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

February 24, 2020

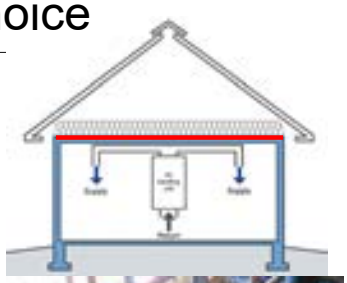
1

Background

2

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)



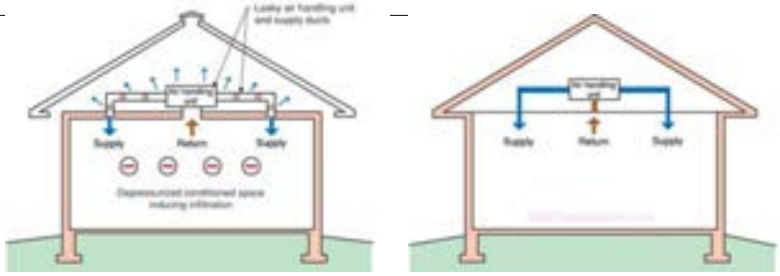
3

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

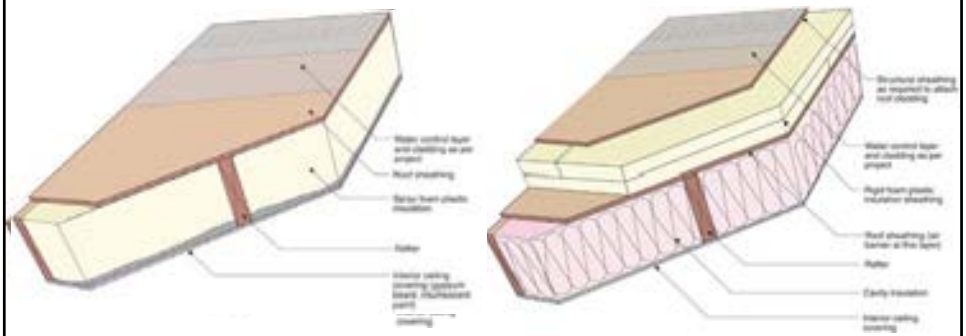
4

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

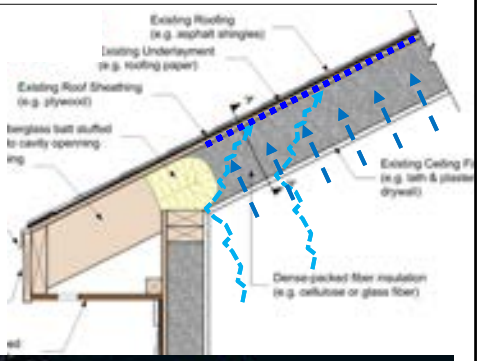
Fibrous Insulation Unvented Roofs

- 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)

7

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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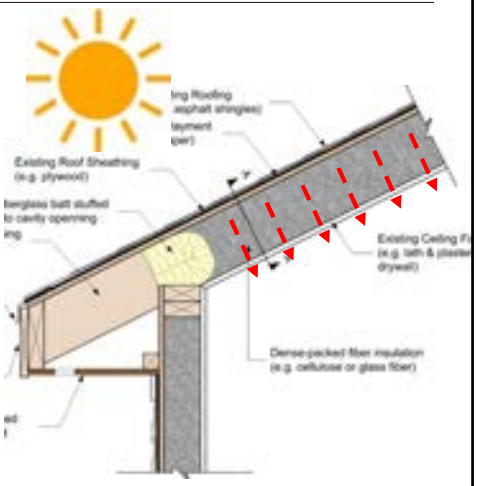
8

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

11

Houston and Jacksonville (CZ 2A) 2001

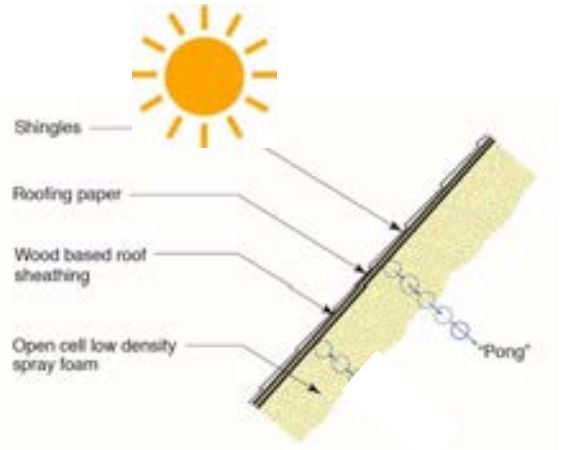



12

Moisture Buoyancy

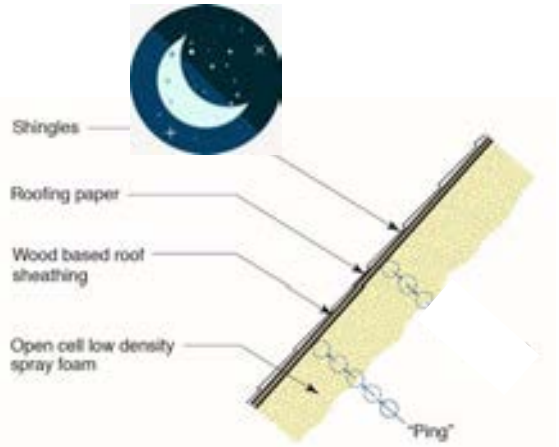
- Moisture concentrated at highest point in conditioned attic (ridge)
- Not a simple one-dimensional problem
- Not a straight-up air leakage problem
- Problem with open-cell spray foam (ocSPF) unvented roofs (high RHs in attic)-many climates
  - But not ccSPF—lower vapor permeance
- Concentration of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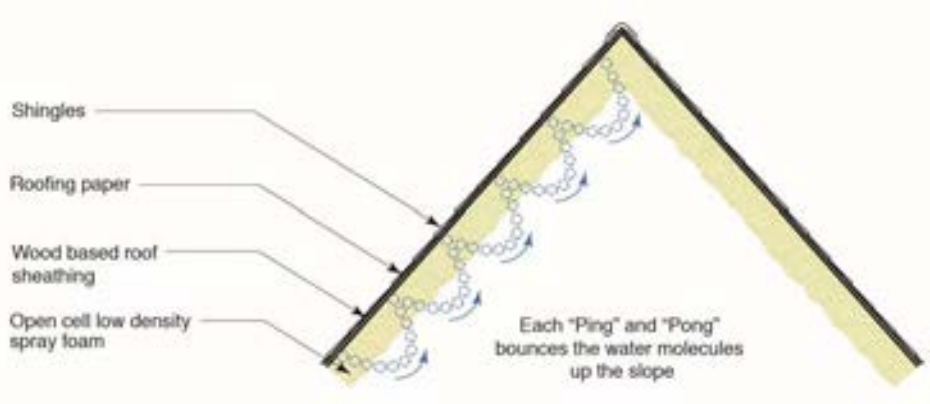
“Ping Pong” Water



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

Previous Building America Research

17

Previous Building America Research

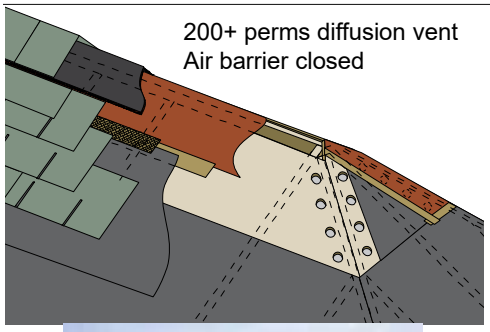
- Chicago (CZ 5A):
  - One winter, 50% RH
  - Unvented roofs-high risk
  - Cellulose lower risk than FG batt
  - Vented compact roof (chute) safe-but poor air leakage
- Houston/Orlando (CZ 2A):
  - 2 attics, multiple seasons
  - Diffusion vents allow greater drying, avoid moisture problems

Chicago roof disassembly


Houston roof w. diffusion vent

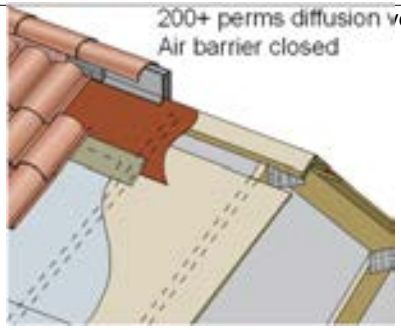
18

Diffusion Vent Prototype (Houston)



19

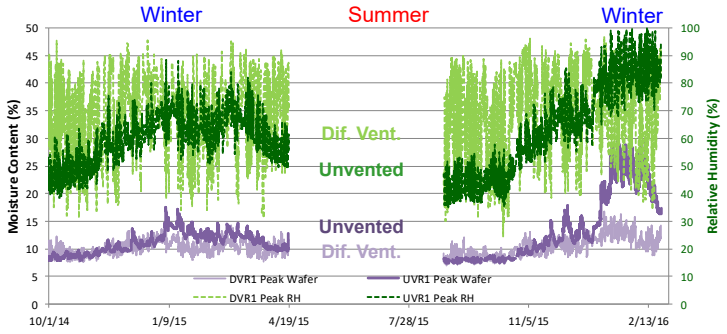
Diffusion Vent Prototype (Orlando-Tile)



20

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



21

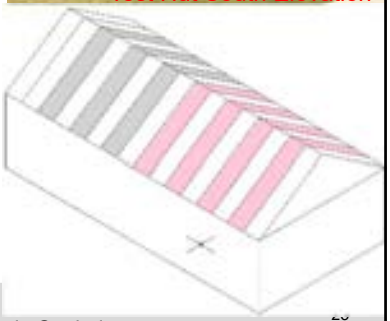
Test Hut Approach & Construction

22

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



23

Diffusion Vent


Ridge cap over 6" diffusion vent


"Small" and "tight" DV options


"Small" and "tight" DV options

24

Test Hut Construction

- Instrumentation completion

25

Test Hut Construction

- Interior air/vapor control installed

26

Research Findings

27

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

28

Ridge Retrofits, Insulation Settling

29

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

30

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

35

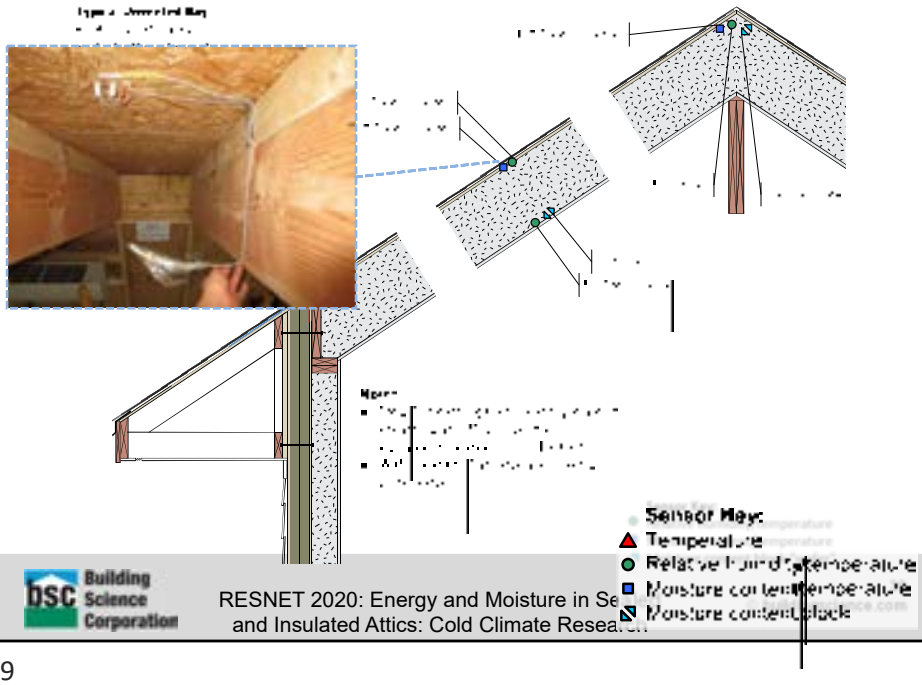
Disassembly

36

Data Results

Instrumentation Design: Fibrous Insulation

Instrumentation Design: Fibrous Insulation



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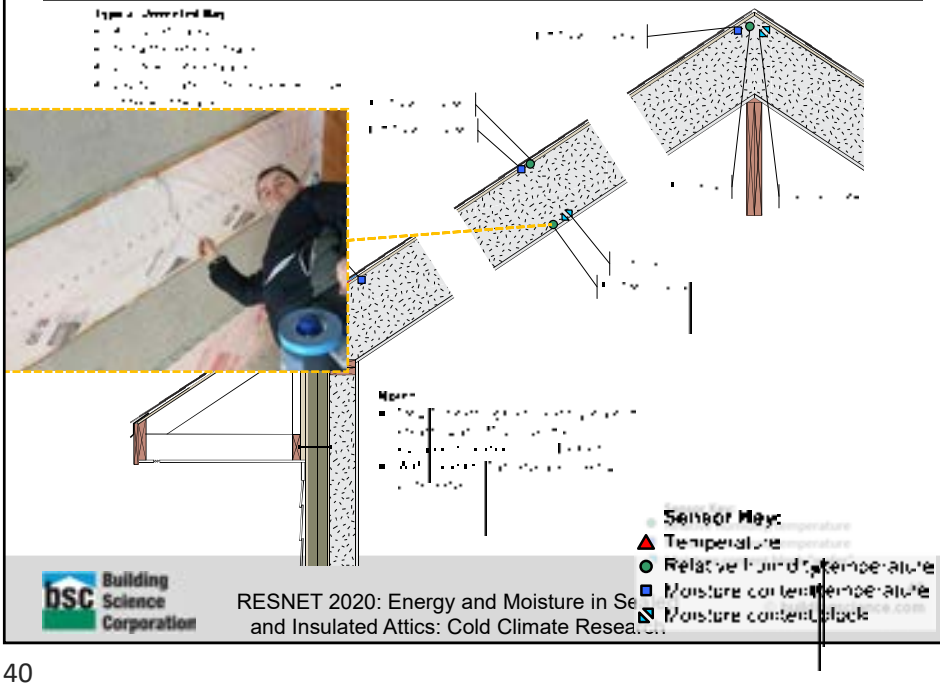
39

Instrumentation Design: Fibrous Insulation



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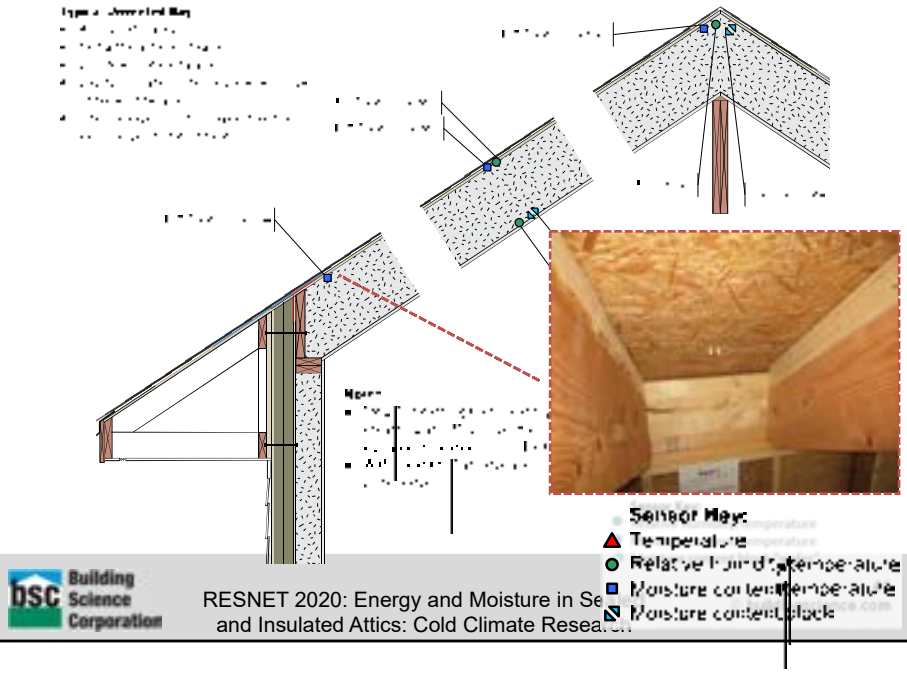
40

Instrumentation Design: Fibrous Insulation



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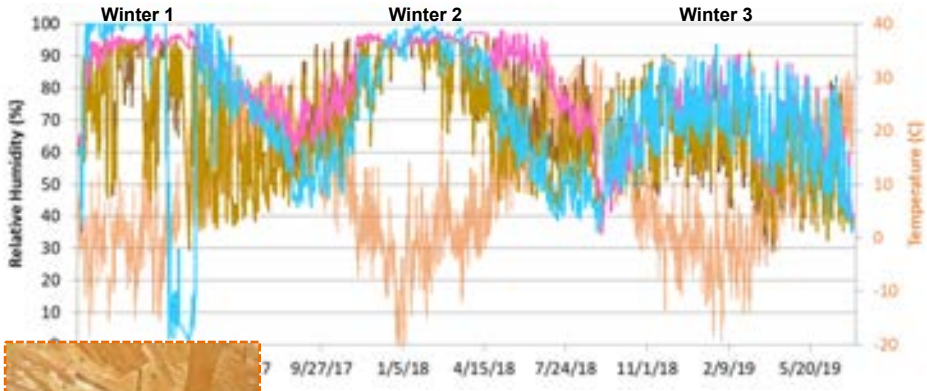
41

Fiberglass Roofs: Ridge RH 24 hr Average



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

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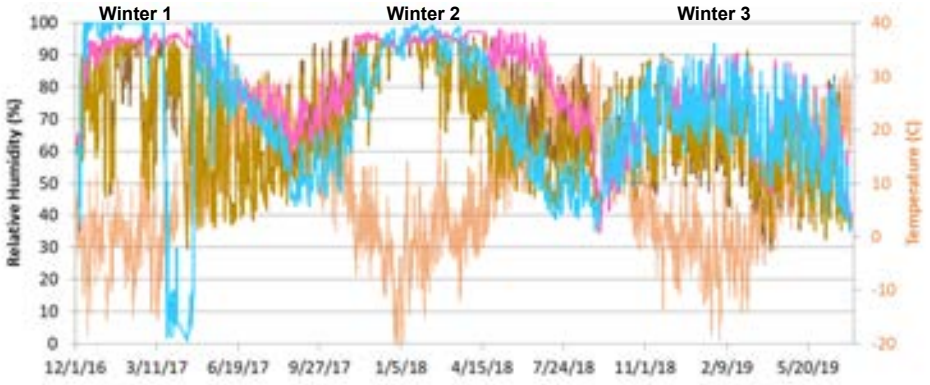
42

42

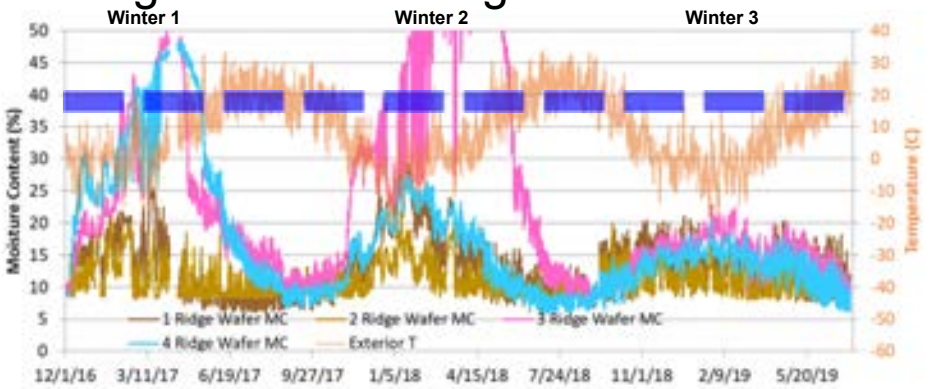
Fiberglass Roofs: Ridge RH 24 hr Average



- 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

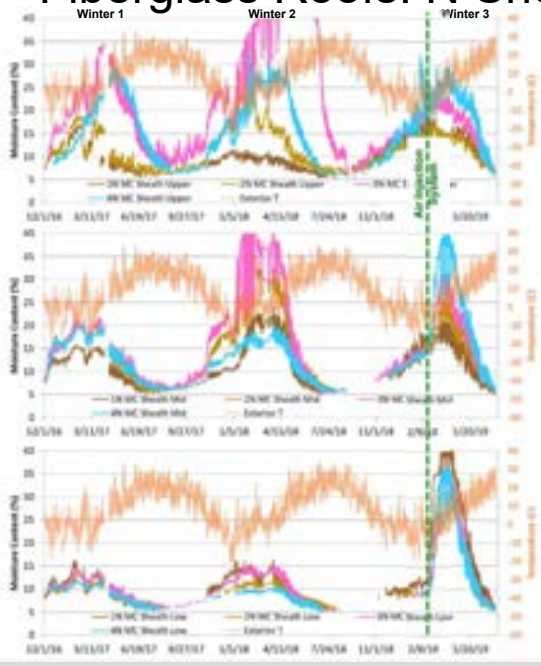
Fiberglass Roofs: Ridge Wafers



- 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

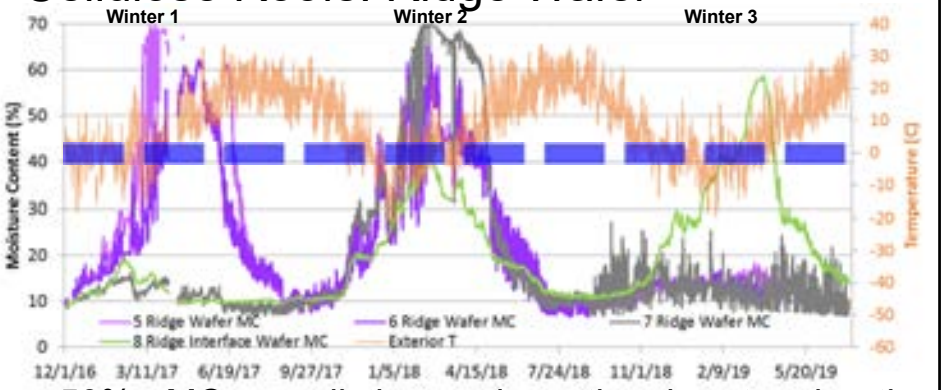
Fiberglass Roofs: N Sheathing MCs



- 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

45

Cellulose Roofs: Ridge Wafer

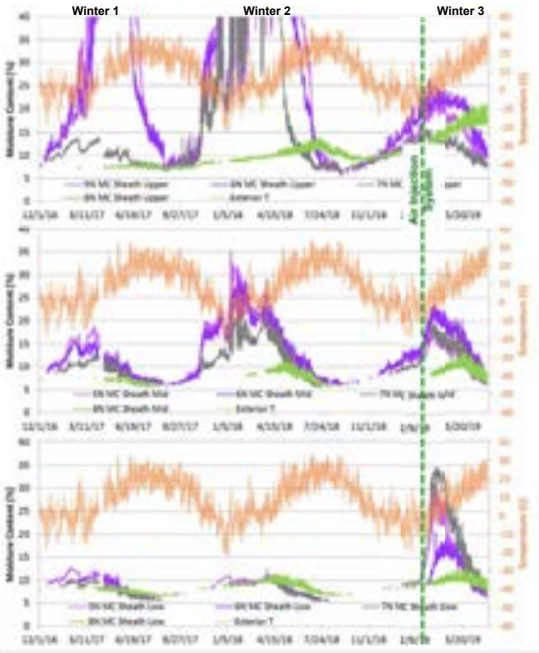


- 50%+ MC unrealistic: condensation, borate migration
- Winter 3 much drier than Winter 2
- **Roof 8** (hybrid) condensation-range MCs?
  - Not replaced between Winters 2/3

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

46

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

47

Conclusions and Recommendations

48

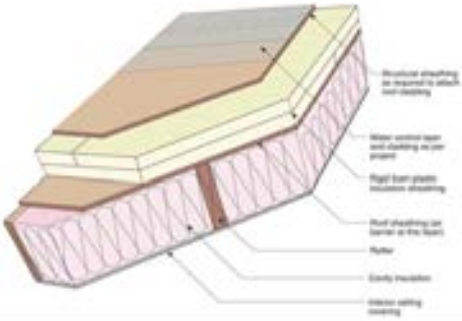
Recommendations and Further Work

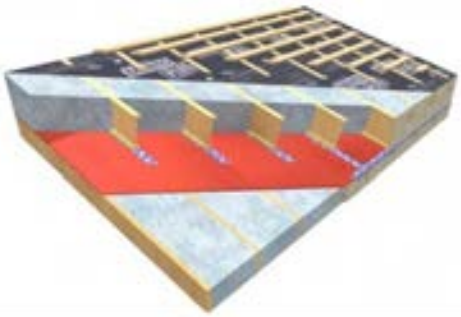
- Unvented fibrous insulation roofs **can** work, **BUT**
  - Ensure complete packing of insulation
  - Still vulnerable to small (0.5 CFM) air leaks
- Mold found after Winter 2, despite mold index < 3.0
  - Vulnerability to moisture damage at ridge
- Difficult to recommend for widespread use and acceptance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

49

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



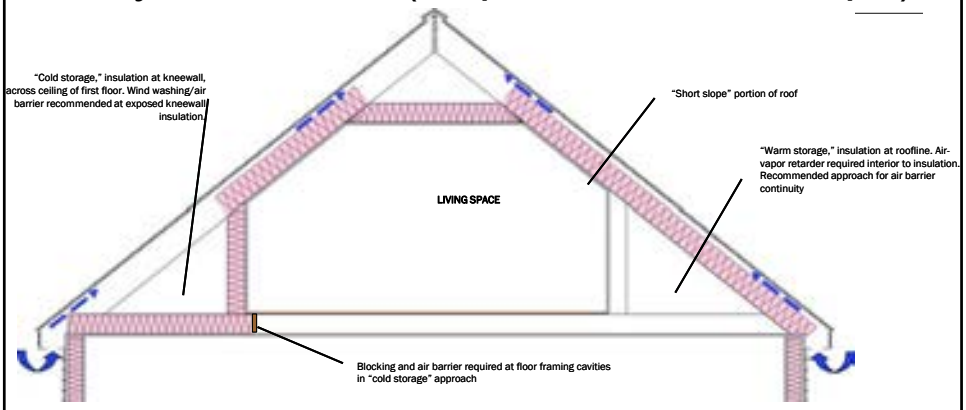


50

Recommendations and Further Work

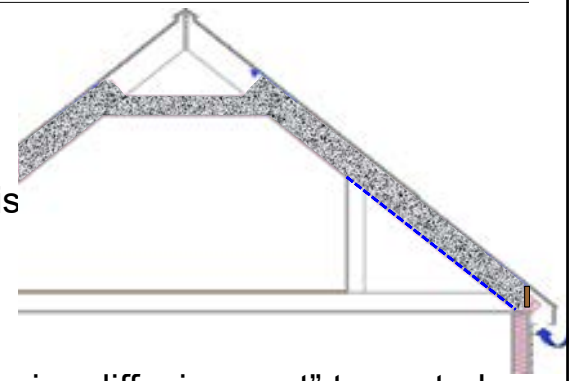
- If implementing unvented fibrous insulation roofs
  - Keep interior RH low for life of building
  - Airtightness of interior air/vapor control layer
  - Variable-perm vapor retarder (allows downward drying)
  - Large 300 perm diffusion vent recommended
  - Fibrous insulation without voids or empty 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

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

Questions?

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

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