<tr>
<td>Mandatory +</td>
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<tr>
<td>Performance</td>
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<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Above-code Program</td>
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<tr>
<td>Mandatory +</td>
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<tr>
<td>Prescriptive U-Factors</td>
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<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Prescriptive Total UA</td>
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<tr>
<td>Mandatory +</td>
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<tr>
<td>Performance</td>
</tr>
<tr>
<td>Mandatory +</td>
</tr>
<tr>
<td>Above-code Program</td>
</tr>
</tbody>
</table>
“The code official...shall be permitted to deem a national, state or local energy efficiency program to exceed the energy efficiency required by this code.”
(Mandatory requirements must be met.)
<table>
<thead>
<tr>
<th>Provision</th>
<th>Code</th>
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</thead>
<tbody>
<tr>
<td>Certificate</td>
<td>R401.3</td>
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<tr>
<td>Air Leakage (Testing &amp; Visual Checklist)</td>
<td>R402.4</td>
</tr>
<tr>
<td>Controls for Heating and Cooling System</td>
<td>R403.1</td>
</tr>
<tr>
<td>Duct Sealing</td>
<td>R403.2</td>
</tr>
<tr>
<td>No Building Cavities as Ducts</td>
<td>R403.2.3</td>
</tr>
<tr>
<td>Mechanical System Pipe Insulation</td>
<td>R403.3</td>
</tr>
<tr>
<td>Mechanical Ventilation Required</td>
<td>R403.5</td>
</tr>
<tr>
<td>Equipment Sizing (ACCA Manuals S &amp; J)</td>
<td>R403.6</td>
</tr>
<tr>
<td>Lighting Minimum Requirements</td>
<td>R404.1</td>
</tr>
</tbody>
</table>

Applies to all performance paths. Can not be traded off.
Certificate (Mandatory)

- Specify Compliance Path
- Envelope Air Leakage
- Duct System Air Leakage
- Builder Signature

Place on electrical panel box.
It's About the Movement of.....

→ Heat
→ Air
→ Moisture
The 3 Heat Transfer Mechanisms

Conduction

Convection

Radiation

Source: NCAT
Conduction

• Heat flow through solid objects and materials.

• Molecules vibrate more vigorously, passing heat through the material.

• Generally the **slowest** of the three heat transfer methods.
Convection

- Heat transfer by a moving fluid such as air or water.
- Caused by density difference between warmer and cooler parts of fluid.
- Heat transfer by convection is considered the fastest because the molecules physically move.
Radiation

• Hot surfaces are able to warm objects distant from them because they have a higher temperature.

• Radiation requires a temperature difference, a gap, and “line of sight”
R-Values and U-Values

R-Values Measure Thermal Resistance

R-Values are additive \((R-1 + R-1 = R-2)\)

R-Value is the inverse of U-value \((R=1/U \text{ and } U=1/R)\)

U-Value: Heat flow through a material at specific
- Area (SF)
- Temperature difference (°F)
- Period of time (Hr)

U-Value is in units of Btus/ft\(^2\)•hr•°F
R-Values and U-Values

R-Values are additive and useful for comparing the insulating qualities of both materials and assemblies.

U-Factors can be used to calculate heat loss and gain.

Heat Load in BTUs = Area x U-Value x Temp. Diff.

**British Thermal Unit (Btu) =**
Amount of heat required to raise one pound of water on degree.
Reduced Heat Loss

- R-1 to R-2: 50%
- R-10 to R-11: 9.1%
- R-20 to R-21: 2.4%
- R-30 to R-31: 1.1%
- R-40 to R-41: 0.06%
- R-50 to R-51: 0.04%
Common Insulation Materials

Batt Insulation In Ceiling

- **R 2.6 - 4.2**

Blown-in Insulation

- **R 3.6 - 4.4**

Spray Foam

- **Spray foam applied along the underside of the roof deck**

High-density Polyurethane

- **R 6.0 – 7.0**

Low-density Polyurethane

- **R 3.5 – 3.8**

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates
Uninsulated walls transmit heat through its air space by convection and radiation.
Heat Transfer Through Walls

Insulating walls reduces convection and radiation heat transfer but increases conduction.

Source - NCAT
Vapor Diffusion vs. Air Transport

Air movement is typically far more important than vapor diffusion.

Water vapor moves in two ways

• Vapor Diffusion (movement through solid material)
• Air Transport (the more important)

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates
Air and Vapor Migration

Air Molecules

Water Molecules

Low Pressure

High Pressure

Source - NCAT
Vapor Retarders

Class I or II vapor retarder at warm side of wall required. Exception: Basement Walls and any portion or below grade walls.

Class III vapor retarder permitted if:
• Vented cladding over fiberboard
• Vented cladding over gypsum’
• Insulated sheathing with R >= 7.5 over 2x4 wall
• Insulated sheathing R >= 11.25 over 2x6 wall

IRC R702.7                              Vapor Retarders
Vapor Retarder Class

Class I: 0.1 Perm or Less
Class II: 0.1 < Perm <= 1.0 Perm
Class III: 1.0 < Perm <= 10 Perm

Class I: Sheet Polyethylene, Aluminum Foil
Class II: Kraft-faced Fiberglass Batts
Class III: Latex or Enamel Paint

IRC R702.7.2
Vapor Retarders

Poly Vapor Retarder

Kraft-faced Vapor Retarder

USDOE Building Energy Codes Program
1. Air Barrier and Thermal Barrier

**Insulation:**

- **Resists Heat Flow**
- **Air Flow**

...need **Air Barrier**

any solid material that blocks air flow
including sealing at edges and seams
Air Barrier - A system of materials designed and constructed to control airflow between a conditioned and an unconditioned space.

- An air barrier is intended to resist the air pressure differences that act on them. Rigid materials such as gypsum board, plywood, OSB, and supported flexible barriers are typically effective air barriers if joints are sealed.
- **Exterior air barriers** keep outside air out of the building enclosure.
- **Interior air barriers** keep inside air out of the building enclosure.
Common Air Barrier Systems in Residential Construction

- **Interior** air barrier system using gypsum board and framing
- **Interior** air barrier system using polyethylene
- **Exterior** air barrier system using exterior sheathing
- **Exterior** air barrier system using house wraps
- Damp spray cellulose is not an air barrier, it is an air retarder

Source: Paul Tschida, MT DEQ
## Vapor Retarders

### Vapor Retarder Definitions

The 2009 IRC R601.3 gives the following definitions and examples for vapor retarder classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.1 perm or less</td>
<td>Sheet polyethylene, sheet metal, non-perforated aluminum foil</td>
</tr>
<tr>
<td>II</td>
<td>Greater than 0.1 perm to less than 1.0 perm</td>
<td>Kraft-faced fiberglass batts or low-perm paint</td>
</tr>
<tr>
<td>III</td>
<td>Greater than 1.0 perm to less than 10 perm</td>
<td>Latex or enamel paint</td>
</tr>
</tbody>
</table>

Impermeable = vapor barrier

Semi-impermeable

Semi-permeable

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates
## Perm Ratings of Common Sheathing Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Perm Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plywood sheathing</td>
<td>More than 1.0 perm</td>
</tr>
<tr>
<td>OSB</td>
<td>More than 1.0 perm</td>
</tr>
<tr>
<td>Exterior gypsum</td>
<td>More than 1.0 perm</td>
</tr>
<tr>
<td>Fiberboard sheathing</td>
<td>More than 1.0 perm</td>
</tr>
<tr>
<td>Extruded polystyrene foam sheathing 1 inch</td>
<td>1.0 perm or less</td>
</tr>
<tr>
<td>Film-faced extruded polystyrene 0.5 inch thick with perforated facing</td>
<td>More than 1.0 perm</td>
</tr>
<tr>
<td>Nonperforated foil-faced rigid insulation</td>
<td>Less than 0.1 perm</td>
</tr>
<tr>
<td>Polypropylene-faced rigid insulation</td>
<td>Less than 0.1 perm</td>
</tr>
<tr>
<td>Three-coat, hard-coat stucco over 2 layers of Type D asphalt-saturated Kraft paper and OSB</td>
<td>Less than 1.0 perm</td>
</tr>
</tbody>
</table>

**Hygroscopic Materials**: Materials that absorb water, their vapor permeability goes up as the relative humidity goes up.

**Hydrophobic Materials**: Materials with permeance that does not change with relative humidity.

Refer to Residential Energy for a Vapor Permeability Table

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates

Source: Lstiburek 2006. See Building Science Corporation 2006 for an extensive list of building material perm ratings.
Class I or II vapor retarders required on interior side of frame walls except at:
  • Basement or any below grade walls
  • If moisture and freezing will not damage materials

Class III vapor retarders may be used if:
  • Vented Cladding over SIPS, fiberboard, or gypsum
  • Insulated sheathing R-Value >= 5 over 2x4 wall
  • Insulated sheathing R-Value >= 11.25 over 2x6 wall
Moisture in Construction Cavities is a Major Problem

- Water is related to 90% of building and material failures (ASHRAE)
- Estimated $9 Billion/year in repairs for water related failures
Relative Humidity and Dew Point

Important Relative Humidity Considerations

• The tighter the house the higher the RH
• The higher the RH the greater likelihood of condensation
• To reduce likelihood of condensation:
  ▪ Reduce of eliminate moisture sources
  ▪ Provide mechanical ventilation

When condensation appears on the glass of ice water the glass has reached the dew point temperature.
## Fenestration and Skylight U-Factors

### TABLE R402.1.1

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>FENESTRATION U-FACTOR&lt;sup&gt;b&lt;/sup&gt;</th>
<th>SKYLIGHT&lt;sup&gt;b&lt;/sup&gt; U-FACTOR</th>
<th>GLAZED FENESTRATION SHGC&lt;sup&gt;c,h&lt;/sup&gt;</th>
<th>CEILING R-VALUE</th>
<th>WOOD FRAME WALL R-VALUE</th>
<th>MASS WALL R-VALUE&lt;sup&gt;e&lt;/sup&gt;</th>
<th>FLOOR R-VALUE</th>
<th>BASEMENT&lt;sup&gt;c&lt;/sup&gt; WALL R-VALUE</th>
<th>SLAB&lt;sup&gt;d&lt;/sup&gt; R-VALUE &amp; DEPTH</th>
<th>CRAWL SPACE&lt;sup&gt;c&lt;/sup&gt; WALL R-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NR</td>
<td>0.75</td>
<td>0.25</td>
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<td>3/4</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>0.4</td>
<td>0.65</td>
<td>0.25</td>
<td>38</td>
<td>13</td>
<td>4/6</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.55</td>
<td>0.25</td>
<td>38</td>
<td>20 or 13+5&lt;sup&gt;h&lt;/sup&gt;</td>
<td>8/13</td>
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<td>5/13&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0</td>
<td>#######</td>
</tr>
<tr>
<td>4 except Marine</td>
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</tr>
</tbody>
</table>
Window U-Factor

U-Factor

from 0.32 to 0.33

Lower means less heat loss.

Source: www.nfrc.org
Window Solar Heat Gain Coefficient

R402.1.1

No requirement for Zone 6 (Montana)

Lower means less solar gain. Single pane glass is 0.87

Source: www.nfrc.org
Window Visible Transmittance

No code requirement.

Higher means greater potential for daylighting.

Source: www.nfrc.org
Windows – Maximum Air Leakage

0.3 cfm/SF No change.

Lower means less leakage.

Source: www.nfrc.org
Window Condensation Resistance

No code requirement.

Higher means better as resisting condensation.

Source: www.nfrc.org
Window Condensation Chart
If Fenestration Not Labeled by NFRC

If not NFRC labeled, must use tables 303.1.3(1&2) to assign a default SHGC and U-Factor
Other Window Provisions – All Compliance Options

No code change.

Hard Limits – Can’t be exceeded, even in trade-offs.

Glazed Fenestration: Maximum area weighted U-Factor .40

Skylights: Maximum area weighted U-Factor .75
Skylights

**U-Factor**

from 0.60 to 0.55

Source: USDOE Building Energy Codes University
National Fenestration Rating Council

World's Best Door Co.
Entrance Door CPD#000-x-000
Insulated Steel Wood Edge Door

ENERGY PERFORMANCE RATINGS

<table>
<thead>
<tr>
<th>Product Description</th>
<th>U-Factor/Solar Heat Gain Coefficient (SHGC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4 Lit. ≤410 ft²</td>
</tr>
<tr>
<td>2/A1/na/AIR/0.250</td>
<td>0.23</td>
</tr>
<tr>
<td>2/A1/.020(3)/ARG/0.750</td>
<td>0.21</td>
</tr>
<tr>
<td>2/A1/na/AIR/0.675</td>
<td>0.28</td>
</tr>
<tr>
<td>3/SS/na/AIR/0.250</td>
<td>0.21</td>
</tr>
<tr>
<td>Flush/Embossed</td>
<td>U-Factor 0.19</td>
</tr>
</tbody>
</table>

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size.

* #glazing layers / spacer type / low-e emissivity (surface) / gap fill / gap width (na-net applicable)
per NFRC 100 Section B3.24 † square inches

www.nfrc.org
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<td>0.25</td>
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Energy Trusses Allow R-38

Scissor trusses solve the problem of how to insulate a cathedral ceiling while allowing room to ventilate the insulated space.

Raised-heel trusses allow the full depth of attic insulation to extend over the top of the exterior wall.

Source - Residential Energy
Eave Baffles Required

R402.2.3 Required for air permeable insulations in vented attics

Source: USDOE Building Technologies Program, Introduction to Building Systems Performance: Houses That Work II
Ice Dams

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates
Weatherstrip and insulate doors from conditioned spaces to unconditioned spaces (e.g., attics and crawl spaces)

- Insulate to level equivalent to surrounding surfaces
  - e.g., required ceiling insulation = R-38, then attic hatch must be insulated to R-38

Provide access to all equipment that prevents damaging or compressing the insulation

Install a wood framed or equivalent baffle or retainer when loose fill insulation is installed

Source: USDOE Building Energy Codes University
# Wood Frame Wall R-Value

**TABLE R402.1.1**

## INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT

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Wood Frame Wall R-Value

R402.1.1

From R21 or R13+R5 to No Change

2012 IECC

R20+R5 or R13+R10

- Exterior above-grade walls
- Attic kneewalls
- Skylight shaft walls
- Perimeter joists
- Basement walls
- Garage walls (shared with conditioned space)
It is not just about the R-Value

Why can fiberglass batt insulation perform so poorly?
Common Batt Insulation Installation Defects

- Misalignment
- Void
- Compression
- Gap
Fiberglass Batts (Real World)

- Rated R-value: 19
- "Best Practice\*\*": 13
- Typical Installation\*: 11
- Steel Stud wall: 9
Correct Installation
Loose Fill Fiberglass Methods

Blown in—open attics

- Desired R-value achieved by installing the number of bags specified by the manufacturer (by square feet)

Blown in Blanket (BIB) system

- Loose fill fiberglass installed behind netting stapled over framing members
- Installed R-value dependent on density
- Typical for a 2x6 wall is R-21 to R-23
Grade I Assessment

Installed according to manufacturer’s instructions, fills each cavity completely, no substantial gaps or voids, split and fit tightly around wiring and other services.

**Boundary condition for “Grade I”**

- Gaps clear through insulation—minimal
- Compression or incomplete fill: <2% of area, compressed by <30% of intended thickness
Moderate to frequent defects such as gaps around wiring, electrical outlets, plumbing, and other services; rounded edges or shoulders.

**Boundary condition for “Grade II”**

- Gaps clear through insulation: <2%
- Compression or incomplete fill: <10% of area, compressed by <30% of intended thickness
Insulation Grading

To be **Grade I floor insulation** must be in complete contact with the surface it is intended to insulate.
Why Continuous Insulated Sheathing in 2012 IECC?

Source: DOW Chemical Company publication titled “Improve Energy Efficiency and Air Sealing in Above-Grade Walls.”
Why Insulated Sheathing?

Rigid Insulation = Air Barrier + Insulation + Thermal Break

Where code acceptable, consider using at:

- Exterior Sheathing
- Attic Knee Walls
- Skylight Shafts
- Porch/House Interface
Continuous Insulated Sheathing – Not in the MT Code

Source: DOW Chemical Company publication titled “Improve Energy Efficiency and Air Sealing in Above-Grade Walls.”
Effective R-Value of Typical Wall Assemblies

R-Value

R-19
R-10
R-5

R-14.4  R-19.4  R-18.8  R-23.8
Wall Drying Potential - Cold Climate

- Cooler, Lower Humidity: Exterior
- Warmer, Higher Humidity: Interior

Semi-Permeable Vapor Retarder Layer

Drying Primarily to the Exterior
Wall Drying Potential – Hot Humid Climate

**Vapor Retarder Layer**
- Semi-Impermeable or Impermeable

**Exterior**
- Warmer
- Higher Humidity

**Interior**
- Cooler Lower Humidity

**Permeable or Semi-Permeable Interior Finish**

Drying Primarily to the Interior
Wall Drying Potential – Mixed-Humid Climate

- Exterior
- Interior

Semi-Permeable or Permeable

Semi-Permeable or Permeable Interior Finish

No Vapor Retarder Layer in Wall

Drying to both the Exterior and Interior
Exterior Insulated Sheathing & Condensation Resistance

32 F  →  33 F

32 F  →  40 F

32 F  →  44 F
Condensation Risk on Back of Exterior Sheathing

Interior: 70 F and 35% Humidity

Period of Condensation Risk

Mid-November to Mid-March
Mid-December to Mid-February
None

Chicago example by Building Science Corporation (buildingscience.com)
House as a System – Other Factors

What We Can’t Control:
- Outdoor Temperature
- Outdoor Humidity
- Wind
House as a System – Other Factors

What we can control:
Indoor Temperature (sort of)
Indoor Humidity (sort of)
Thermal Resistance of Components
Permeability of Components
# Exterior Sheathing Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>R-Value/Inch</th>
<th>Density (pcf)</th>
<th>Permeability (Perms)</th>
<th>Compressive Strength (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Polystyrene (EPS)</td>
<td>3.9</td>
<td>1.0</td>
<td>5.0</td>
<td>10</td>
</tr>
<tr>
<td>Extruded Polystyrene (XPS)</td>
<td>5.0</td>
<td>1.3</td>
<td>1.1</td>
<td>15</td>
</tr>
<tr>
<td>Polyisocyanurate (ISO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foil Faced</td>
<td>6.5</td>
<td>2.0</td>
<td>0.03</td>
<td>25</td>
</tr>
<tr>
<td>Glass Fiber Faced</td>
<td>6.5</td>
<td>2.0</td>
<td>&lt;1.0</td>
<td>25</td>
</tr>
<tr>
<td>ISO Structural Insulated Sheathing (SIS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOW Styrofoam SIS</td>
<td>5.5</td>
<td>2.0</td>
<td>0.03*</td>
<td>20</td>
</tr>
<tr>
<td>Zip R-Sheathing</td>
<td>3.6</td>
<td>2.0</td>
<td>1.5**</td>
<td>20</td>
</tr>
</tbody>
</table>

**Notes:**
1. R-Values are given at 75 F.
2. Typical values shown. Specific products may vary.
   * - Rating shown is for facer material, the product also includes ISO and fiber board.
   ** - Product includes facer (12-16 perms), ISO, and OSB (2-3 perms).

## Common Brand Names

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<th>EPS</th>
<th>XPS</th>
<th>ISO</th>
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<td>Insulfoam</td>
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<td>Rmax</td>
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<td>Blue Board</td>
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**Common Brand Names:**

- EPS
- XPS
- ISO
- Insulfoam
- Blue Board
- Thermax
- R-Tech
- Formular
- Tuff-R
- Green Guard
- Rmax
Ceilings without Attic Spaces Section

R-30 allowed, if insufficient space, for up to 500 ft$^2$ (or 20% of total insulated ceiling area, whichever is less) where Insulation levels are required greater than R-30

Note: This reduction ONLY applies to the R-value prescriptive path, not the U-factor or Total UA alternatives
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What Is a Basement Wall?

Source: USDOE Building Energy Codes University
Unfinished Basement Insulation Options

Source: Ecocell by Cellulose Material Solutions, LLC

Source: Paul Tschida, MTDEQ
Source: U.S. Department of Energy
Building Energy Codes Program
Basement Foundations

Source: USDOE Building Technologies Program, Introduction to Building Systems Performance: Houses That Work II
Radon Mitigation

EPA recommends that all homes built in Zone 1 have radon reduction systems.

Radon Risk is High in much of the U.S. Check State & local authorities for more detailed information on Radon risk in your area.

Note: these maps indicate average risk by county. However, High levels of Radon can be found anywhere, and soil gases may be toxic!
Radon Mitigation

How Does Radon Enter A House?

Radon enters a home through cracks in concrete, joints in construction below grade, and through poorly sealed crawl space construction.

Source: USEPA Building Radon Out
Radon Mitigation
What’s the problem?
## Slab R-Value

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<th>CLIMATE ZONE</th>
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<th>SKYLIGHT&lt;sup&gt;c&lt;/sup&gt; U-FACTOR</th>
<th>GLAZED FENESTRATION SHGC&lt;sup&gt;d,e&lt;/sup&gt;</th>
<th>CEILING R-VALUE</th>
<th>WOOD FRAME WALL R-VALUE</th>
<th>MASS WALL R-VALUE&lt;sup&gt;e&lt;/sup&gt;</th>
<th>FLOOR R-VALUE</th>
<th>BASEMENT&lt;sup&gt;f&lt;/sup&gt; WALL R-VALUE</th>
<th>SLAB&lt;sup&gt;g&lt;/sup&gt; R-VALUE &amp; DEPTH</th>
<th>CRAWL SPACE&lt;sup&gt;h&lt;/sup&gt; WALL R-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NR</td>
<td>0.75</td>
<td>0.25</td>
<td>30</td>
<td>13</td>
<td>3/4</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.65</td>
<td>0.25</td>
<td>38</td>
<td>13</td>
<td>4/6</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.55</td>
<td>0.25</td>
<td>38</td>
<td>20 or 13+5&lt;sup&gt;h&lt;/sup&gt;</td>
<td>8/13</td>
<td>19</td>
<td>5/13&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0</td>
<td>#</td>
</tr>
<tr>
<td>4 except Marine</td>
<td>0.35</td>
<td>0.55</td>
<td>0.4</td>
<td>49</td>
<td>20 or 13+5&lt;sup&gt;h&lt;/sup&gt;</td>
<td>8/13</td>
<td>19</td>
<td>13-Oct</td>
<td>10, 2 ft</td>
<td>13-Oct</td>
</tr>
<tr>
<td>5 and Marine 4</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20 or 13+5&lt;sup&gt;h&lt;/sup&gt;</td>
<td>13/17</td>
<td>30&lt;sup&gt;g&lt;/sup&gt;</td>
<td>15/19</td>
<td>10.2 ft</td>
<td>15/19</td>
</tr>
<tr>
<td>6</td>
<td>0.33</td>
<td>0.60</td>
<td>0.55</td>
<td>49</td>
<td>21 or 13+5&lt;sup&gt;h&lt;/sup&gt;</td>
<td>15/20</td>
<td>30&lt;sup&gt;g&lt;/sup&gt;</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
<tr>
<td>7 and 8</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20+5 or 13+10&lt;sup&gt;h&lt;/sup&gt;</td>
<td>19/21</td>
<td>38&lt;sup&gt;g&lt;/sup&gt;</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
</tbody>
</table>
Slab Insulation

R402.2.9

R-10 for 4’ Vertical or Horizontal
Add R-5 if the slab has radiant heat

Source: USDOE Building Energy Codes University
Slab Insulation

Source: USDOE Building Energy Codes University
## TABLE R402.1.1

### INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>FENESTRATION U-FACTOR$^b$</th>
<th>SKYLIGHT$^a$ U-FACTOR</th>
<th>GLAZED FENESTRATION SHGC$^{b,c}$</th>
<th>CEILING R-VALUE</th>
<th>WOOD FRAME WALL R-VALUE</th>
<th>MASS WALL R-VALUE</th>
<th>FLOOR R-VALUE</th>
<th>BASEMENT WALL R-VALUE</th>
<th>SLAB$^d$ R-VALUE &amp; DEPTH</th>
<th>CRAWL SPACE WALL R-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NR</td>
<td>0.75</td>
<td>0.25</td>
<td>30</td>
<td>13</td>
<td>3/4</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.65</td>
<td>0.25</td>
<td>38</td>
<td>13</td>
<td>4/6</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.55</td>
<td>0.25</td>
<td>38</td>
<td>20 or 13+5$^h$</td>
<td>8/13</td>
<td>19</td>
<td>5/13$^f$</td>
<td>0</td>
<td>#######</td>
</tr>
<tr>
<td>4 except Marine</td>
<td>0.35</td>
<td>0.55</td>
<td>0.4</td>
<td>49</td>
<td>20 or 13+5$^h$</td>
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<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20 or 13+5$^h$</td>
<td>13/17</td>
<td>30$^g$</td>
<td>15/19</td>
<td>10, 2 ft</td>
<td>15/19</td>
</tr>
<tr>
<td>6</td>
<td>0.33</td>
<td>0.60</td>
<td>0.55</td>
<td>NR</td>
<td>21 or 13+5$^h$</td>
<td>15/20</td>
<td>30$^g$</td>
<td>15/19</td>
<td>10, 4 ft</td>
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</tr>
<tr>
<td>7 and 8</td>
<td>0.32</td>
<td>0.55</td>
<td>NR</td>
<td>49</td>
<td>20+5 or 13+10$^h$</td>
<td>19/21</td>
<td>38$^g$</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
</tbody>
</table>
Crawlspace Wall

R402.1.1

From R10 / R19 to R15 / R19

R-Value

(Continuous / Cavity)

- Must choose to insulate either floor or walls
- Either mechanically vented or minimally conditioned (IRC)
- Continuous Class I vapor retarder at exposed earth
Class I Vapor Retarder at Exposed Earth
• 6” overlap sealed or taped
• Extend 6” up stem wall attached and sealed
Unvented Crawlspaces – Two Design Options

Continuous **Exhaust** to Exterior
- 1 CFM/50 SF Crawlspace Area
- Air Pathway to Common Area

**Conditioned** Air Supply
- 1 CFM/50 SF Crawlspace Area
- Air Pathway to Common Area
Foam Plastics

Surface Burning Characteristics
Flame Spread Index $\leq 75$
Smoke Developed Index $\leq 450$

Thermal Barrier
Shall be separated from interior of building by 1/2” gypsum board or equivalent thermal barrier

Crawlspace and attic thermal barriers are not required under certain conditions. (IRC R316.5.3 and R316.5.4)
Foam Plastics at Sill Plates & Headers

Thermal Barrier may be omitted at sill plates and headers if:

- Maximum thickness 3 ½”
- Foam density 0.5 to 2.0 lbs/CF
- Flame spread <=25 & smoke developed index <=450
Crawlspace Foundations

Source: USDOE Building Technologies Program, Introduction to Building Systems Performance: Houses That Work II
The Importance of a Continuous Vapor Barrier

A ground vapor barrier in an unvented crawlspace. Note the obvious moisture collecting below the polyethylene. The state code requires that the vapor barrier be lapped and sealed.
The Importance of a Continuous Vapor Barrier

Here is an example of a much better unvented crawlspace. The builder used an insulated concrete foundation (ICF) and 10 mill sealed polyethylene for ground vapor barrier. Some code officials require fire protection such as gypsum board for the exposed foam of the ICF.
Exterior Crawlspace Insulation

- Insulation Facing
- Rigid Insulation
- Foam at Rim Joist
- Sill Gasket
- Nailer and Sealant
- Continuous Vapor Barrier
Exterior Crawlspace Insulation

- Insulation Facing
- Rigid Insulation
- Sill Gasket
- Nailer and Sealant
- Continuous Vapor Barrier
Interior Crawlspace Batt Insulation

Traditional Vinyl Faced Batts (Metal Building Insulation) is not accepted by ENERGY STAR.
Interior Crawlspace Rigid Board Insulation

- Foam at Rim Joist
- Sill Gasket
- Rigid Foam with IRC Flame and Thermal Protection
- Nailer and Sealant
- Continuous Vapor Barrier
Floor assemblies shall be provided with a ½ gypsum board membrane. Exception 2: Floor assemblies located directly over a crawl space not intended for storage or fuel-fired appliances.
Air Leakage (Mandatory)

Thermal envelope must comply with both:

Table R402.4.1

Testing (402.4.1.2) Air Barrier and Insulation Installation

“Where required by the code official, testing shall be conducted by an approved third party.”
## Typical House Tightness Levels

<table>
<thead>
<tr>
<th></th>
<th>ACH50</th>
<th>CFM 2000 SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older Homes</td>
<td>10+</td>
<td>&gt;2600</td>
</tr>
<tr>
<td>Typical New Home ~2000</td>
<td>7</td>
<td>1800</td>
</tr>
<tr>
<td>2009 IECC Tightness Limit Zone 6</td>
<td>7</td>
<td>1800</td>
</tr>
<tr>
<td>Montana State Energy Code</td>
<td>4</td>
<td>1050</td>
</tr>
<tr>
<td>Proposed MT State Energy Code</td>
<td>4</td>
<td>1050</td>
</tr>
<tr>
<td>Energy Star Homes</td>
<td>4</td>
<td>1050</td>
</tr>
<tr>
<td>Idaho New Homes 2013</td>
<td>3.6</td>
<td>930</td>
</tr>
<tr>
<td>2012 IECC Tightness Limit Zone 6</td>
<td>3</td>
<td>800</td>
</tr>
</tbody>
</table>

Example based on 2,000 Ft² house with n = 14.5.
Stack Effect

Diagram is based on **inside air being warmer** than outside air.

When **outside air is warmer** than inside air, this process is reversed.
Sources of Household Water Vapor

- Perspiration
- Houseplants
- Bathing
- Wet Clothes
- Condensation
- Cooking
- Laundry
- Washing
- Exposed Soil
How Much Water?

Daily water vapor produced by family of 4:

- Respiration and perspiration 14 lb
- Showers & bathing 3 lb
- Cooking 2 lb
- Other activities 2 lb

Total 21 lb = 2.5 gal

US. Forest Products Lab estimated 12 gallons per day in a high ground water area
Options for Controlling Mold

- Eliminate mold spores (can’t do it!)
- Freeze or burn them (and drive us out too!)
- Control nutrient sources - Elimination is difficult
- **Control moisture - Best strategy**

Source: Paul Tschida, MT DEQ
Vapor Retarder Recommendations

1. Allow building assemblies to dry to either the exterior or the interior or both.
2. Avoid use of a less permeable vapor retarder where a more permeable retarder will provide satisfactory performance, to encourage drying.
3. Avoid installing vapor barriers on both sides of assemblies, i.e., double vapor barriers, to facilitate assembly drying in at least one direction.
4. Avoid installing Class I vapor barriers (polyethylene sheet, foil-faced batt) on the interior of air conditioned assemblies.
5. Avoid vinyl wall coverings on the inside of air conditioned assemblies.
6. Ventilate to ASHRAE 62.2.

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates, from Lstiburek 2006c
“Build it tight and ventilate it right”

A tight house starts with a basic and simply floor and roof plan. This makes detailing the continuous air and thermal barrier much easier.
## 16 Installation Components

### Table R402.4.1.1 Air Barrier and Insulation Installation

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air barrier and thermal barrier</td>
<td>A continuous air barrier shall be installed in the building envelope. Exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed. Air-permeable insulation shall not be used as a sealing material.</td>
</tr>
<tr>
<td>Ceiling/attic</td>
<td>The air barrier in any dropped ceiling/soffit shall be aligned with the insulation and any gaps in the air barrier sealed. Access openings, drop down stair or knee wall doors to unconditioned attic spaces shall be sealed.</td>
</tr>
<tr>
<td>Walls</td>
<td>Corners and headers shall be insulated and the junction of the foundation and sill plate shall be sealed. The junction of the top plate and top of exterior walls shall be sealed. Exterior thermal envelope insulation for framed walls shall be installed in substantial contact and continuous alignment with the air barrier. Knee walls shall be sealed.</td>
</tr>
<tr>
<td>Windows, skylights and doors</td>
<td>The space between window/door jambs and framing and skylights and framing shall be sealed.</td>
</tr>
<tr>
<td>Rim joists</td>
<td>Rim joists shall be insulated and include the air barrier.</td>
</tr>
<tr>
<td>Floors (including above-garage and cantilevered floors)</td>
<td>Insulation shall be installed to maintain permanent contact with underside of subfloor decking. The air barrier shall be installed at any exposed edge of insulation.</td>
</tr>
<tr>
<td>Crawl space walls</td>
<td>Where provided in lieu of floor insulation, insulation shall be permanently attached to the crawlspace walls. Exposed earth in unvented crawlspace shall be covered with a Class I vapor retarder with overlapping joints taped.</td>
</tr>
<tr>
<td>Shafts, penetrations</td>
<td>Duct shafts, utility penetrations, and flue shafts opening to exterior or unconditioned space shall be sealed.</td>
</tr>
<tr>
<td>Narrow cavities</td>
<td>Batts in narrow cavities shall be cut to fit, or narrow cavities shall be filled by insulation that on installation readily conforms to the available cavity space.</td>
</tr>
<tr>
<td>Garage separation</td>
<td>Air sealing shall be provided between the garage and conditioned spaces.</td>
</tr>
<tr>
<td>Recessed lighting</td>
<td>Recessed light fixtures installed in the building thermal envelope shall be air tight, IC rated, and sealed to the drywall.</td>
</tr>
<tr>
<td>Plumbing and wiring</td>
<td>Batt insulation shall be cut neatly to fit around wiring and plumbing in exterior walls, or insulation that on installation readily conforms to available space shall extend behind piping and wiring.</td>
</tr>
<tr>
<td>Shower/tub on exterior wall</td>
<td>Exterior walls adjacent to shower and tubs shall be insulated and the air barrier installed separating them from the showers and tubs.</td>
</tr>
<tr>
<td>Electrical/phone box on exterior walls</td>
<td>The air barrier shall be installed behind electrical or communication boxes or air sealed boxes shall be installed.</td>
</tr>
<tr>
<td>HVAC register boots</td>
<td>HVAC register boots that penetrate building thermal envelope shall be sealed to the subfloor or drywall.</td>
</tr>
<tr>
<td>Fireplace</td>
<td>An air barrier shall be installed on fireplace walls. Fireplaces shall have gasketed doors.</td>
</tr>
</tbody>
</table>
1. Air Barrier and Thermal Barrier

- Continuous air barrier shall be installed.
- Exterior thermal envelope contains a continuous air barrier.
1. Air Barrier and Thermal Barrier

Table R402.4.1.1

Interior Air Barrier Using Polyethylene

Source - Builder’s Guide to CC
1. Air Barrier and Thermal Barrier

Table R402.4.1.1
2. Ceiling/attic

Table R402.4.1.1

COMMON AIR LEAKS

Air leaking into the house
Air leaking out of the house

Attic Hatch
Recessed Light
Plumbing Vent Stack
Duct Register
Top Plate

HomeEnvelope
Dropped Soffit
Holes in the top plate for wiring are sealed with foam.

Source: USDOE Building Technologies Program, Whole-House Energy Savings in Cold and Very Cold Climates
3. Walls

Table R402.4.1.1

Source: ENERGY STAR New Homes

Source: ENERGY STAR New Homes
3. Walls

Table R402.4.1.1

Air sealing key points continued

Appendix 2009 IECC
4. Windows, Skylights, and Doors

Table R402.4.1.1

Source: USDOE Building Energy Codes University

Source: ENERGY STAR New Homes

Appendix 2009 IECC
5. Rim Joists

Table R402.4.1.1
5. Rim Joists

Table R402.4.1.1
6. Floors

Table R402.4.1.1
7. Crawl Space Walls

Table R402.4.1.1
8. Shafts, Penetrations

Source: USDOE Building Energy Codes University
9. Narrow Cavities
10. Garage Separation

Source: ENERGY STAR New Homes
11. Recessed Lighting

Table R402.4.1.1

Source: ENERGY STAR New Homes
12. Plumbing and Wiring

Table R402.4.1.1

Does Not Comply with Code
13. Shower/Tub on Exterior Wall

Source: ENERGY STAR New Homes

Source: ENERGY STAR New Homes
14. Electrical/Phone Box

Table R402.4.1.1

Source: USDOE Building Energy Codes University
15. HVAC Register Boots

Table R402.4.1.1

Source: ENERGY STAR New Homes
16. Fireplace

Table R402.4.1.1

Source: ENERGY STAR New Homes
Air Leakage Test (Mandatory)

MT Amendment: Less than 4 ACH50

$\text{CFM air in} = \text{CFM air out}$

Blower Door Test
Applying Mastic

R403.2.2

PLUG, don’t paint!
THICK AS A NICKEL
Duct Tightness Testing

R403.2.2

**Postconstruction Test**
Total Leakage or **Leakage to the Outside** <= 4 cfm/100 SF (at 25 PA)
Formerly Leakage to Outside limit was 8 cfm/100 SF
Formerly Total Leakage limit was 12 cfm/100 SF

**Rough-in Test**
Total Leakage <= 4 cfm/100 SF (at 25 PA)
Formerly Total Leakage limit was 6 cfm/100 SF

*Testing not required if ducts and air handler entirely within building thermal envelope.*
Duct Leakage to the Outside

Digital Manometers
Supply Registers
Return Registers
Duct Tester Fan
Blower
Door
Fan
Supply and Return Registers Must be Sealed
Air Handler

Source: NCAT
Sealed Air Handler

Air handlers to have a manufacturer’s designation for an air leakage of $\leq 2\%$ of design air flow rate per ASHRAE 193

Source: USDOE Building Energy Codes University
Moving Air Hates to Make Hard Turns


Source: PTCS
Many Causes of Low Air Flow
Many Causes of Low Air Flow
Designing the Duct System

- Factors that influence the static pressure of the ducts:
  - Duct length
  - Duct diameter
  - Duct type
  - Duct turns
  - Other components, like filters

Source: EPA
The Never Connected and the Disconnected

Source: PTCS
Building Cavities as Return Ducts (Mandatory)  

2012 IECC prohibits use of building cavities for either supply or return.

Montana amended to allow use of building cavities for return.

Source: USDOE Building Energy Codes University
R-3 Insulation on:

- Piping > ¾ in. nominal diameter
- Piping serving more than one dwelling unit
- Piping from the water heater to kitchen outlets
- Piping located outside the conditioned space
- Piping from the water heater to a distribution manifold
- Piping under a floor slab
- Buried piping
- Supply and return piping in recirculating systems other than demand recirculation systems
- Piping with run lengths > maximum run lengths for nominal pipe diameter in Table R403.4.2

All remaining piping to be at least R-3 or meet run length requirements in Table R403.4.2
Whole-house mechanical ventilation system fans to meet efficacy in Table R403.5.1

Exception When fans are integral to tested and listed HVAC equipment, powered by electronically commutated motor
**TABLE M1507.3.3(1)**  
CONTINUOUS WHOLE-HOUSE MECHANICAL VENTILATION SYSTEM  
AIRFLOW RATE REQUIREMENTS

<table>
<thead>
<tr>
<th>DWELLING UNIT FLOOR AREA (square feet)</th>
<th>0-1</th>
<th>2-3</th>
<th>4-5</th>
<th>6-7</th>
<th>&gt; 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1,500</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>1,501 - 3,000</td>
<td>45</td>
<td>60</td>
<td>75</td>
<td>90</td>
<td>105</td>
</tr>
<tr>
<td>3,001 - 4,500</td>
<td>60</td>
<td>75</td>
<td>90</td>
<td>105</td>
<td>120</td>
</tr>
<tr>
<td>4,501 - 6,000</td>
<td>75</td>
<td>90</td>
<td>105</td>
<td>120</td>
<td>135</td>
</tr>
<tr>
<td>6,001 - 7,500</td>
<td>90</td>
<td>105</td>
<td>120</td>
<td>135</td>
<td>150</td>
</tr>
<tr>
<td>&gt; 7,500</td>
<td>105</td>
<td>120</td>
<td>135</td>
<td>150</td>
<td>165</td>
</tr>
</tbody>
</table>
TABLE M1507.3.3(2)
Intermittent Whole-House Mechanical Ventilation Rate Factors

<table>
<thead>
<tr>
<th>Run-Time Percent in Each 4-Hour Segment</th>
<th>25%</th>
<th>33%</th>
<th>50%</th>
<th>66%</th>
<th>75%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
<td>1.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table M1507.4
Minimum Required Local Exhaust Rates for One- and Two-Family Dwellings

<table>
<thead>
<tr>
<th>Area to Be Exhausted</th>
<th>Exhaust Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchens</td>
<td>100 cfm intermittent or 25 cfm continuous</td>
</tr>
<tr>
<td>Bathrooms-Toilet Rooms</td>
<td>Mechanical exhaust capacity of 50 cfm intermittent or 20 cfm continuous</td>
</tr>
</tbody>
</table>
## IMC Table 403.3

**IMC M403.3**

Minimum Ventilation Rates - Private Dwellings, single and multiple

<table>
<thead>
<tr>
<th>Occupancy Classification</th>
<th>Occupant Density</th>
<th>Airflow Rate in Breathing Zone, ( R_p ) CFM/Person</th>
<th>Exhaust Airflow Rate CFM/SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garages, common for multiple units</td>
<td>-----------------</td>
<td>-----------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Garages, separate for each dwelling</td>
<td>-----------------</td>
<td>100 cfm per car</td>
<td></td>
</tr>
<tr>
<td>Kitchens</td>
<td>-----------------</td>
<td>50/100*</td>
<td></td>
</tr>
<tr>
<td>Living Areas</td>
<td>Based on number of bedrooms. First Bedroom 2, each additional bedroom</td>
<td>0.35 ACH but not less than 15 cfm/person</td>
<td></td>
</tr>
<tr>
<td>Toilet Rooms and Bathrooms</td>
<td></td>
<td>20/50*</td>
<td></td>
</tr>
</tbody>
</table>

* - Continuous / Intermittent
Do Homebuyers Care about IAQ?

- **Moisture and mold litigation - Up**
  [~9,000 moisture and mold court cases - American Banker, 1/03]

- **Home moisture problem inquiries - High**
  [30%, double the next closest subject - NAHB Research Center]

- **Asthma prevalence - High**
  [19% of US households have at least 1 person with asthma - EPA]

- **Air cleaner product sales - Up**
  [$1.2 Billion annual sales - Levin, 2005]

- **Radon mitigation sales - Up**
  [300% increase in home radon mitigations since 1990 - EPA]
IAQ Risk Reduction Principles

1. **Source Control**
   eliminate, substitute, or modify pollutant sources
   Should be highest priority!

2. **Dilution**
   ventilate to dilute unavoidable pollutants
   The role of mechanical ventilation!

3. **Filtration**
   remove targeted pollutants,
   last resort after source control & dilution
   Both difficult and expensive in residential applications.
<table>
<thead>
<tr>
<th></th>
<th>Infiltration</th>
<th>Mechanical Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable appropriate quantity of air</td>
<td>NO</td>
<td>Yes</td>
</tr>
<tr>
<td>Air delivered to appropriate spaces</td>
<td>NO</td>
<td>Yes</td>
</tr>
<tr>
<td>Can be shut off if house is unoccupied</td>
<td>NO</td>
<td>Yes</td>
</tr>
<tr>
<td>Quality of air good as outdoor air</td>
<td>NO</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: This assumes mechanical system is properly designed.
Mechanical Ventilation Strategies

Exhaust Only

Supply Only

Balanced without Heat Recovery
Balanced with Heat Recovery
Exhaust and Supply Ventilation Systems

CEILING MOUNTED FAN - MUST MEET SONE RATING REQUIREMENTS
Arguments for Balanced Mechanical Ventilation Systems

1. Avoids problems of creating positive and negative pressures
2. More likely to actually provided design air quantities
3. Provides air through planned pathways, improves air quality
4. Many systems provide option for heat recovery

A simple controller for intermittent use of mechanical ventilation systems.
Central Balanced Exhaust without Heat Recovery

Balanced ventilation system with fresh air intake integrated with air handler and exhaust fan(s).
Fresh Air Intake Interconnected to Exhaust Fan

Source: www.aircycler.com
Central Balanced Exhaust with Heat Recovery

Balanced ventilation system with heat recovery ventilator.
Heat Recovery Ventilator (HRV)

Source: Venmar FAE 125M
Heat Recovery Ventilator (HRV)

- Furnace Supply
- Fresh Air from Outside
- Exhaust Air from Building
- Fresh Air to Building
- Exhaust Air to Outside
- Furnace Return
Some interesting stuff:

- Designer range hoods can be 500-1200 CFM
- Older clothes dryers are about 150 CFM
- New clothes dryers are 150-300 CFM
- Some jurisdictions in Canada required ducted fresh air to bedrooms
- In a typical bathroom 70 CFM fan must operate for 45 minutes to exhaust moisture from a shower.
Heating and Cooling Equipment

- Sized according to **ACCA Manual S**
- Based on loads calculated per **ACCA Manual J**
  (or other approved calculation methodology)
# ACCA Manual J Room by Room Heat Load Calculations


<table>
<thead>
<tr>
<th>Room</th>
<th>Area (ft²)</th>
<th>Heating load (Btuh)</th>
<th>Cooling load (Btuh)</th>
<th>Heating Airflow (cfm)</th>
<th>Cooling Airflow (cfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>255</td>
<td>4670</td>
<td>4568</td>
<td>188</td>
<td>221</td>
</tr>
<tr>
<td>Dining room</td>
<td>224</td>
<td>4219</td>
<td>2271</td>
<td>195</td>
<td>188</td>
</tr>
<tr>
<td>Kitchen</td>
<td>144</td>
<td>3201</td>
<td>2456</td>
<td>91</td>
<td>119</td>
</tr>
<tr>
<td>Bedroom 1</td>
<td>158</td>
<td>4410</td>
<td>1799</td>
<td>142</td>
<td>98</td>
</tr>
<tr>
<td>Bedroom 2</td>
<td>106</td>
<td>1730</td>
<td>771</td>
<td>53</td>
<td>41</td>
</tr>
<tr>
<td>Bedroom 3</td>
<td>99</td>
<td>3941</td>
<td>2492</td>
<td>151</td>
<td>136</td>
</tr>
<tr>
<td>Bathroom 1</td>
<td>80</td>
<td>1532</td>
<td>1206</td>
<td>65</td>
<td>78</td>
</tr>
<tr>
<td>Bathroom 2</td>
<td>60</td>
<td>771</td>
<td>521</td>
<td>29</td>
<td>39</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>1126</strong></td>
<td><strong>24,474</strong></td>
<td><strong>16,084</strong></td>
<td><strong>914</strong></td>
<td><strong>920</strong></td>
</tr>
</tbody>
</table>

Source - [Residential Energy](#)
## Variation in AC Capacity Per Ton

<table>
<thead>
<tr>
<th>System size sf/ton</th>
<th>Air flow cfm/sf</th>
<th>Air exchange rate ACH nat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historic “Rule of Thumb”</td>
<td>400</td>
<td>1.0</td>
</tr>
<tr>
<td>Energy Star – Cold Climate</td>
<td>1107</td>
<td>0.35</td>
</tr>
<tr>
<td>Energy Star – Mixed Humid Climate</td>
<td>1124</td>
<td>0.34</td>
</tr>
<tr>
<td>40% BA – Cold Climate</td>
<td>1476</td>
<td>0.26</td>
</tr>
<tr>
<td>40% BA – Mixed Humid Climate</td>
<td>1311</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Oversizing results in short cycling.

- Reduces equipment life
- Reduces efficiency
- Results in poor humidification
- Reduces filter effectiveness
75% of lamps in permanently installed fixtures shall be high efficacy lamps

- 60 lumens per watt if over 40 W
- 50 lumens per watt if between 40 and 15 W
- 40 lumens per watt if 15 W less

<table>
<thead>
<tr>
<th>Lamp Efficacy</th>
<th>Lum/Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent Tungsten Filament</td>
<td>7-18</td>
</tr>
<tr>
<td>Incandescent Tungsten Halogen</td>
<td>12-26</td>
</tr>
<tr>
<td>Linear Fluorescent</td>
<td>45-104</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>33-75</td>
</tr>
<tr>
<td>LED</td>
<td>70-140</td>
</tr>
</tbody>
</table>
Simulated Performance Alternative (Performance) R405

Allows credit for:

- Exterior Shading
- Solar Heat Gain
- Innovative Framing Techniques
- Cool Roofing Systems
- Thermal Mass
- Solar Energy Systems
- Low Infiltration
Proposed design must have annual energy cost less or equal to reference design.

Mandatory provisions are required.

Characteristics based on Table R405.5.2(1)

U-Factors of Table R402.1.3
### TABLE R405.5.2(1)
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

<table>
<thead>
<tr>
<th>BUILDING COMPONENT</th>
<th>STANDARD REFERENCE DESIGN</th>
<th>PROPOSED DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above-grade walls</td>
<td>Type: Mass wall if proposed wall is mass; otherwise wood frame.</td>
<td>As proposed</td>
</tr>
<tr>
<td></td>
<td>Gross area: Same as proposed</td>
<td>As proposed</td>
</tr>
<tr>
<td></td>
<td>U-factor: From Table R402.1.3</td>
<td>As proposed</td>
</tr>
<tr>
<td></td>
<td>Solar absorptance = 0.75</td>
<td>As proposed</td>
</tr>
<tr>
<td></td>
<td>Remittance = 0.90</td>
<td>As proposed</td>
</tr>
</tbody>
</table>

| Below-grade walls      | Type: Same as proposed                                         | As proposed              |
|                        | Gross area: Same as proposed                                   | As proposed              |
|                        | U-factor: From Table R402.1.3                                   | As proposed              |
|                        | With insulation layer on interior side of walls.               | As proposed              |

| Above-grade floors     | Type: Wood frame                                               | As proposed              |
|                        | Gross area: Same as proposed                                   | As proposed              |
|                        | U-factor: From Table R402.1.3                                   | As proposed              |

| TABLE R405.5.2(1)
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

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| Below-grade walls      | Type: Same as proposed                                         | As proposed              |
|                        | Gross area: Same as proposed                                   | As proposed              |
|                        | U-factor: From Table R402.1.3                                   | As proposed              |

| Above-grade floors     | Type: Wood frame                                               | As proposed              |
|                        | Gross area: Same as proposed                                   | As proposed              |
|                        | U-factor: From Table R402.1.3                                   | As proposed              |

orientations (N, E, S & W).

U-factor: From Table R402.1.3

SHGC: From Table R402.1.1 except that for climates with no requirement (NR) SHGC = 0.40 shall be used.

Interior shade fraction: 0.92 - (0.21 x SHGC for the standard reference design)

External shading: None

As proposed
## Performance Compliance

### R405.5.2(1)

#### TABLE R405.5.2(1)

**SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS**

<table>
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<th>BUILDING COMPONENT</th>
<th>STANDARD REFERENCE DESIGN</th>
<th>PROPOSED DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total area&lt;sup&gt;b&lt;/sup&gt; =</td>
<td>(a) The proposed glazing area; where proposed glazing area is less than 15% of the conditioned floor area. (b) 15% of the conditioned floor area; where the proposed glazing area is 15% or more of the conditioned floor area.</td>
<td>As proposed</td>
</tr>
<tr>
<td>Orientation: Equally distributed to four cardinal compass orientations (N, E, S &amp; W).</td>
<td>As proposed</td>
<td></td>
</tr>
<tr>
<td>U-factor: From Table R402.1.3</td>
<td>As proposed</td>
<td></td>
</tr>
<tr>
<td>SHGC: From Table R402.1.1 except that for climates with no requirement (NR) SHGC = 0.40 shall be used.</td>
<td>As proposed</td>
<td></td>
</tr>
<tr>
<td>Interior shade fraction: 0.92 - (0.21 × SHGC for the standard reference design)</td>
<td>0.92 - (0.21 × SHGC as proposed)</td>
<td></td>
</tr>
<tr>
<td>External shading: None</td>
<td>As proposed</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> C-factor: From Table R402.1.3

<sup>b</sup> SHGC: From Table R402.1.1 except that for climates with no requirement (NR) SHGC = 0.40 shall be used.
### Montana Amendment to Reference Design

#### R405.5.2(1)

**Thermal Distribution Systems**

<table>
<thead>
<tr>
<th>Standard Reference Design</th>
<th>Proposed Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untested distribution systems: DSE $= 0.88$</td>
<td>Untested distribution systems: DSE from Table R405.5.2</td>
</tr>
<tr>
<td>Tested Ducts: Leakage rate to outside conditioned space per R403.2.2(1)</td>
<td>Tested Ducts: Tested Leakage rate to outside conditioned space</td>
</tr>
<tr>
<td>Tested duct location: Inside thermal envelope</td>
<td>Duct location: As proposed</td>
</tr>
<tr>
<td>Tested duct insulation: in accordance with R403.2.1</td>
<td>Duct Insulation: As proposed</td>
</tr>
</tbody>
</table>