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Energy and Moisture in Sealed and Insulated Attics: Cold Climate Research

April 2020

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NATIONAL HOME PERFORMANCE
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Background

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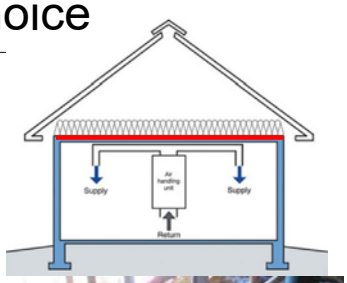
Ventilated Attics—Best Choice

- 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 vented attic

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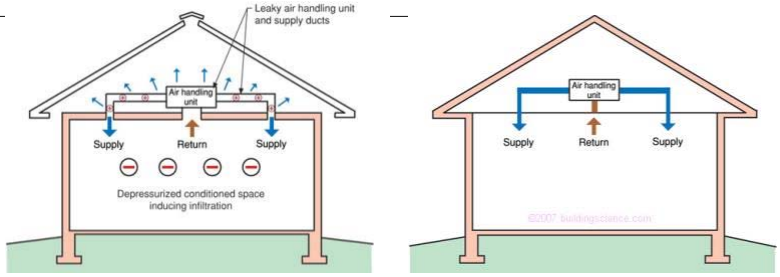
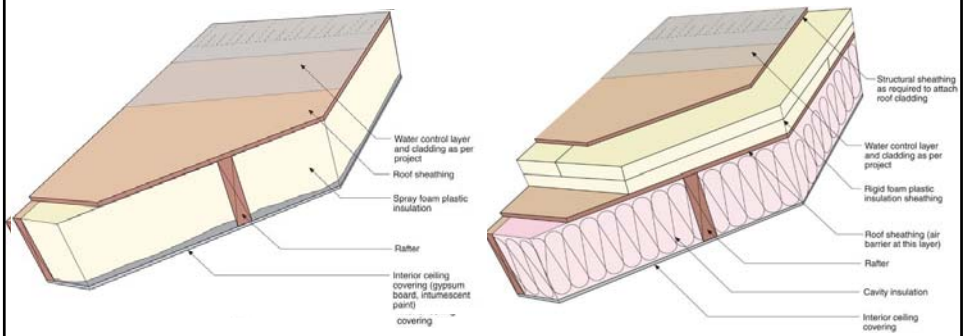
Unvented Roofs & HVAC Placement



- Ducts in unconditioned attic = huge energy losses
  - Industry reluctant to move ducts out of attic
  - Ice dam issues due to duct losses
- Solution: bring ducts into conditioned space
- Unvented/conditioned attic—keeps ductwork in conditioned space, duct leak issues eliminated

Spray Foam/Exterior Insulation Roofs



- 2009 IRC: R806.4 Unvented attic assemblies
- Minimum R-value of “air impermeable insulation”
  - Actually ratio of R-values (BSI-100 Hybrid Assemblies)
- Nail base needed with rigid foam on roof deck

Fibrous Insulation Unvented Roofs

- Dense pack insulation 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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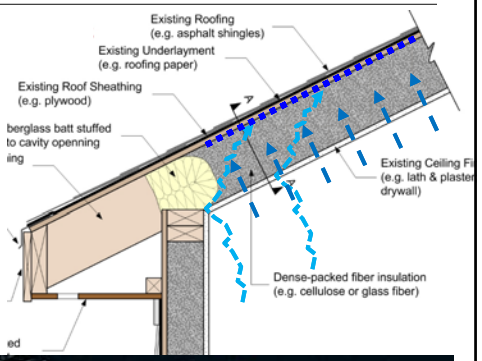
Why Unvented + Fibrous Risky?

- 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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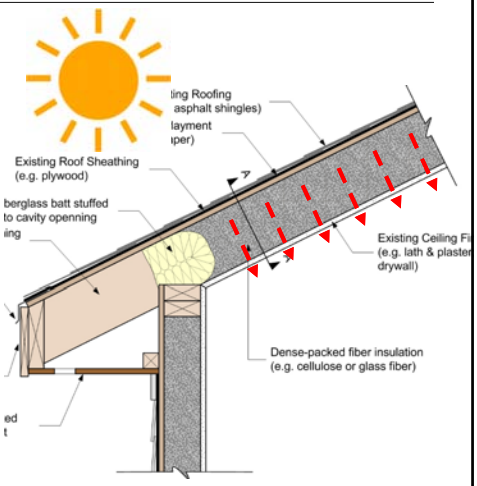
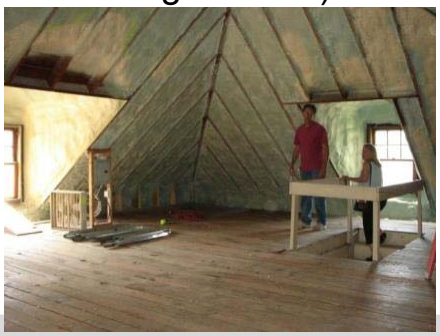
Why Unvented + Loose Fill Risky?

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



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 removing finishes)



"Ridge Rot" and Moisture Buoyancy

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Houston and Jacksonville (CZ 2A) 2001




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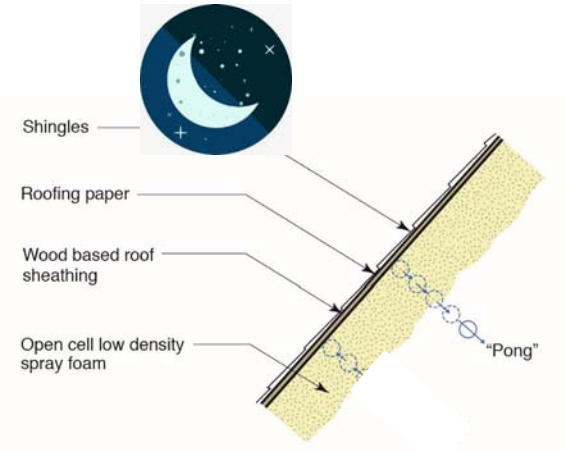
Moisture Buoyancy

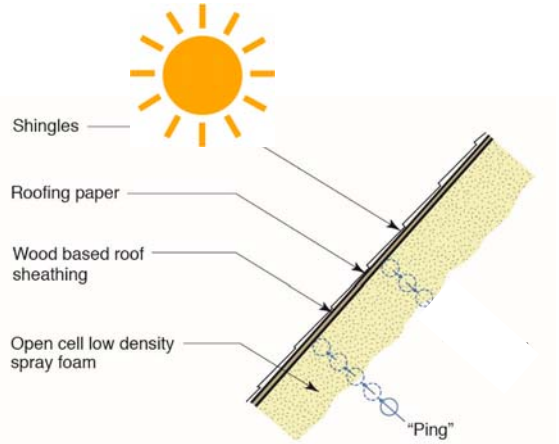
- Moisture concentrated at highest point in conditioned attic (ridge)
- Not a simple one-dimensional problem
- Not a straight-up air leakage problem
- Problem with open-cell spray foam (ocSPF) unvented roofs (high RHs in attic)-many climates
  - But not ccSPF—lower vapor permeance
- Concentration of 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



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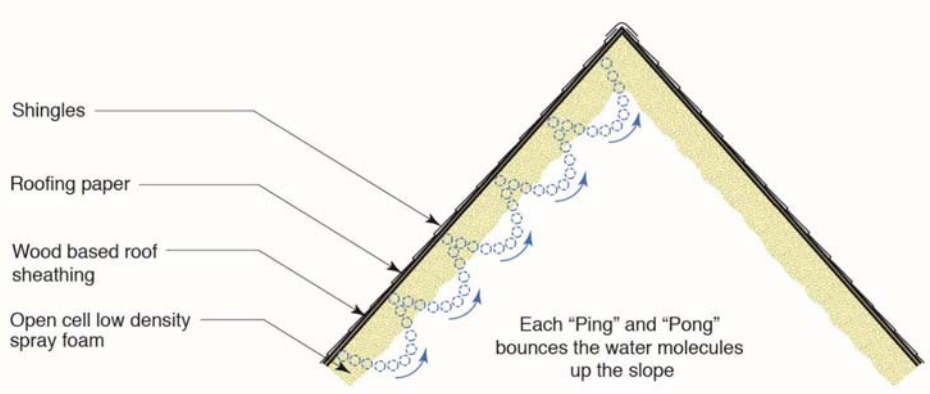
“Ping Pong” Water



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

Previous Building America Research

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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 poor air leakage
- Houston/Orlando (CZ 2A):
  - 2 attics, multiple seasons
  - Diffusion vents allow greater drying, avoid moisture problems

Chicago roof disassembly


Houston roof w. diffusion vent

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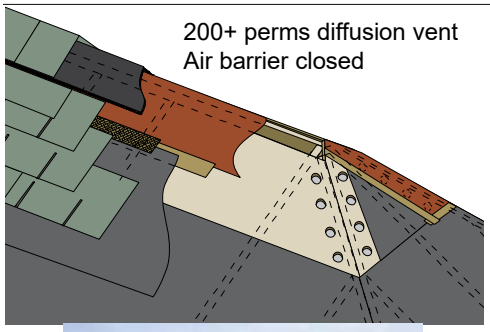
Diffusion Vent Prototype (Houston)



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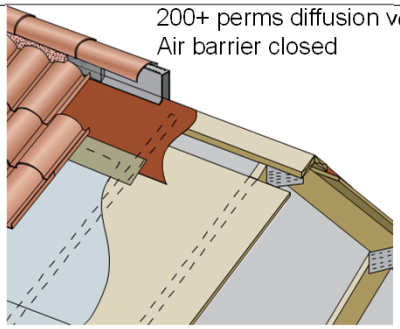
Diffusion Vent Prototype (Orlando-Tile)



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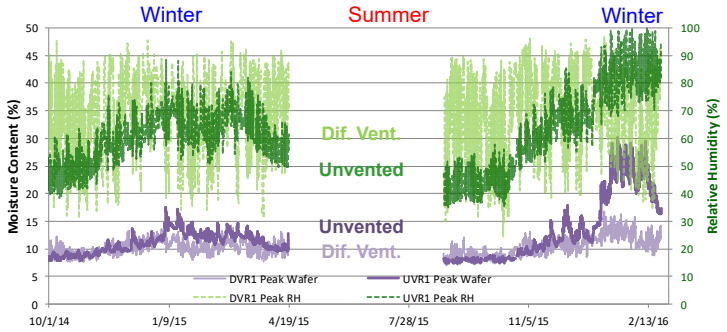
Houston/Orlando Results

- Diffusion vent avoids wintertime ridge accumulation problems (ridge peak RHs/MCs)
- No failures at low interior RH, bigger difference at higher RH (interior humidification)
- Airtightness disappointing in some cases-no SPF
- Unvented + fibrous + DV: in 2018 IRC, CZ 1, 2, 3



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Orlando Decommissioning

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Test Hut Approach & Construction

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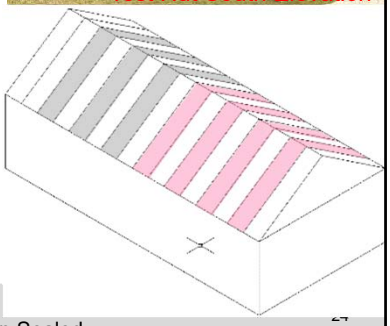
Test Hut Experimental Approach

- 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):
  - Vapor retarder: variable perm vs. fixed perm, various permeance curves
  - Diffusion vent at ridge: full size, none, "small," or "tight"
  - Fiberglass vs. cellulose
  - "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



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Diffusion Vent

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Test Hut Construction

- Instrumentation completion

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Test Hut Construction

- Interior air/vapor control installed

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Research Findings

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Year 1 Findings (“Normal” Conditions)

- Roofs with diffusion vent & variable-perm vapor retarder safest
- Non-diffusion vent roofs worst; high moisture levels at ridge
- Viitanen mold index values below risk thresholds (3.0 MI); meets ASHRAE Standard 160
- Visible settling of insulation (when cutting new ridge openings from above)
- Summertime inward drive at fixed-perm VR roofs
- Eliminated non-diffusion vent roofs (“small”, “tight”) for following research

Ridge Retrofits, Insulation Settling

Ridge Retrofits, Insulation Settling

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Ridge Retrofits, Insulation Settling

Cellulose settling along entire roof length only occurred on north side

Roofs left as-is for Winter 2: realistic settling of insulation? Also, damage to instruments when retrofitting insulation

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Year 2 Findings (50% RH Constant)

- Interior at 50% RH creates much more challenging conditions: many pushing edge of risk
- Many MCs over 20% to 30%, sustained high RH
- Mold Index #s remain below 3.0
- Mold growth occurred on framing & sheathing
- “Tight” diffusion vent did not work acceptably
- Code-compliant ccSPF roof acceptable
- Repacked insulation after disassembly; filling all voids
- Replaced all ridge sensors (data failures)

Summer 2 Ridge Disassembly Work

- Fiberglass: staining, rundown, some mold spotting

Summer 2 Ridge Disassembly Work

- Cellulose: worst mold, settling (greater at north)




Year 3 Setup & Findings (Air Injection)

- Early winter 50% RH, no air leak
- February onward-add air leak
- Air injection system
  - Interior-to-interior leak
  - Very small air leak, 0.5 CFM per bay
  - Comparable to very airtight construction
- Before air injection: much drier than Year 2
  - Repacking insulation suppresses convection?
- Air injection: severe spike in sheathing MC
  - Localized to injection site
  - Disassembly in summer: no visible damage

Air Injection System

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Disassembly

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Data Results

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Instrumentation Design: Fibrous Insulation

Notes

- "MC/T Sheathing High" is at top edge of sheathing at diffusion vent, or equivalent location in non-DV roofs
- Wafer and RH/T at ridge are directly under ridge

Sensor Key:
- Temperature
- Relative humidity/temperature
- Moisture content/temperature
- Moisture content block

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Instrumentation Design: Fibrous Insulation

Typical Unvented Bay
- Asphalt shingles
- Self-adhered membrane
- OSB 5/8" ZIP roof panel)
- Cavity insulation (dense pack cellulose or blown fiberglass)

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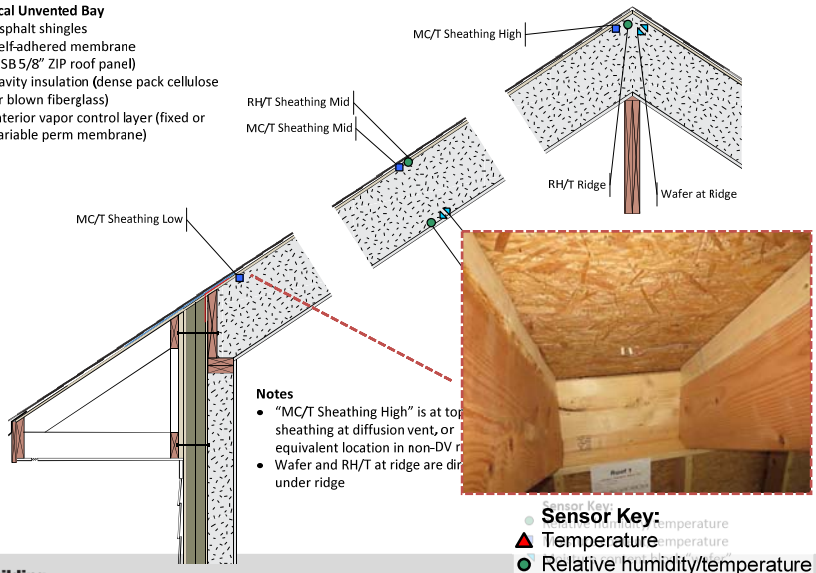
Instrumentation Design: Fibrous Insulation

Typical Unvented Bay

- Asphalt shingles
- Self-adhered membrane
- OSB 5/8" ZIP roof panel)
- Cavity insulation (dense pack cellulose or blown fiberglass)
- Interior vapor control layer (fixed or variable perm membrane)



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Sensor Key:

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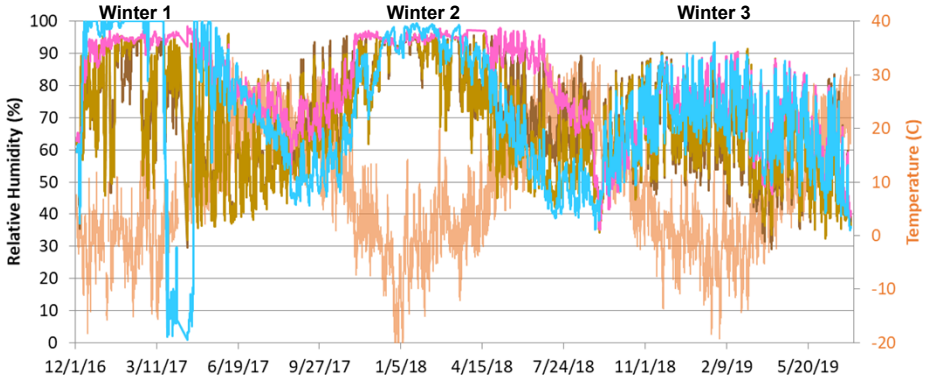
Fiberglass Roofs: Ridge RH 24 hr Average



- 24 hr. averaging for readability
- Winter 1 dry, Winter 2 wetter
- Winter 3 much drier than Winter 2

Roof	Short Name
1	FG-VB-DV
2	FG-SVR-DV
3	FG-tVR-DV
4	FG-SVR-sDV

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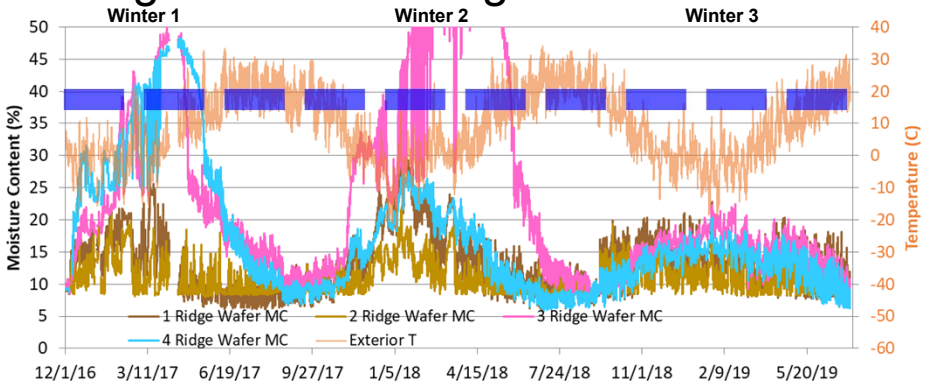
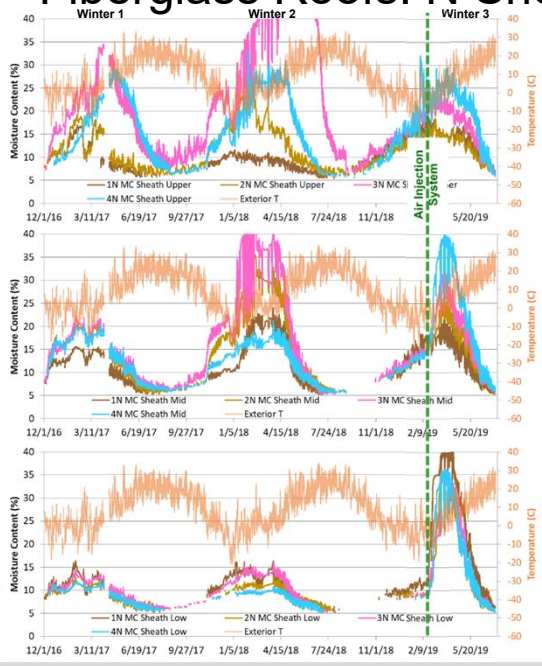
Fiberglass Roofs: Ridge Wafers



- Winter 1 **Roof 3** & **Roof 4** no DV
- Winter 1 vs Winter 2 (50% RH)
- Winter 3 also 50% RH-but low moisture
  - And wafer sensor replaced

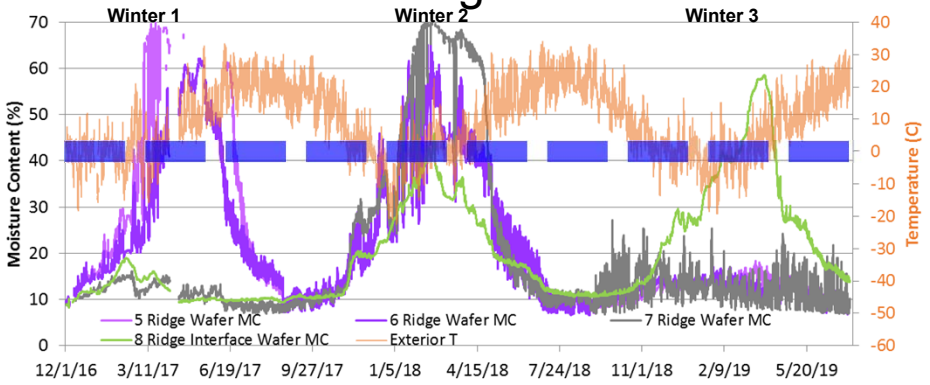
Roof	Short Name
1	FG-VB-DV
2	FG-SVR-DV
3	FG-tVR-DV
4	FG-SVR-sDV

Fiberglass Roofs: N Sheathing MCs



- Winter 1 **DV roofs** vs. **non-DV roofs**
- Much higher MCs in Winter 2 (50% RH)
- Winter 3 drier "trajectory" (same 50% RH)
- After air injection: MCs increase
- 30-40% MC @ lower & mid sheathings

Cellulose Roofs: Ridge Wafer



- 50%+ MC unrealistic: condensation, borate migration
- Winter 3 much drier than Winter 2
- **Roof 8** (hybrid) condensation-range MCs?
  - Not replaced between Winters 2/3

Roof	Short Name
5	Cell-tVR-DV
6	Cell-SVR-sDV
7	Cell-SVR-DV
8	ccSPF-Cell

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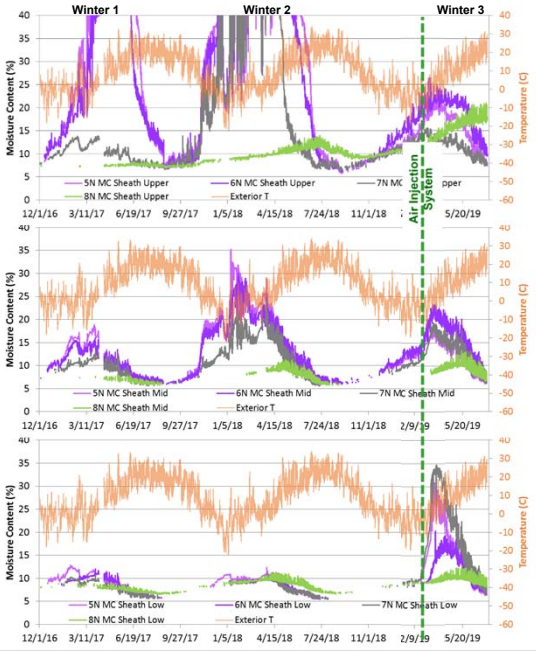
Cellulose Roofs: N Sheathing MCs



- North sheathing MCs
- Upper: condensation & borate migration
- Winter 3 starts out drier than Winter 2
- Air injection: rise in MCs low & mid
- Peak MCs lower than fiberglass: storage

Roof	Short Name
5	Cell-tVR-DV
6	Cell-SVR-sDV
7	Cell-SVR-DV
8	ccSPF-Cell

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Conclusions and Recommendations

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Recommendations and Further Work

- Unvented fibrous insulation roofs **can** work, **BUT**
  - Ensure complete packing of insulation
  - Still vulnerable to small (0.5 CFM) air leaks
- Mold found after Winter 2, despite mold index < 3.0
  - Vulnerability to moisture damage at ridge
- Difficult to recommend for widespread use and acceptance in building 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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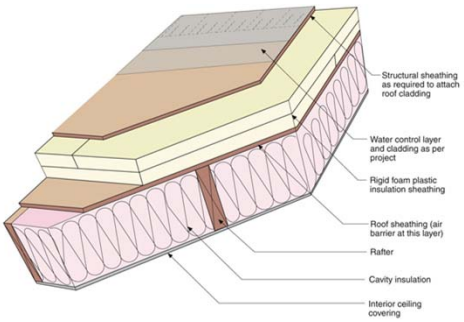
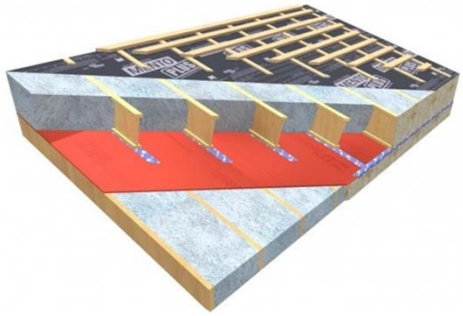
Recommendations and Further Work

- Foam-free unvented roof options
  - Fibrous + continuous exterior insulation outside air barrier, per § R806.5
  - Ventilated cavity outboard of vapor-permeable air/water control membrane

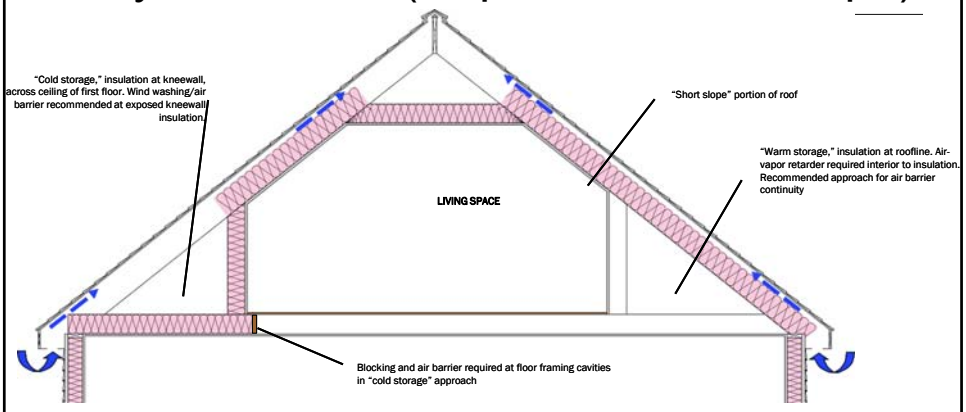




Recommendations and Further Work

- If implementing unvented fibrous insulation roofs
  - Keep interior RH low for life of building
  - Airtightness of interior air/vapor control layer
  - Variable-perm vapor retarder (allows downward drying)
  - Large 300 perm diffusion vent recommended
  - Fibrous insulation without voids or empty cavities
  - Light colored roofs & shading increase risks
- Future work?
  - Moisture risks demonstrated; not sure if additional research useful
  - “Story and a Half Geometry” (Cape Cod short slope)

Story and a Half (Cape Cod Short Slope)



- Possible application to retrofitting "short slope" of kneewall attic geometry
- Eliminates "chute," possible to retrofit longer runs

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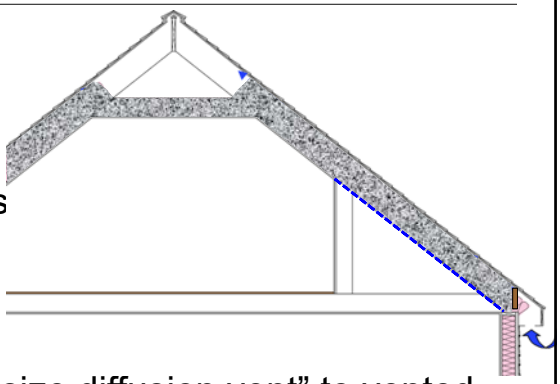
Story and a Half (Cape Cod Short Slope)

- Higher R-value in limited cavity
- Not proven by this research, but this is "lower half of roof" geometry (low risk portion)



- Rafter bay has "full-size diffusion vent" to vented attic above
- Common practice in weatherization NE/Midwest
- State code change proposals in process

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Questions?

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