Best Practices for the Design and Construction of the Building Envelope

Merle McBride, Ph.D., P.E. – Research Fellow
Harry Alter – Research Associate
Greg Keeler – Technical Services Manager
Dave Wolf, Ph.D. – Senior Research Associate

Owens Corning
Center of Science and Technology
2790 Columbus Road
Granville, Ohio

OSU – Green Housing Workshop
May 16, 2017
Agenda

Residential Envelope

1 - Energy Performance
2 - Air Infiltration
3 - Roof Systems
4 - Water Management
5 - Acoustics
1 - Energy Performance

Fundamental Driving Forces:
- Energy Codes
- Economics - Fuel Prices, Construction Costs
- Environmental Goals
Energy Codes

Climate Zones
- HDD65 – Heating Degree Days to Base 65°F
- CDD50 – Cooling Degree Days to Base 50°F
- Moisture Level – Moist, Dry, Marine

Thermal Performance
- Thermal Resistance - R-value
- Thermal Transmittance - U-factor
- Solar Heat Gain Factor - SHGC
Climate Zones Defined by Heating Degree Days & Cooling Degree Days

HDD65

HDD65 = Base - Daily Avg. Temp.
HDD65 = 65 - 40 = 25

CDD50

CDD50 = Daily Avg. Temp. - Base
CDD50 = 85 - 50 = 35
Columbus – Long Term Averages

Columbus, OH Heating and Cooling Degree Days (Base 65°F)
Current Climate Zone Map

All of Alaska is in Zone 7 except for the following boroughs in Zone 8:
- Bethel
- Dillingham
- Fairbanks N. Star
- Nome
- North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands.
New Climate Zone Map
Current (9) vs New (24) Climate Zones
ASHRAE Std. 169-2013 Climate Zones

U.S. Weather Data for 4725 Stations
Ohio has 96 Stations

Graph showing climate zones with HDD65 and CDD50 axes.
ASHRAE Std. 90-1975
(Eliminate lowest 20%)
BCAP – Residential
(Ohio Adopted IECC 2012 on 9/30/16, Effective 1/1/2017)
<table>
<thead>
<tr>
<th>Material</th>
<th>R-value</th>
<th>Material</th>
<th>R-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Glass Pane</td>
<td>0.11</td>
<td>Double Pane Window</td>
<td>3.0</td>
</tr>
<tr>
<td>Asphalt Shingles</td>
<td>0.44</td>
<td>2x4 Wood Stud</td>
<td>4.35</td>
</tr>
<tr>
<td>½ inch Drywall</td>
<td>0.45</td>
<td>1 inch XPS Board</td>
<td>5.00</td>
</tr>
<tr>
<td>½ inch OSB</td>
<td>0.61</td>
<td>2x6 Wood Stud</td>
<td>6.88</td>
</tr>
<tr>
<td>Aluminum Siding</td>
<td>0.61</td>
<td>3.5 inches F/G</td>
<td>11, 13,15</td>
</tr>
<tr>
<td>8 inch CMU</td>
<td>1.0</td>
<td>6.0 inches F/G</td>
<td>19, 21</td>
</tr>
<tr>
<td>Carpet &amp; Pad</td>
<td>2.08</td>
<td>12.0 inches F/G</td>
<td>38</td>
</tr>
</tbody>
</table>
### IECC 2015 Residential Criteria

#### TABLE R402.1.2

**Insulation and Fenestration Requirements by Component**

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>FENESTRATION U-FACTORb</th>
<th>SKYLIGHTb U-FACTOR</th>
<th>GLAZED FENESTRATION SHGCb,e</th>
<th>CEILING R-VALUE</th>
<th>WOOD FRAME WALL R-VALUE</th>
<th>MASS WALL R-VALUE1</th>
<th>FLOOR R-VALUE</th>
<th>BASEMENT WALL R-VALUE</th>
<th>SLABd 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+5h</td>
<td>8/13</td>
<td>19</td>
<td>5/13f</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+5h</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+5h</td>
<td>13/17</td>
<td>30g</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+10h</td>
<td>15/20</td>
<td>30g</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+10h</td>
<td>15/21</td>
<td>38g</td>
<td>15/19</td>
<td>10, 4 ft</td>
<td>15/19</td>
</tr>
</tbody>
</table>
Fenestration

173 Fenestration Options vs 2015 IECC Criteria

- SHGC vs U-factor graph
- Options, CZ 1, CZ 2, CZ 3, CZ 4, CZ 5-8
Fenestration Study
Economics
Fuel Prices

Residential Energy Prices

Year

Gas - $/therm
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60

Elec - Cents/kWh
0 2 4 6 8 10 12 14 16

- Gas
- Elec
Economics
Characteristic Cost Curve
Life-Cycle Cost Analysis – First Costs
Life-Cycle Cost Analysis – Energy Costs
Life-Cycle Cost Analysis – Total Costs

Life Cycle Cost Analysis

Cost - $

Insulation R-value

First Cost  Energy Costs  LLC
Life-Cycle Cost Analysis - Optimum
Life-Cycle Cost Analysis - Options

Life Cycle Cost Analysis

Cost - $

Insulation R-value

First Cost  Energy Costs  LLC  Optimum  Tradeoffs

A

B
Eliminate Lowest 80%
Environmental Goals

AIA 2030 Challenge

- Edward Mazria, FAIA, Hon. FRAIC
  Founder and CEO

Alignment on 2030 Goal
- ASHRAE
- AIA
- USGBC
- U.S. Conference of Mayors
- State of Florida

- “Net Zero Energy Buildings by 2030”
Net Zero Energy

![Conceptual Path to Zero Energy](image)

- Life Cycle Costs ($)
- Energy Savings (%)

Legend:
- Life Cycle Costs ($)
- IECC 2015
Energy Savings

Decades of Progress - New Residential Construction Code Stringency 1975-2010
(2010 to 2015 are project improvements based on 30% and 50% goals)

- Regulated Loads: Envelope, Air Infiltration, Lighting, HVAC, SWH
Energy Savings

Decades of Progress - New Residential Construction Code Stringency 1975-2010
(2010 to 2015 are project improvements based on 30% and 50% goals)

- Regulated Loads: Envelope, Air Infiltration, Lighting, HVAC, SWH
- Plug Loads: Refrigerator, Oven, Microwave, Toaster, Coffee Maker, Washer, Dryer, Iron, Sweeper, Stereo, Radio, TV, Computer, Printer, Clocks
**Energy Savings**

Decades of Progress - New Residential Construction Code Stringency 1975-2010
(2010 to 2015 are project improvements based on 30% and 50% goals)

- **Regulated Loads**: Envelope, Air Infiltration, Lighting, HVAC, SWH
- **Plug Loads**: Refrigerator, Oven, Microwave, Toaster, Coffee Maker, Washer, Dryer, Iron, Sweeper, Stereo, Radio, TV, Computer, Printer, Clocks
- **Renewables**: Photovoltaics, Wind, Passive Solar
Thermal Bridges

“a low thermal resistance path connecting two surfaces”

2x4 Wood Frame Wall
Cavity = R-11.0, Total Wall = R-18.6

2x4 Steel Frame Wall
Cavity = R-6.0, Total Wall = R-12.9
Thermal Bridges
Fenestration Thermal Bridge
Slab Thermal Bridge
Basement Walls
Window Framing Details
Window and Door Framing
Wood Framing Details
Wood Framing Corner Details
Wood Framing Corner Details
Wood Framing Details
Steel Framing
Eave Details

• Standard Truss

• Raised Heel
Foam Board Sheathing

One Inch Foam Board
R-5 XPS
R-6 Polyiso
Foam Board Temperature Dependence
(FTC Rule 460 requires ratings at 75°F)

XPS

Polyiso
Foam Board Temperature Dependence

(FTC Rule 460 requires ratings at 75°F)
2 - Air Infiltration

The flow of air from one side of the envelope to the other due to pressure and openings.
How leaky is a typical house?

Leaky enough to exchange all of its volume with the outside every two hours.

Median air leakage of existing homes is 0.5 NACH. *Residential Energy*, Krigger & Dorsi.
What’s the energy penalty?

• It depends on many factors …
  • Climate
  • Size of house
  • Baseline leakiness
  • And more

• In general, air leakage accounts for between 25% and 40% percent of the energy used for heating and cooling in a typical residence.¹

¹Building Envelope Improvement: Air Sealing, U.S. Environmental Protection Agency
Testing Requirements

• A blower door test can quantify the air leakage of a building.

• The newest model energy code (2015 IECC) requires blower door testing to demonstrate performance.

• CZ 3-8 requires 3ACH50
The Builder’s Challenge

With nearly a mile of joints on a typical house that connect the inside to the outside ...

... which ones are the most important to air seal?
Air Infiltration

- 50 Pa ~ 20 mph
- 4 Pa ~ 4 mph
- 10ACH50 ~ 0.80 ACH Natural
- 7ACH50 ~ 0.56 ACH Natural
- 5ACH50 ~ 0.40 ACH Natural
- 3ACH50 ~ 0.24 ACH Natural
Owens Corning’s Response

Air Sealing Study
• From Owens Corning Building Science
  • Best-in-industry knowledge and experience
• Peer-reviewed research
• Tells you where to seal to get the most “bang for your buck”
Bang for the Air Sealing Buck

- Recessed lights
- Duct boots
- Top Plate-to-Drywall at Attic
- Garage Wall
- Band Joists

Big Bang
- Recessed lights
- Duct boots
- Top Plate-to-Drywall at Attic
- Garage Wall
- Band Joists

House Type: 2-story, slab, 1,624 SF
Drywall/Trim: minimal constraint
Bang for the Air Sealing Buck

- Top & bottom plates to sheathing
- Inside & outside corners
- Bottom plate to subfloor/slab

House Type: 2-story, slab, 1,624 SF
Drywall/Trim: minimal constraint
Bang for the Air Sealing Buck

- Between exterior top plates
- Window/door framing to sheathing
- Vertical sheathing joints

Little Bang

Installed Cost

Reduced Air Leakage, ACH50

-3
-2
-1
0
$0 $100 $200 $300 $400 $500 $600 $700

W/D Framing-to-Sheathing
Between Ext. Top Plates (1st Fl. only)
Vertical Sheathing Joints

House Type: 2-story, slab, 1,624 SF
Drywall/Trim: minimal constraint
3 - Roof Systems

An integrated roofing system, layer by protective layer.
Roof – Asphalt Shingles

- Strip (3-tab) shingles
- Laminate Shingles
  - Standard weight
  - Heavyweight
  - Thick butt
- Hip & Ridge Shingles
Roof - Sheathing Requirements

Asphalt shingles shall be fastened to solidly sheathed decks.
Proper fastening is crucial to shingle performance.

1. Properly Driven: straight, good penetration and flush with shingle surface
2. Underdriven: inadequate deck penetration
3. Overdriven: too deep cuts into shingle
4. Crooked: inadequate anchorage

- 3/8” min. diameter
- 3/4” min.
Roof - Ventilation

**Ventilation required**
- Applies to enclosed attics and enclosed rafter spaces
- Requires cross ventilation for each separate space by ventilating openings protected against the entrance of rain or snow
- Ventilation opening dimensions
  - 1/16 inch (1.6 mm) minimum
  - 1/4 inch (6.4 mm) maximum.
  - If openings larger than 1/4 inch (6.4 mm), provide corrosion-resistant wire cloth screening, hardware cloth, or similar material with openings meeting the above.
Figure R301.2(4)A – Basic Wind Speeds

3 Wind resistance ratings per D7158:
- Class D – Pass at wind speeds of 90 mph
- Class G – Pass at wind speeds of 120 mph
- Class H – Pass at wind speeds of 150 mph

Note 1 indicates wind speeds that are shown are based on a 33’ height above ground for Exposure Category C.
Roof - Impact Resistance

### 4 Impact Resistance Ratings

<table>
<thead>
<tr>
<th>Class</th>
<th>Steel ball diameter</th>
<th>Distance</th>
<th>Kinetic energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches (mm)</td>
<td>Feet (m)</td>
<td>ft-lbf (J)</td>
</tr>
<tr>
<td>1</td>
<td>1-1/4 (31.8)</td>
<td>12.0 (3.7)</td>
<td>3.53 (4.78)</td>
</tr>
<tr>
<td>2</td>
<td>1-1/2 (38.1)</td>
<td>15.0 (4.6)</td>
<td>7.35 (9.95)</td>
</tr>
<tr>
<td>3</td>
<td>1-3/4 (44.5)</td>
<td>17.0 (5.2)</td>
<td>13.56 (18.37)</td>
</tr>
<tr>
<td>4</td>
<td>2 (50.8)</td>
<td>20.0 (6.1)</td>
<td>23.71 (32.12)</td>
</tr>
</tbody>
</table>

Table 5.1: Drop height and kinetic energy
Roof - Slope

Asphalt shingles shall be used only on roof slopes of two units vertical in 12 units horizontal (2:12) or greater. For roof slopes from two units vertical in 12 units horizontal (2:12) up to four units vertical in 12 units horizontal (4:12), double underlayment application is required.
An ice barrier that consists of at least two layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet, shall be used in lieu of normal underlayment and extend from the lowest edges of all roof surfaces to a point at least 24 inches (610 mm) inside the exterior wall line of the building.
Roof - Drip Edge and Underlayment
Roof - Fire

Consists of 3 primary fire tests:

- Burning Brand
  - 4 consecutive decks must pass
- Spread of Flame
  - 2 consecutive decks must pass
- Intermittent Flame
  - 2 consecutive decks must pass
4 - Water Management
Water Management
Water Management
Water Management
Foundation Drainage
5 - Acoustics

Problem – Noise is unwanted sound.

Solution – Quiet is achieved when the noise is significantly reduced and/or blocked from transmitting and is no longer bothersome.
Acoustics

• Attenuation Locations:
  • Home Office
  • Bedrooms
  • Dedicated Entertainment Room
  • Home Theater

• Noise Sources:
  • Exterior
    • Traffic
    • Airplanes
    • Trains
    • Lawn Mowers
  • Interior
    • Entertainment Systems – Sound, TV
    • Exhaust Fans – Kitchen, Bathrooms
    • Dishwasher
    • Laundry Appliances
    • Vacuum Sweeper
    • Active Children
Acoustics

• Target Areas:
  • Ceiling
  • Interior Walls
  • Exterior Walls
  • Floors
  • Doors
  • Ducting
  • Plumbing
  • Electrical Service Boxes

• Solutions:
  • Cavity insulation – ceiling, wall, floor
  • Caulking – seal all air paths
  • Double layers of gypsum wallboard
  • Doors – solid and sealed
  • Electrical Boxes – sealed
  • Ducts – insulated and isolated to a single room
  • Windows – sealed
  • Walls – double studs or split with resilient connections
  • Floors – blocking between rooms
  • Plumbing – isolated with resilient mounts or hangers
Residential Noise Control Best Practices
Some Do’s and Don’ts

Basic Principles for Controlling Noise

Absorb
- Sound Insulation

Block
- Partition Membranes, Sheathings (drywall)
- Acoustic Sealant (caulk)

Vibration Breaks
- Decouple Energy Pathways (Double Walls)

Isolators
- Spring Isolators (RC channel, floating floor membranes)
Best Noise Control Practices - Independent of Partition Type

• Do Seal All Open Penetrations!

Air infiltration and sound penetration through partitions occur as one in the same. If air penetrates through the assembly then sound (or noise) can too. In fact, it takes very little air leakage to cause significant sound leakage.

For example, a wall designed to achieve a sound transmission loss of 50 dB can reduce to 39 dB (an 11 dB drop) when only 0.01 percent of the partition surface area is unsealed.

• Don’t use sealants that can shrink or become brittle & crack over time.
**Best Noise Control Practices - Independent of Partition Type**

- **Do “Decouple” The Vibration Path**

  Acoustic energy flow through a partition follows the path of least resistance.

  For a standard wood stud wall or joist floor assembly the greatest acoustic energy is transmitted through the partition via the sheathing or drywall into the wood framing to the adjacent sheathing or drywall.

  Decoupling the sheathing, or drywall from the wood framing via resilient channels and/or a floating floor topping can isolate energy paths and increase noise attenuation. (STC and IIC)

- **Don’t Install Resilient Channels On Top Of Existing Drywall.**

  *The entrapped air stiffens the spring action of the channel and can actually result in an increase in sound transmission.*
Best Noise Control Practices - Independent of Partition Type

• Do Utilize Cavity Insulation To Absorb Sound Vibrations

One of the most efficient and cost effective means to control sound in walls, floors, and ceilings is through the use of cavity insulation.

Airborne sound vibrations cause air particles to vibrate back and forth much like a piston. When a sound (vibrating air particles) enters a porous material such as fiberglass or mineral wool the vibrating particles create resistance or drag over and around the many fibers to cause friction to occur. As a result, sound vibrations are converted to heat and sound energy is quickly dissipated.

• If You Are Seeking Higher Levels Of Noise Control Don’t Rely On Cavity Insulation Alone.

*Combine cavity insulation with resilient channels and layers of drywall.*
Best Noise Control Practices Independent of Partition Type

• **Do Use Mass Wisely To Increase Noise Attenuation**

  For each doubling of the weight or frequency of a partition, mass law predicts a 6 dB increase in transmission loss.

  Doubling the mass of a partition can quickly and noticeably increase the partition’s noise attenuation.

• **Don’t rely only on mass alone to increase noise control. It can quickly become unreasonable and combining basic acoustic principles can be more efficient & effective.**

*Question: How many sheets of Type X drywall would be needed to achieve STC-50?*

- 1 Sheet of Gypsum
  - STC=26
- 2 Sheets of Gypsum
  - STC=32
- 4 Sheets of Gypsum
  - STC=38
- 8 Sheets of Gypsum
  - STC=44
- 16 Sheets of Gypsum
  - STC=50
  - Weight: 1024 lbs.
  - (16) 4x8 sheets
**Best Noise Control Practices - Independent of Partition Type**

- **Do Try To Minimize The Effects of Flanking Noise**

  Flanking noise transmission is the transmission of sound between rooms by paths other than directly through the wall or floor partition of concern.

  Flanking noise exists in all buildings and must be considered whenever designing effective room environments for noise control.

- **Don’t Mismatch Wall, Floor, and Ceiling Acoustic Performance Levels.**

  Pay close attention to juncture details between walls, floors, and ceilings.

**Example:** With a single stud wall construction, horizontal flanking transmission is strongest with joists perpendicular to (and continuous under) the party wall.
Best Practices for the Design and Construction of the Building Envelope

Merle McBride, Ph.D., P.E. – Research Fellow

OSU – Green Housing Workshop
May 16, 2017