Kohta Ueno

Edge of Risk Assemblies - Double Stud Walls & Fibrous Insulated Cathedral Ceilings

Building Science Corporation

NORTH CENTRAL BUILDING SCIENCE SYMPOSIUM

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Course Description

Double stud walls and unvented dense pack cellulose roofs are sometimes touted as simpler-to-build and lower cost alternatives to assemblies involving exterior rigid insulation (on walls) or spray foam insulation (on roofs). However, there is substantial building science research and monitoring that demonstrate that these assemblies are at least at the "edge of risk," if not too risky to include in the building codes. Participants will be able to understand the risks associated with these assemblies, gauge and ameliorate the risks if they choose to use them, and provide alternate assemblies that avoid these risks

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Learning Objectives

At the end of this course, participants will be able to answer:

1. Explain the moisture risks associated with unvented roofs using only fibrous insulation (e.g., dense pack unvented roofs).
2. Define the roles that vapor diffusion and air leakage have moisture levels in roofs.
3. Explain the difference in performance between code-level insulated walls and double stud walls insulated with fibrous insulation.
4. Explain the benefits of exterior insulation or air-impermeable rigid insulation in reducing condensation in wall assemblies.

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Double Stud Wall Background

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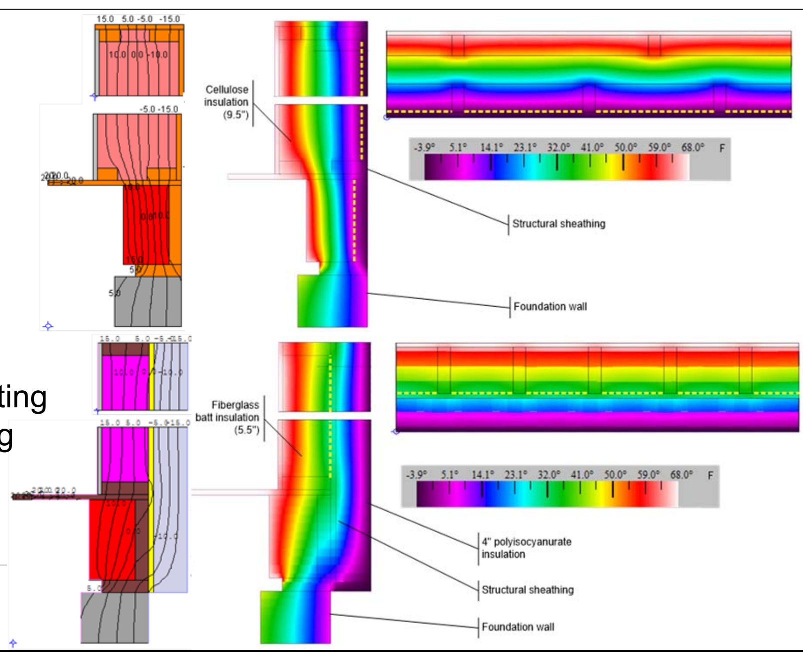
Double Stud Walls Overview

- Double stud wall advantages:
  - High R values
  - Simplifies exterior detailing (few changes to standard practice)
  - Lower cost vs. other high-R walls?
- Moisture risks due to interstitial condensation?
  - Most common failure, after rain control issues
  - Air barrier imperfections—increase risk
  - Air permeable low-density insulations—increase risk (convective looping)
  - Air impermeable insulations—decrease risk

Wall Condensation Potentials

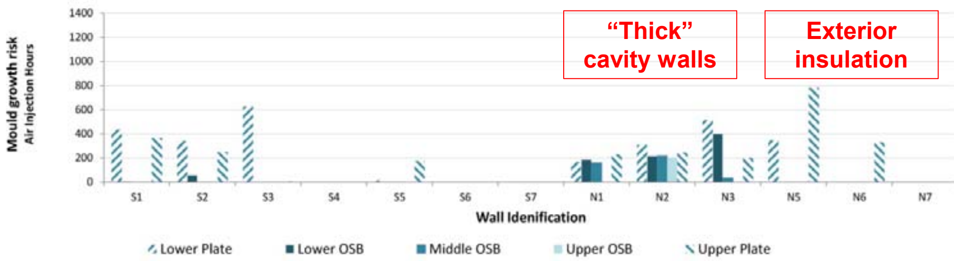
Double stud wall

4” insulating sheathing (on 2x6)



Exterior Continuous Wall Insulation

- Decades of papers: exterior insulation → drier sheathing (warm dry side)
- Fox (2014): high-R walls, air injection & drying
- Vapor-impermeable exterior rigid insulation
  - Cuts off outward drying (impermeable)
  - Reduces interior-sourced condensation risks
  - Worst case: thin vapor-impermeable foam



Double Stud Test Wall Work

Wall Construction

- Vinyl siding
- ZIP wall sheathing (OSB)
- 12” ocSPF, double stud
  - Builder was considering cellulose alternate
- Class III vapor control (latex paint) on GWB

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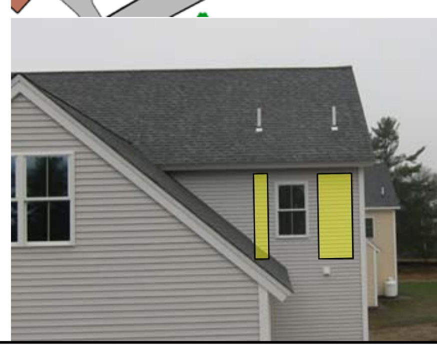
Site and Orientation



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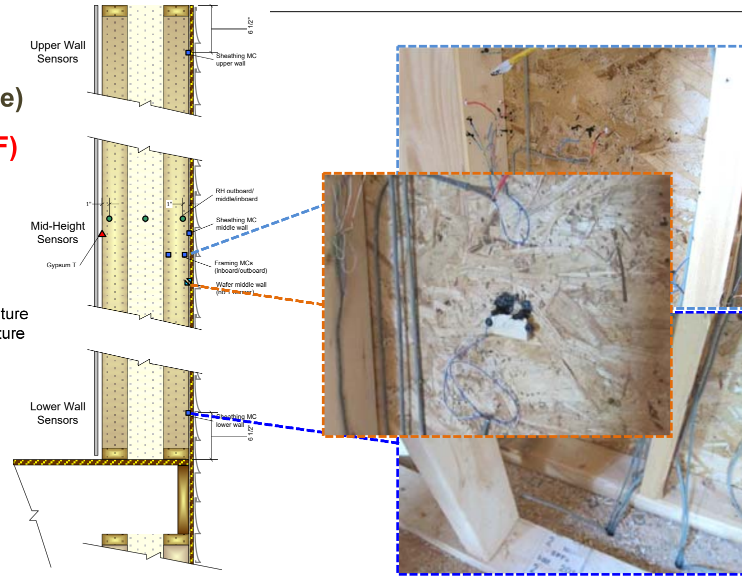
Test Wall Instrumentation

N1/S1 (12-in. ocSPF)

N2/S2 (12 in. cellulose)

N3/S3 (5-½ -in. ocSPF)

Sensor Key:
- ▲ Temperature
- ● Relative humidity/temperature
- ■ Moisture content/temperature
- ◪ Moisture content block

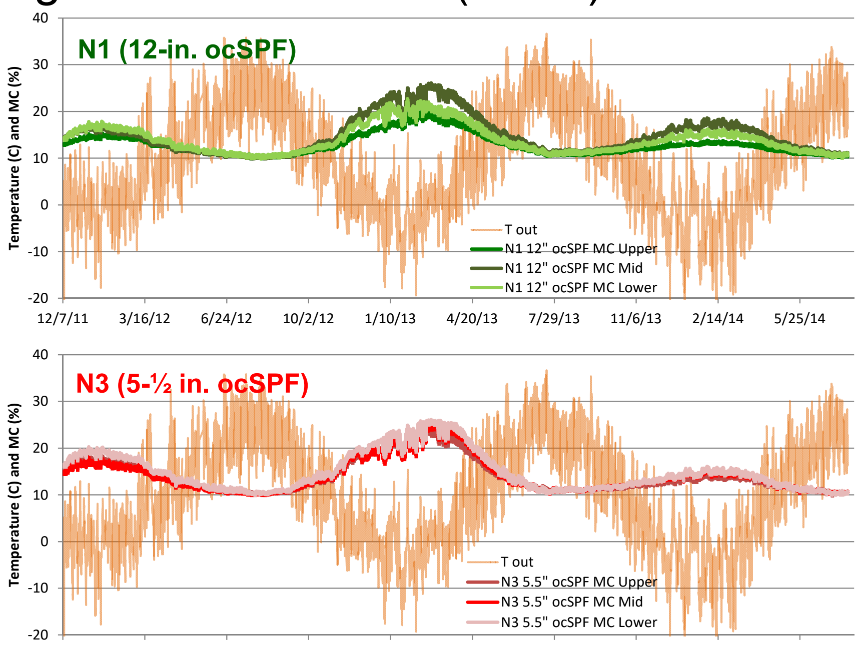


Operating (Boundary) Conditions

- First Winter (Partial)
  - Unoccupied conditions (no occupant moisture generation)
  - Very low interior RH
  - Wimpy winter (5220 HDD vs. 6220 HDD “normal”)
- Second Winter
  - Occupied family of four (2 adults, 2 children)
  - Ventilation system not running, ~1 ACH 50 → High RHs
- Third Winter
  - Winter of the “polar vortex”
  - Occupied conditions (same family)
  - Ventilation system running → RHs ~15-30%

Results: Double Stud Wall Monitoring

Sheathing Moisture Content (North)



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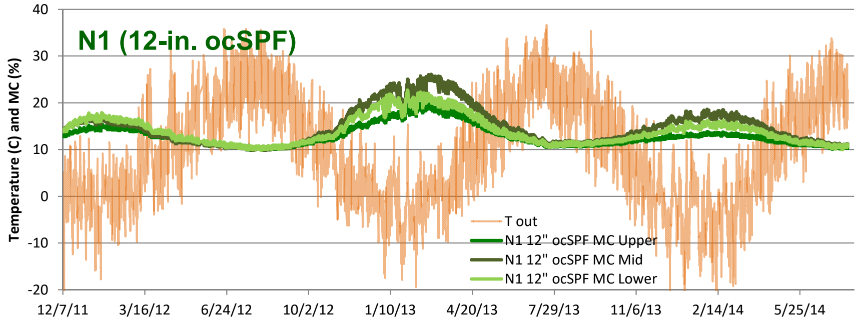

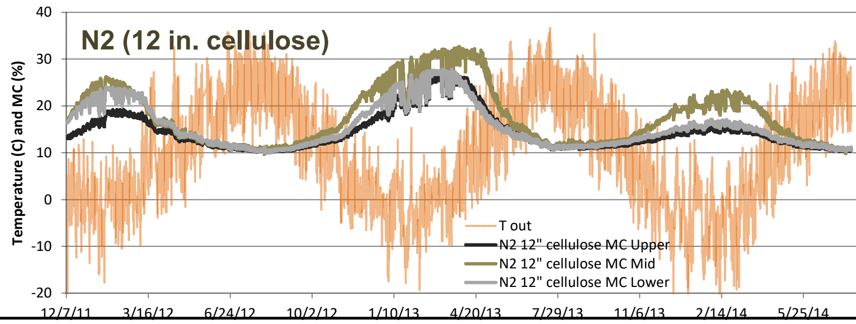

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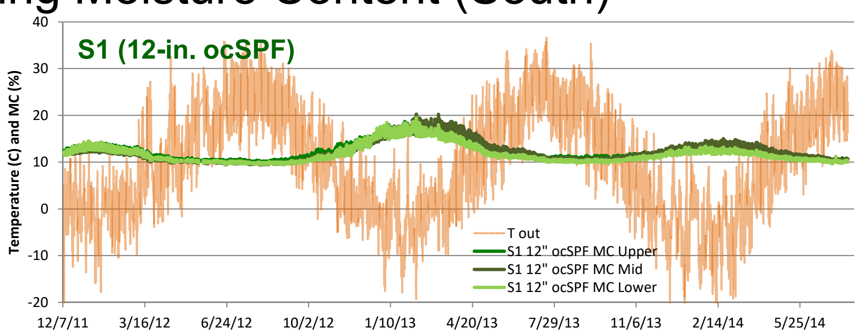
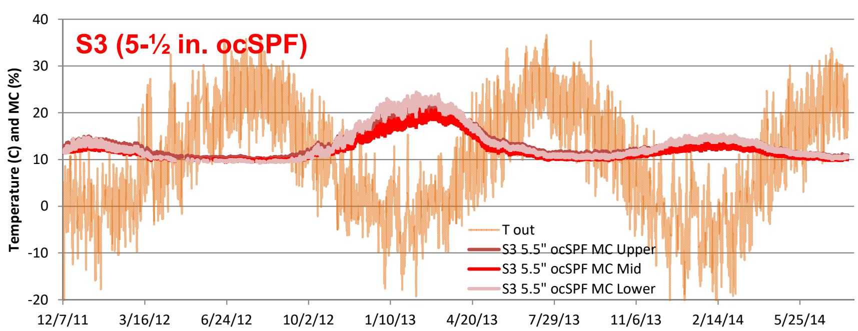
Sheathing Moisture Content (South)





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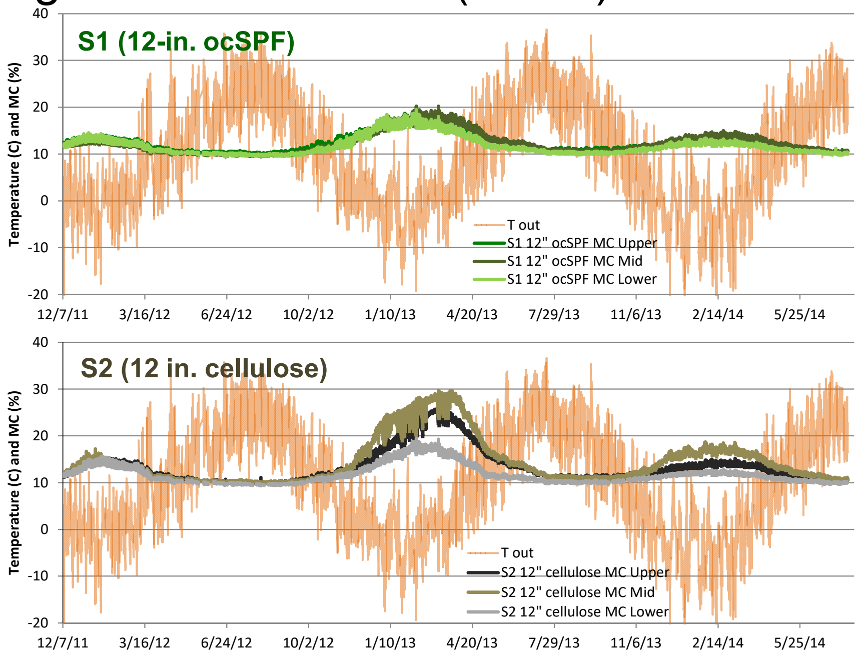
Sheathing Moisture Content (South)



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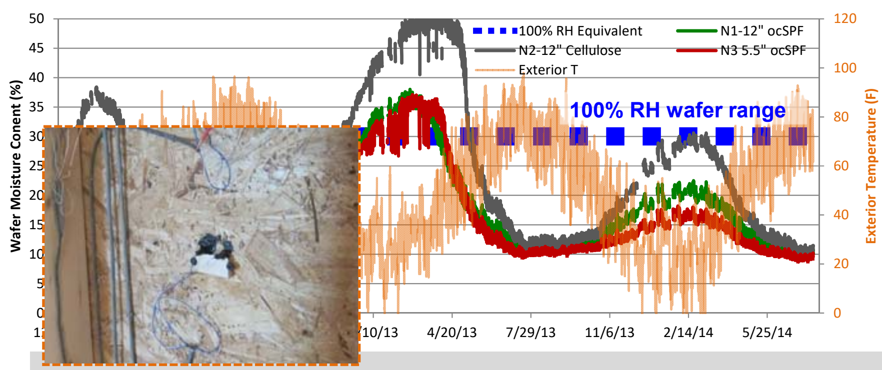
Sheathing “Wafer” Moisture Contents

- 30% MC wafer ≈ 100% RH
- 40-45% MC wafer → liquid water immersion
- Data consistent with condensation at sheathing
- Same indication of condensation on south side



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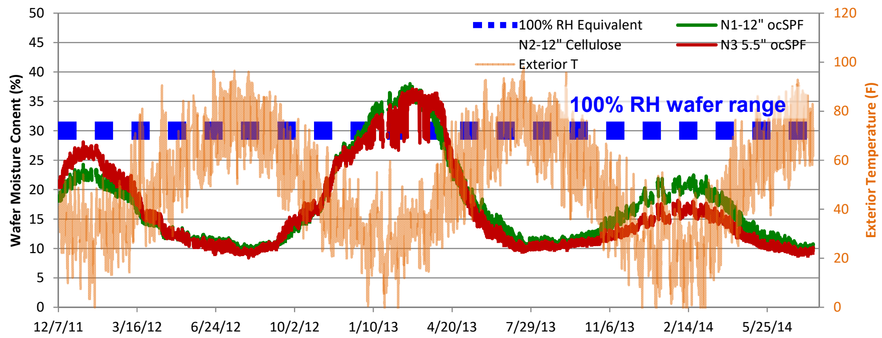

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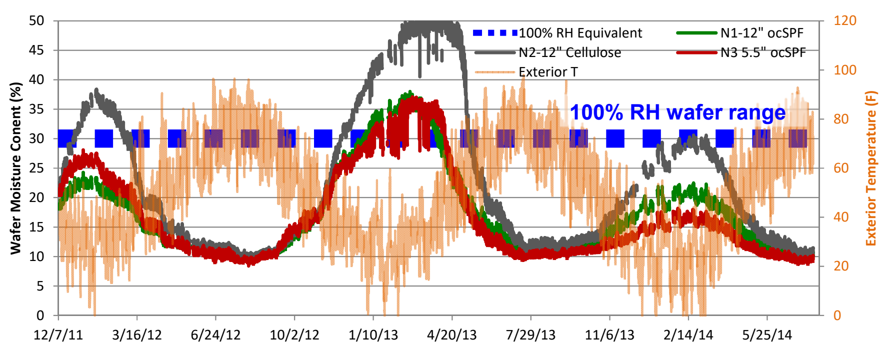
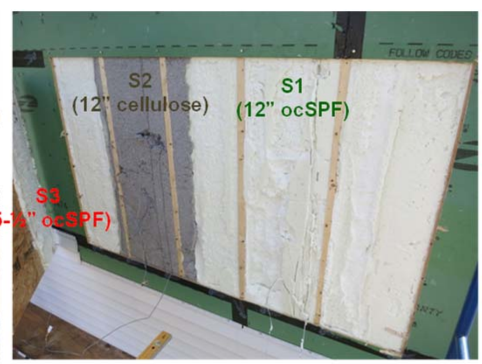


Double Stud Wall Disassembly

South Side Disassembly



South Side Disassembly

North Side Disassembly

North Side Disassembly

North Side Disassembly

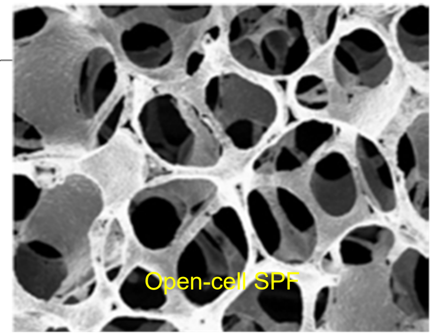
Double Stud Wall Conclusions

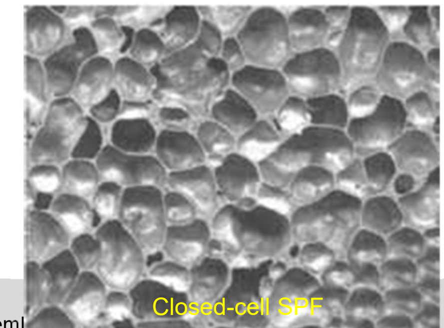
Why Aren't The Walls Oatmeal?

- 20% MC or lower—decay fungi inhibited
- Best growth 25-30% MC range
- All walls had MCs over 20% in winter 2; cellulose 30%+
- Condensation indicated—liquid water is kicker for decay activity

Protective Mechanisms

- OSB Sheathing—all MDI adhesive (no PF)
- Cellulose fiber insulation
  - Borate preservative/fire retardant—also leaches into adjacent materials
  - Moisture storage in cellulose
  - Airflow retarding qualities
- Open cell polyurethane spray foam
  - Oxygen restriction?
  - “Flash heating”? Hot enough long enough?
  - Surface treatment (film formation)?
  - Capillary redistribution (through ocSPF pores)?





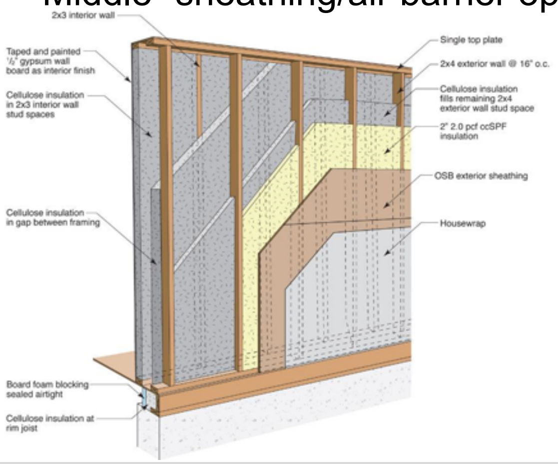
Images c/o SPFA

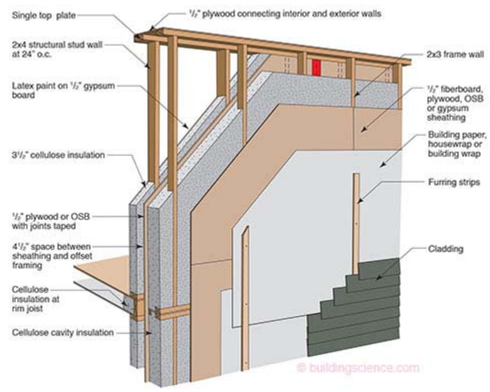
Double Stud Recommendations

- Double stud always riskier than correctly-done exterior insulation
- Class II vapor retarder (variable perm best) safest (vs. Class III)
- ocSPF might be OK on its own
- Air leakage testing/quality control
- Plywood vs. OSB (vs. other sheathings)
- Double stud sensitivity to high wintertime interior RHs
  - More and more likely to occur!
- “The Yeti of Building Science” (Dan Kolbert, Ben Bogie)
  - Double stud not a bad assembly with good quality control/airtightness
  - BUT poor quality control, air leakage, air permeable insulation
  - 1960’s car vs. 2020’s car (airbags or no airbags)

Double Stud Recommendations

- Flash and batt construction option
- "Middle" sheathing/air barrier option





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Unvented Roofs Background

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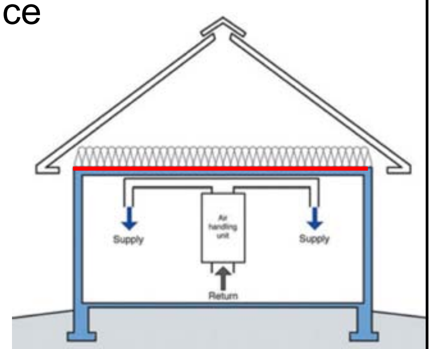
Ventilated Attics—Best Choice

- Roof sheathing dries to ventilated attic-moisture safe
- Interior moisture (air leaks) ventilated away in winter
- Air sealing at ceiling critical for best performance
  - (e.g., spray foam air barrier, detail with sealant)



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Then Why Unvented Roofs?

- Living space built into roof
- Vented cathedral assemblies—often poor performance
- Complicated rooflines, hip geometries—how to vent?
- Unworkable air barrier at ceiling line
- Blown-in rain (coastal)
- Hurricane tear-off
- HVAC in unconditioned attic–energy losses
  - Bring attic and ductwork into conditioned space

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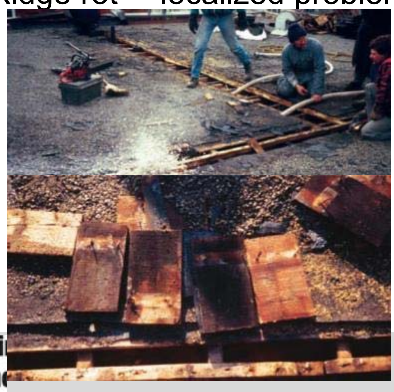
Fibrous Insulation Unvented Roofs

- Dense pack of unvented roofs common in cold-climate retrofits
  - Moisture risks (see BSI-043 “Don't Be Dense—Cellulose and Dense-Pack Insulation”)—2 in 10 failure?
  - Violates I-codes (see IRC § R806.4/R806.5)
  - “Ridge rot”—localized problems (SIPS same problem)



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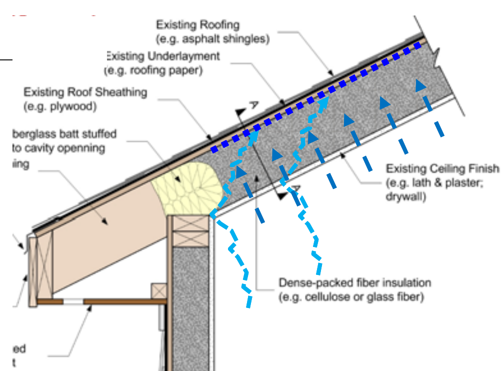
Why Unvented + Fibrous Risky?

- Different than walls?
- Moisture risks at sheathing
  - Interior-sourced air leakage
  - Vapor contributing too?
  - Zero-perm exterior (“wrong side perfect vapor barrier”)
  - Night sky radiation cooling
  - Stack effect in winter
  - “Ridge rot” (thermal and moisture buoyancy)



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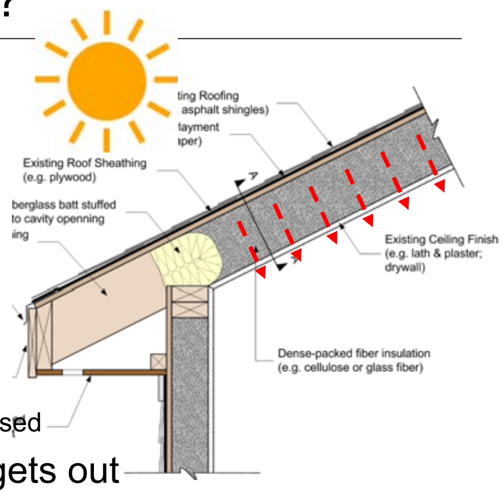
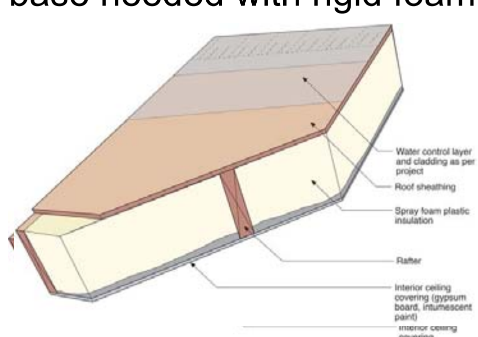
Why Unvented + Loose Fill Risky?

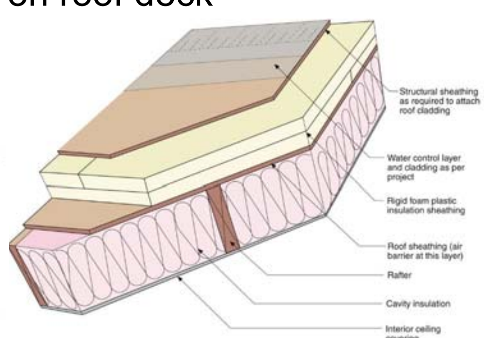
- Risk reduced by:
  - Airtightness of ceiling
  - Dense insulations that suppress airflow
  - Solar drive (north vs. south)
    - But white roofs, shading
  - Lower interior RH (winter)
    - Why many of them work?
  - Lower permeance interior
    - Need good airtightness—vapor retarder not bypassed
- Moisture accumulation: what gets in vs. gets out



Spray Foam/Exterior Insulation Roofs

- 2006 IRC: R806.4 Unvented attic assemblies
- Minimum R-value of “air impermeable insulation”
  - Actually <u>ratio</u> of R-values (BSI-100 Hybrid Assemblies)
- Nail base needed with rigid foam on roof deck





Why Fibrous Fill Unvented Roofs?

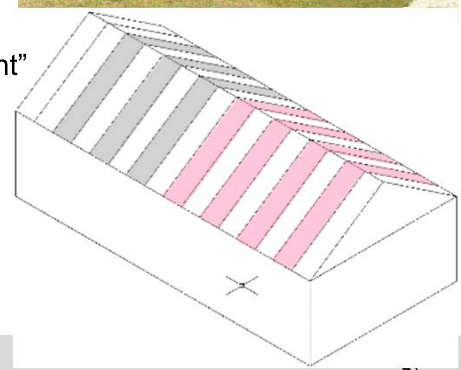
- Unvented roofs without spray/board foams could reduce costs and increase market penetration… IF moisture damage risks are addressed
- Retrofit opportunities (existing uninsulated living space at roof line, without demolishing finishes)

Unvented Test Hut Research

Test Hut Experimental Approach

- Climate Zone 5A test hut
- Eight north-south roof bays; guard bays
- ±R-50 (14-¾" framing, 2012 IECC)
- Test variables (changed year-to-year):
  - Fiberglass vs. cellulose
  - Vapor retarder: variable vs. fixed perm
  - Diffusion vent at ridge: full size, none, "small," or "tight"
  - "Control" comparison § R806.4 spray foam + fibrous
- Varying interior boundary conditions
  - Winter 1: "Normal" interior conditions
  - Winter 2: Elevated RH (50% constant)
  - Winter 3: Air leakage into rafter bays


Test Hut South Elevation



Test Hut Construction

- Test bays & guard bays alternate
- Cellulose & FG
- Various VBs
- Too much data to talk about here…

Summer 2 Disassembly Work: Found Some Mold

Unvented Roofs Recommendations

Recommendations and Further Work

- Unvented fibrous insulation roofs **can** work, **BUT**
  - Ensure complete packing of insulation/density
  - Still vulnerable to small (0.5 CFM) air leaks
- Mold found after Winter 2, despite “calculated safe” (mold index < 3.0)
  - Vulnerability to moisture damage at ridge
- Difficult to recommend for widespread use and acceptance in codes
  - High indoor RHs more likely w. tighter construction and high occupant density/multifamily
- Retrofit solution for failing assemblies?
  - Demolition + spray foam not possible?
  - No place in code to allow

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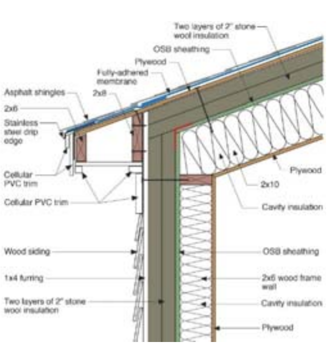
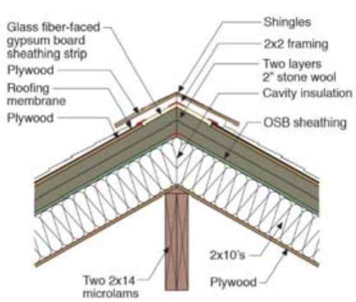
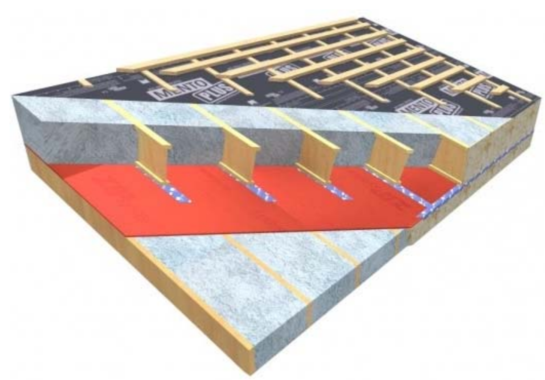
Recommendations

- Code-compliant (IRC § R806.5) still safest
  (spray foam or exterior rigid insulation)
  - Foam free: mineral fiber, wood fiberboard exterior rigid insulation
  - Corson/EcoCor/PH roof assembly







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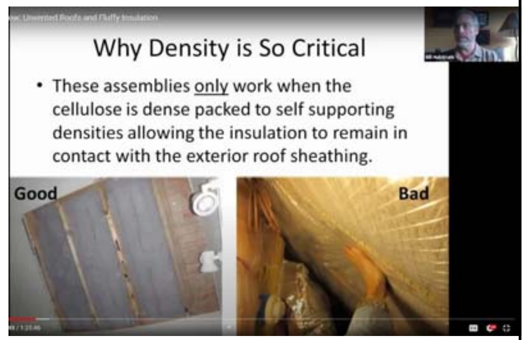
Fibrous Insulation Unvented Roofs Debates Rage On

- The BS* + Beer Show: Unvented Roofs and Fluffy Insulation (with Bill Hulstrunk/ NatureTech), May 2020
- Moisture buffering from cellulose storage
- Critical role of density



- https://www.youtube.com/watch?v=xZlnpQYdsuM&t=1551s

If Implementing Unvented Fibrous Insulation Roofs

- “Against medical advice” (AMA)
- Keep interior RH low for life of building
- Airtightness of interior air/vapor control layer
  - Air leakage testing/quality control
- Variable-perm vapor retarder (downward drying)
  - CertainTeed MemBrain, Intello
- Large 300 perm diffusion vent recommended
- Fibrous insulation without voids/empty cavities
- Light colored roofs & shading increase risks

Closing

- This concludes The American Institute of Architects Continuing Education Systems Course
- Edge of Risk Assemblies - Double Stud Walls & Fibrous Insulated Cathedral Ceilings
- Course #: (TBD - waiting on final approval from AIA)
- Provider: Huber Engineered Woods
- Provider #: K094
- Contact: Anna Moore
- Email: Anna.Moore@huber.com

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Questions?

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Presentation will be available at:
https://buildingscience.com/past-events

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Document Resources (Double Stud Walls)

- BA-1501: Monitoring Double-Stud Wall Moisture Conditions in the Northeast
  https://buildingscience.com/documents/bareports/ba-1501-monitor-double-stud-moisture-conditions-northeast/view
- BA-1316: Moisture Management for High R-Value Walls
  https://buildingscience.com/documents/bareports/ba-1316-moisture-management-for-high-r-value-walls/view
- ETW: Wall - Double Stud Wall Construction
  https://buildingscience.com/documents/enclosures-that-work/high-r-value-wall-assemblies/high-r-value-double-stud-wall-construction
- ETW: Wall - Double Stud with Spray Foam Wall Construction
  https://buildingscience.com/documents/enclosures-that-work/high-r-value-wall-assemblies/high-r-wall-double-stud-with-spray-foam-wall-construction
- Lstiburek's Ideal Double-Stud Wall Design: Air and vapor control layers inside the wall are key
  https://www.greenbuildingadvisor.com/article/lstibureks-ideal-double-stud-wall-design
- Double-Stud Wall vs. Exterior Insulation
  https://www.greenbuildingadvisor.com/article/double-stud-wall-vs-exterior-insulation
- The Hygrothermal Performance of Exterior Insulated Wall Systems
  https://uwspace.uwaterloo.ca/handle/10012/8550
- Hygrothermal Performance of Highly Insulated Wood Frame Walls With Air Leakage: Field Measurements And Simulations
  https://digital.library.ryerson.ca/islandora/object/RULA%3A2603

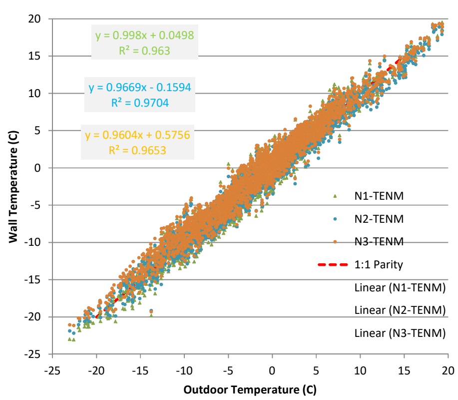
Document Resources (Unvented Roofs)

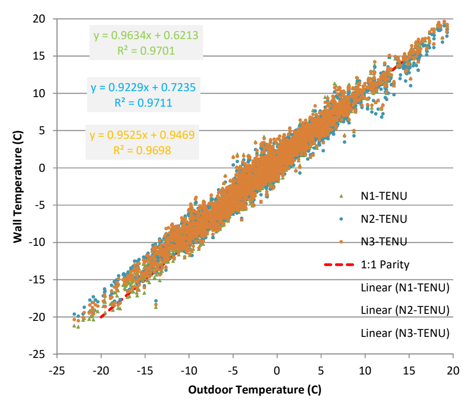
- NESEA Building Energy Boston 2020: Unvented Roofs Without Spray Foam: The Rest of the Story
  https://buildingscience.com/other-event/nesea-building-energy-boston-2020-unvented-roofs-without-spray-foam-rest-story-0
- BA-2001: Monitoring of Unvented Roofs with Fibrous Insulation, Diffusion Vents, and Interior Vapor Control in a Cold Climate
  https://buildingscience.com/documents/building-america-reports/ba-2001-monitoring-unvented-roofs-fibrous-insulation-diffusion
- BA-1409: Field Testing Unvented Roofs with Asphalt Shingles in Cold and Hot-Humid Climates
  https://buildingscience.com/documents/building-america-reports/ba-1409-field-testing-unvented-roofs-asphalt-shingles-cold-and
- BSI-043: Don't Be Dense—Cellulose and Dense-Pack Insulation
  https://buildingscience.com/documents/insights/bsi-043-dont-be-dense

Double Stud Sheathing Temperature

Colder Sheathing with More Insulation?

- Outdoor temperature vs. wall sheathing temperature
- Can you see a difference? I can't…





Colder Sheathing with More Insulation?

- Double stud wall sheathing maybe ~1 F or less colder at coldest conditions
- Steady state analysis predicts 0.8 F difference @ 7 F outdoors
- Wintertime energy/Btu's through sheathing possibly more important (drying energy): doubling insulation = halving heat flow
- 12" vs. 5.5" cavity insulation different than cavity vs. exterior insulation!

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Double Stud Vapor Permeance

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Vapor Permeability of Insulation Layer

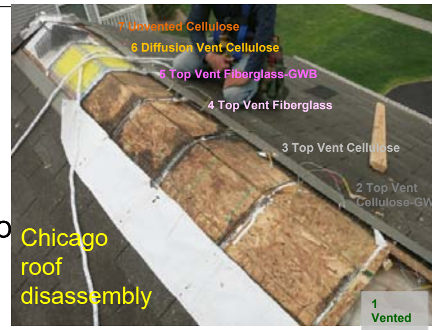
- Insulation-only perms
- Adding 10 perm Class III vapor retarder (latex paint)
- 12" of ocSPF provides reasonable interior vapor control

Wall ID	Insulation Material	Vapor Permeability (Insulation Only)	Vapor Permeability (Add 10 Perm Class III Vapor Retarder)
N1/S1	12 in. 0.5 PCF foam	1.8–2.5 perms	1.5–2.0 perms
N2/S2	12 in. cellulose	7.0–10 perms	4.0–5.0 perms
N3/S3	5-½ in. 0.5 PCF foam	4.0–5.5 perms	2.9–3.5 perms

Previous Building America Unvented Roof Research

Previous Building America Research

- Chicago (CZ 5A):
  - One winter, 50% RH
  - Unvented roofs-high risk
  - Cellulose lower risk than FG batt
  - Vented compact roof (chute) safe-but po
- Houston/Orlando (CZ 2A):
  - 2 attics, multiple seasons
  - Diffusion vents allow greater drying, avoi



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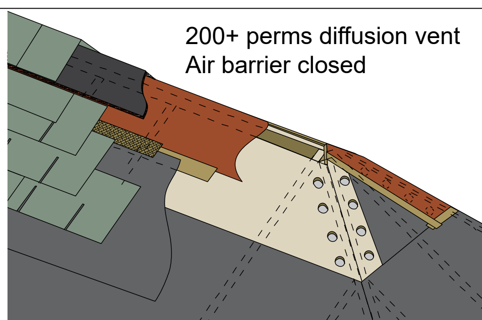
Diffusion Vent Prototype (Houston)



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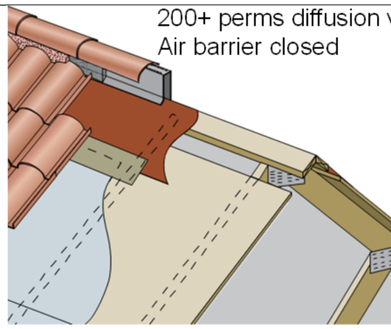
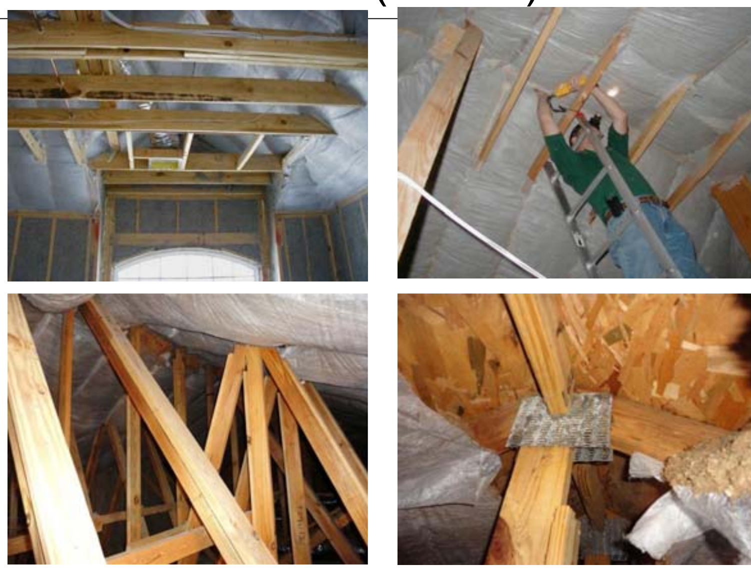
Diffusion Vent Prototype (Orlando-Tile)

200+ perms diffusion vent
Air barrier closed



“Ridge Rot” and Moisture Buoyancy

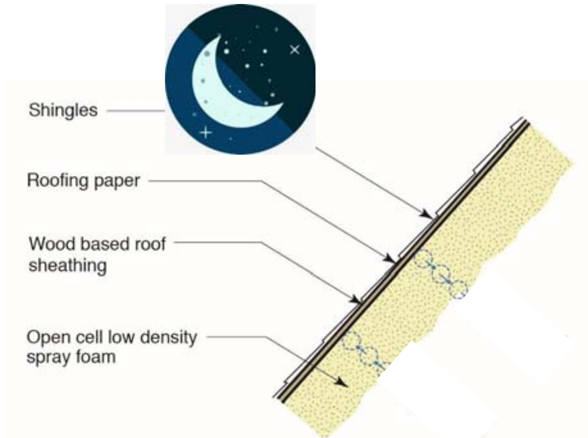
Houston and Jacksonville (CZ 2A) 2001



Moisture Buoyancy

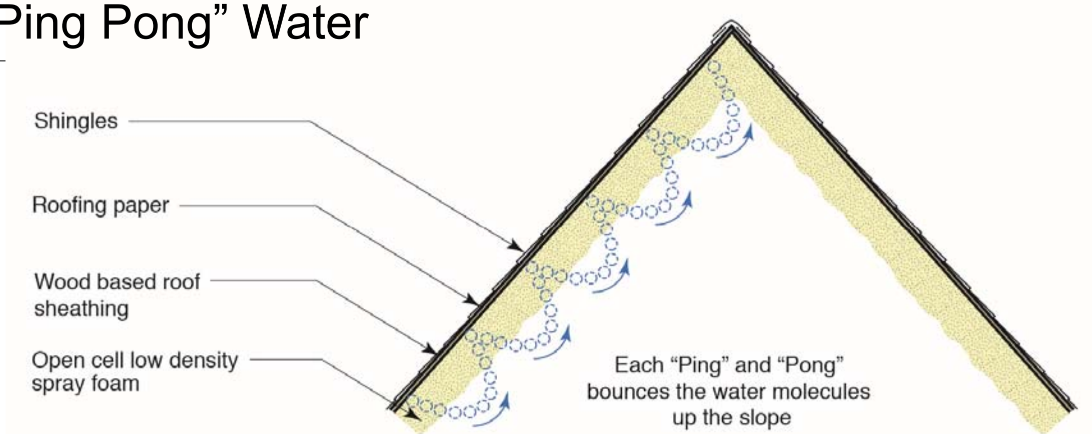
- Moisture concentrated at highest point in conditioned attic (ridge)
- Not a simple one-dimensional problem
- Not a straight-up air leakage problem
- Problem with open-cell spray foam (ocSPF) unvented roofs (high RHs in attic)-many climates
  - But not ccSPF—lower vapor permeance
- Concentration of interior-sourced moisture
- Moist air is lower density (“lighter”) than dry air
- Others: “system in equilibrium has same dewpoint in connected air space”

“Ping Pong” Water



- See BSI-016: Ping Pong Water and The Chemical Engineer

“Ping Pong” Water



- “Gas separation process similar to pressure swing adsorption”
- Solar-powered moisture concentration machine

Orlando Decommissioning

Orlando Decommissioning

- Temperature and dewpoint stratification directly measured
- 90%+ RH near ridge
- System is not in equilibrium