Wood-frame Building Enclosure Design Guides

  - Emphasis on best practices, moisture and new energy codes
  - Focus on highly insulated wood-frame assemblies to meet current and upcoming energy codes
- CLT Handbook
Building Science Basics
Separate indoors from outdoors, by controlling:
- Heat flow
- Air flow
- Vapor diffusion
- Water penetration
- Condensation
- Light and solar radiation
- Noise, fire, and smoke

While at the same time:
- Transferring structural loads
- Being durable and maintainable
- Being economical & constructible
- Looking good!
The Old Way
The New Way – “Light & Tight”
Old versus New

- Trend towards more energy efficiently building enclosures
- Air barriers now required in 2012 IECC and 2013 CEC
- Continuous insulation becoming more common
  - Seeing more new building materials, enclosure assemblies and construction techniques

- **More insulation = less heat flow to dry out moisture**
  - “Marginal” assemblies that worked in the past may no longer work
  - Amount, type and placement of insulations matters, for vapor, air and moisture control

- **Need to fully understand the science and interaction of design parameters**
What do we know?

**Building Enclosure**

- Control Rain
- Control Air
- Control Vapor
- Control heat
Building Enclosure Control Layers

1. Water
   - Building Form & Features
   - Water Shedding Surface (WSS)

2. Air
   - Water-Resistive Barrier (WRB)
   - Air Barrier System
   - Thermal Insulation
   - Vapor Retarder/Barrier

3. Heat

4. Vapor

5. Sound

6. Fire

Primary Relationship

Secondary Relationship

1 – Water is defined here as precipitation (rain, snow, hail, etc.) and ground water
2 – Vapor is separately defined here as the water vapor in air, as well as condensate moisture
How do Walls get Wet and Dry?

1. Precipitation (rain or snow)
2. Water vapor transported by diffusion and/or air movement (outward or inward)
3. Built-in construction moisture
4. Groundwater

1. Evaporation of water at surfaces
2. Water vapor transport by diffusion and/or air movement (outward or inward)
3. Drainage
4. Ventilation drying by air exchange
Water Penetration Control Strategies

- **Face Seal**
  - Single plane of water penetration control at exterior surface
  - Single plane of water penetration control at sheathing membrane
  - Protected by cladding

- **Concealed Barrier**
  - Two planes of water penetration control
  - Some drainage possible at sheathing membrane
  - Protected by cladding

- **Drained**
  - Two planes of water penetration control

- **Vented Rainscreen**
  - Two planes of water penetration control
  - Clear drainage
  - Vented

- **Ventilated Rainscreen**
  - Two planes of water penetration control
  - Clear drainage
  - Ventilated
Rainscreen Cladding
9. **Air barrier.** To meet the requirement of Table 140.3-A, all buildings shall have a continuous air barrier that is designed and constructed to control air leakage into, and out of, the building’s conditioned space. The air barrier shall be sealed at all joints for its entire length and shall be composed of:

A. Materials that have an air permeance not exceeding 0.004 cfm/ft², under a pressure differential of 0.3 in. w.g. (1.57 psf) (0.02 L/m² at 75 pa), when tested in accordance with ASTM E 2178; or

B. Assemblies of materials and components that have an average air leakage not exceeding 0.04 cfm/ft², under a pressure differential of 0.3 in. w.g (1.57 psf) (0.2 L/m² at 75 pa), when tested in accordance with ASTM E 2357, ASTM E 1677, ASTM E 1680 or ASTM E 283; or

C. The entire building has an air leakage rate not exceeding 0.40 cfm/ft² at a pressure differential of 0.3 in w.g. (1.57 psf) (2.0 L/m² at 75 pa), when the entire building is tested, after completion of construction, in accordance with ASTM E 779 or another test method approved by the Commission.
Air Penetration Control – Why?

→ Code requirement

→ Moisture
  → Air holds moisture that can be transported and deposited within assemblies.

→ Energy
  → Unintentional airflow through the building enclosure can account for as much as 50% of the space heat loss/gain in buildings.
Air, Vapor, or Water Barrier?

→ Air is made up of oxygen, nitrogen, and water vapor (water vapor is the smallest molecule)

Ice (solid water)  Water (liquid)  Water Vapor (gas)

Tyvek  GoreTex  HDPE
Air Leakage vs. Diffusion
Why Does Air Leakage Cause Condensation?
Air Leakage Condensation Damage

Details, Details, Details!
Types of Air Barrier Systems

- **Sealed Gypsum Sheathing** - Sealant Filler at Joints
- **Liquid Applied** - Silicone sealants and silicone membrane at Joints
- **Sealed Plywood Sheathing** - Sealant & Membrane at Joints
- **Sealed Sheathing** - Membrane at Joints
- **Self-Adhered vapor permeable membrane**
- **Plywood sheathing with taped joints (good tape)**
Airtightness Does Not Happen By Accident
How to Tell the Membrane is Not the Air Barrier
Definitely Not An Air Barrier… But What Is?
Conductive Heat Loss Control

→ Insulation between studs is most common heat control strategy
→ Need to consider effective R-values
→ Continuous insulation on exterior becoming more common
2013 CEC Requirements

![Table 140.3-C](Image)

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<th>Zones 11, 14, 15, 16</th>
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- U-0.059 = R-16.9
- U-0.042 = R-23.8
- Zones 11, 14, 15, 16
Framing Factor Impact on Effective R-values

Effect of Wood Framing Factor on Effective R-value - 2x4 and 2x6 Walls

Overall Effective Wall R-value vs Framing Factor %

- 2x4 Stud Framing
- 2x6 Stud Framing

Insulation R-value:
- R-22
- R-21
- R-20
- R-19
- R-14
- R-13
- R-12

Framing @ 16" o.c.
Framing @ 24" o.c.
Cladding Attachment Through Exterior Insulation
Thermally Improved Performance?

Continuous metal Z-girts

Fiberglass Clips & Hat-Tracks
The ‘Perfect’ Assembly

→ Rain penetration control: rainscreen cladding over water barrier
→ Air leakage control: robust air barrier system
→ Heat control: continuous insulation layer
→ Locate all barriers **exterior** of structure
  → Keep structure warm and dry
→ 50+ year old concept!
Wood-Frame Assemblies – ‘Perfect’ Wall

- Cladding
- Airspace (ventilated)
- 1x3 wood strapping, screwed through Insulation
- Rigid, mineral-fibre insulation (thickness to meet R-value requirement)
- Vapour-permeable sheathing membrane
- Sheathing (plywood or OSB)
- 2x4 or 2x6 wood framing with batt insulation
- Polyethylene film (cold climates only)
- Gypsum board and paint

INTERIOR
Wood-Frame Assemblies – ‘Perfect’ Roof

**Exterior**
- Pavers and pedestal system (roof deck)
- Waterproof roof membrane system
- Protection board
- Rigid insulation layers
- SAM air/vapour barrier
- Roof sheathing
- Roof joists
- Interior gypsum board

**Interior**

**ROOF DECK**
Wall-to-Roof Detail
Roof Design
The Building Science of Roofs

→ What is the function of a roof assembly?
  → Control water, air, heat, vapor
  → Support structural loads
  → Provide an architectural finish

→ The same as every other building enclosure assembly

→ Nothing ‘magic’ or special about roofs, but…
  → Lots of exposure to rain and sun
→ Control layers
  → Water control - roof membrane
  → Air control - ?
  → Vapor control - ?
  → Thermal control – insulation
→ Need to think about all control layers, not just the roof membrane (water)
→ The order of the control layers affects design, performance, and construction
  → And whether or not we vent
Refresher: Low Slope Roof Types

- Protected Membrane (Inverted)
- Conventional
- Vented/Unvented (Compact)
Inverted Roofs
The ‘Perfect’ Roof – Inverted / PMR / IRMA

→ Control layers
  → Water control - roof membrane
  → Air control – roof membrane
  → Vapor control – roof membrane
  → Thermal control – moisture resistant insulation
→ Membrane directly on sloped structure
→ Insulation above membrane
→ “Finish” – pavers, ballast
Considerations for Inverted/PMR Roofs

How to keep insulation from becoming saturated below pavers, ballast or soil/green roofs
Conventional Roofs
Conventional Roof – Exposed Membrane

→ Control layers
  → Water control - roof membrane
  → Air control
    › Roof membrane?
    › Or separate air barrier?
  → Vapor control
    › Roof membrane?
    › Insulation?
    › Or separate vapor barrier?
→ Thermal control
  › Rigid insulation
Air Leakage vs. Diffusion

VAPOUR DIFFUSION

AIR LEAKAGE

1/3 litre of water

30 litres of water
Considerations for Conventional Roofs

→ As always: details and durability of roof membrane

→ Do I need a vapor barrier?
  → Maybe, but often not in California
  → Most of the time, this is the wrong question

→ Do I need an air barrier?
  → Yes!
  → Location matters
Vented Roofs
Vented Roofs

- Control layers
  - Water control - roof membrane
  - Air control
    - Interior drywall?
    - Polyethylene sheet?
    - Nothing?
  - Vapor control
    - Roof membrane
    - Faced insulation?
  - Thermal control
    - Batt insulation
Vented Roofs – Why do we vent?

→ Because we put the insulation in the wrong spot
→ To control air leakage / vapor diffusion condensation
→ Roof membrane is a strong vapor barrier on ‘cold side’ of insulation
→ The code tells us we have to

→ Historically, this concept has worked (mostly) well in attic construction
Attics – How they work

Attics from the Past
Historically, ventilated attics worked because any moisture deposited within the attic was dried by ventilation in combination with heat from the occupied space below.

Current Attics
Current Construction practices result in reduced heat flow and air leakage into attics.
Attics – How they work

- Heat loss from interior warms attic air, decreasing RH.
- Increased insulation levels have generally occurred along side increases in air tightness
  - Less heat, but less moisture too
  - The balance still works
- Buoyancy and wind ventilate the attic space with exterior air
  - Effectiveness of ventilation is highly variable
What influences attic moisture issues & what can we control by design?

- Roof orientation / slope (solar radiation)
- Roofing material/color
- Adjacent buildings / trees – shading
- Outdoor climate
- Indoor climate
- Roof Leaks
- Insulation R-value
- Air leakage from house
- Duct leakage in attic
- Duct discharge location
- Vent area and distribution
- Sheathing durability
- Roof maintenance
- Other things
Where are we Seeing the Biggest Issues?

- Air leakage (ceiling details)
- Exhaust duct leaks & discharge location (roof, soffit, or wall)
- Inadequate venting provisions (amount, vent location, or materials)
- Outdoor moisture: night sky condensation on underside of sheathing
Air Leakage Through Ducts
Other Not So Great Ideas…
Night Sky Radiation Condensation
Solar and Night Sky Radiation
Night Sky Radiation – Full Venting
Night Sky Radiation – Full Venting

![Graph showing moisture content and temperature over time with various lines representing different conditions and materials.](image-url)
Effectiveness of Venting

- Venting is ‘net drying’ in most climates, but isn’t a panacea for moisture problems.
- There are many periods where venting will add moisture to roof assembly:
  - High RH winter evenings + night sky radiation
  - Does your car have dew on it?
- Minimizing moisture sources from interior space is critical.
- Needs to be coupled with interior heat loss.

Theoretical attic with no air leakage or heat loss into the attic and unrestricted ventilation.
Effectiveness of Venting?
Considerations for... California?
Considerations for... California?
Low-Slope Vented Roofs vs. Attics

→ What is different about low-sloped roofs?

→ Typically on larger buildings with bigger air pressures
→ Greater occupancy moisture loads?
→ More / bigger mechanical equipment?
→ White roof membranes
→ Minimal offset heights to promote buoyance driven ventilation
→ Discrete vents instead of continuous
→ More complicated venting path

HIGHER MOISTURE LOADS

MINIMIZED DRYING

CEILING AIRTIGHTNESS CRITICAL
2013 CBC / 2012 IBC:

1203.2 Attic spaces. Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for each separate space by ventilation openings protected against the entrance of rain and snow. Blocking and bridging shall be arranged so as not to interfere with the movement of air. An airspace of not less than 1 inch (25 mm) shall be provided between the insulation and the roof sheathing. The net free ventilating area shall not be less than 1/150th of the area of the space ventilated.

Can be reduced to 1/300 if:

- Top and bottom venting (3 feet offset)
- Class I or II Vapor barrier is installed

What does this mean for conventional roofs?
2013 CRC:

R806.1 Ventilation required. Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof rafters shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain or snow. Ventilation openings shall have a least dimension of 1/16 inch (1.6 mm) minimum and 1/4 inch (6.4 mm) maximum. Ventilation openings having a least dimension larger than 1/4 inch (6.4 mm) shall be provided with corrosion-resistant wire cloth screening, hardware cloth, or similar material with openings having a least dimension of 1/16 inch (1.6 mm) minimum and 1/4 inch (6.4 mm) maximum.

→ Can be reduced to 1/300 if:
  → Top and bottom venting (3 feet offset)
  → Class 1 or II Vapor barrier is installed (Zone 14 and 16)
Vented Roofs – Residential Code Exceptions

- Residential Code contains additional exceptions:
- Venting not required when:
  - Attic is enclosed by thermal envelope, and no interior vapor barrier
  - Air-impermeable insulation (foam) below deck
  - Air-impermeable insulation below deck + batt
  - Batt below deck + insulation on the exterior
Air Leakage Condensation – Underside of Roof Deck

CODE COMPLIANT VENTING
Air Leakage Condensation – Steel Deck

MORE INSULATION
MORE PROBLEMS
Details of venting path rarely shown in detail
  Faith based ventilation design
  How to achieve ceiling airtightness even more cryptic
    Who is responsible?
    Probably not the roofing contractor
Ceiling Airtightness - Options

→ Airtight drywall approach
  → Can work in theory, but difficult
  → Often mistakenly seen as no different than any other drywall installation
→ Sheet membrane
  → It’s all about the details at penetrations and walls
  → Construction sequencing
→ Spray foam
  → Installed from above ceiling, either at details or throughout
  → Expensive
Airtight Drywall – Done Right?
Vented Roofs – Differences in Perspective

Contractor/Owner Perspective

→ “…typically all of the standard drywall construction details for sound, fire, and thermal have been sufficient to satisfy the air barrier requirements on past projects.”

→ We’ll give you a warranty for 30 years

The Other Perspective

→ As the ‘drying’ variables change, the airtightness requirements also have to change:

  → White roof membranes
  → R30+ depending on climate zone

→ The roof contractor won’t warranty condensation
Re-Roofing Considerations

→ Rule #1: Don’t make it worse
→ Consider the entire assembly, not just the membrane
  → Are you changing the wetting / drying balance?
  → Don’t fix a leaking problem and create a durability problem
→ Be careful when switching to white roof membranes
→ Be extra careful when switching to mechanically fastened white roofs
Re-Roofing Considerations

VENTED + BATT INSULATION

ADD AIR BARRIER & EXTERIOR INSULATION
Split Insulation Approaches

→ Good compromise of performance and cost
→ If sheathing is sufficiently warm, venting not required
→ Ratio of exterior insulation to interior insulation dependent on climate and interior humidity levels
  → Pool in Tahoe requires more exterior insulation than apartment in San Diego
→ Be prepared to convince your building official
Final Thoughts

- Making vented roofs perform well is harder than it used to be

- Air tightness of the ceiling is critical to good performance
  - Details and performance requirements need to be explicit in the design

- Be very careful with ducts and other mechanical penetrations in attic and through ceiling

- Insulate on the exterior and sleep easy
Discussion + Questions

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