BUILDINGENERGY BOSTON

Unvented Roofs Without Spray Foam: The Rest of the Story

August 14, 2020 · 3:00 pm

Presenter:

Kohta Ueno (Building Science Corporation)

1

Kohta Ueno
August 14, 2020

Unvented Roofs Without Spray Foam:

The Rest of the Story

Building Science Corporation

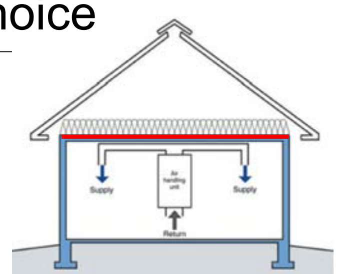
BUILDINGENERGY BOSTON
ONLINE • WEDNESDAY–FRIDAY, AUGUST 12–14, 2020 • NESEA.ORG/BE20
Conference + Trade Show of the Northeast Sustainable Energy Association (NESEA)

2

Background

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)

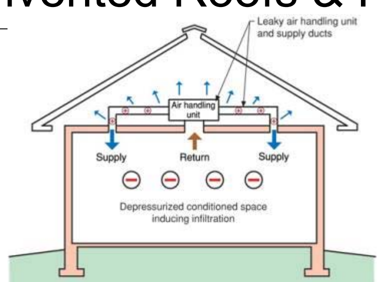


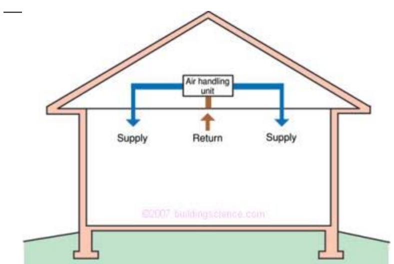
Then Why Unvented Roofs?

- 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

5

Unvented Roofs & HVAC Placement



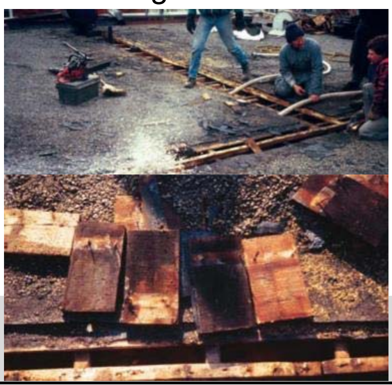


- Ducts in unconditioned attic = energy losses
  - Industry reluctant to move ducts out of attic
  - Ice dam issues due to duct losses
- Solution: bring ducts into conditioned space
- Unvented/conditioned attic—keeps ductwork in conditioned space, duct leak issues eliminated

6

Fibrous Insulation Unvented Roofs

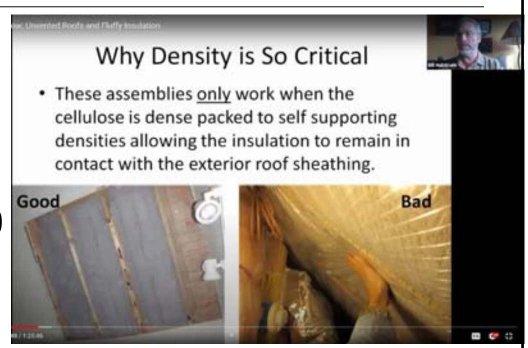
- Dense pack insulation of unvented roofs common in cold-climate retrofits
  - Moisture risks (see BSI-043 “Don't Be Dense—Cellulose and Dense-Pack Insulation”)—2 in 10 failure?
  - Violates I-codes (see IRC § R806.4/R806.5)
  - “Ridge rot”—localized problems (SIPS same problem)



7

Fibrous Insulation Unvented Roofs

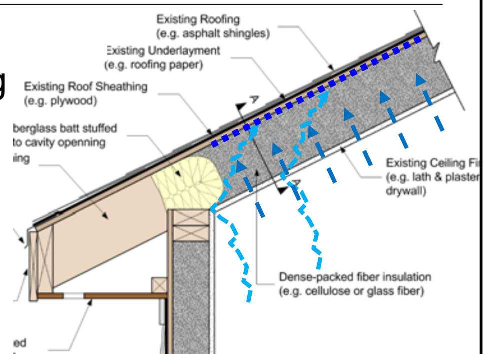
- The BS* + Beer Show: Unvented Roofs and Fluffy Insulation (with Bill Hulstrunk/ NatureTech), May 2020
- Moisture buffering from cellulose storage
- Critical role of density
- https://www.youtube.com/watch?v=xZlnpQYdsuM&t=1551s



8

Why Unvented + Fibrous Risky?

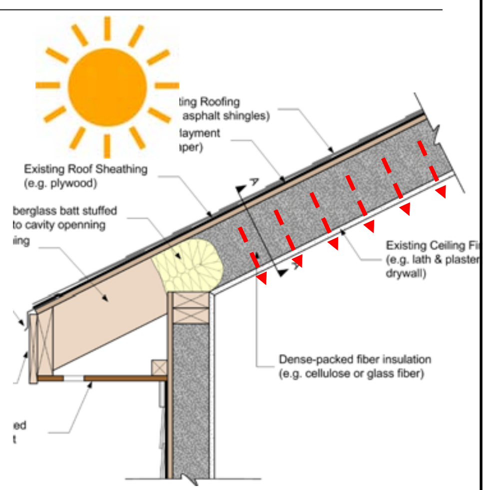
- Different than walls?
- Moisture risks at sheathing
  - Interior-sourced air leakage
  - Vapor contributing too?
  - Zero-perm exterior ("wrong side perfect vapor barrier")
  - Night sky radiation cooling
  - Stack effect in winter
  - "Ridge rot" (thermal and moisture buoyancy)



9

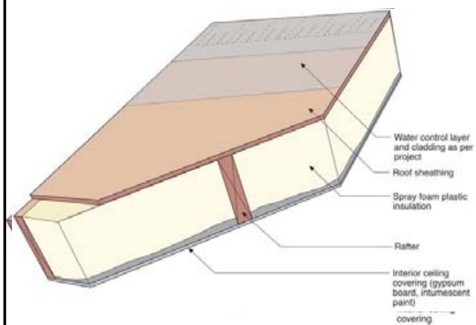
Why Unvented + Loose Fill Risky?

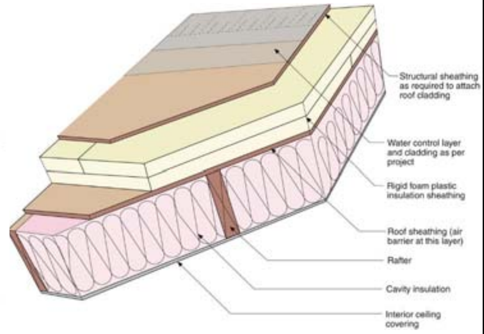
- Risk reduced by:
  - Airtightness of ceiling
  - Dense insulations that suppress airflow
  - Solar drive
    - But white roofs, shading
  - Lower interior RH (winter)
    - Why many of them work?
  - Lower permeance interior
    - Assumes good airtightness—vapor retarder not bypassed
- Moisture accumulation: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



10

Spray Foam/Exterior Insulation Roofs





- 2006 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

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 11 © buildingscience.com

11

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)

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 12 © buildingscience.com

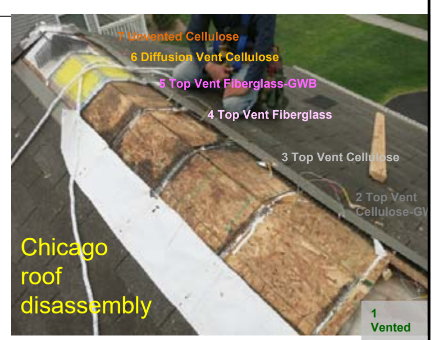
12

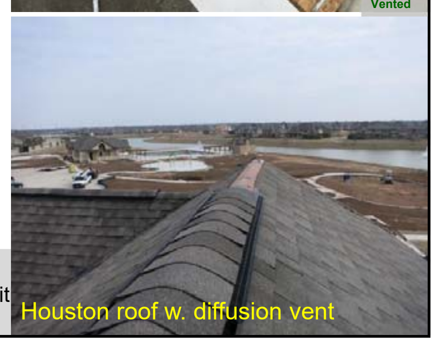
Previous Building America Research

13

Previous Building America Research

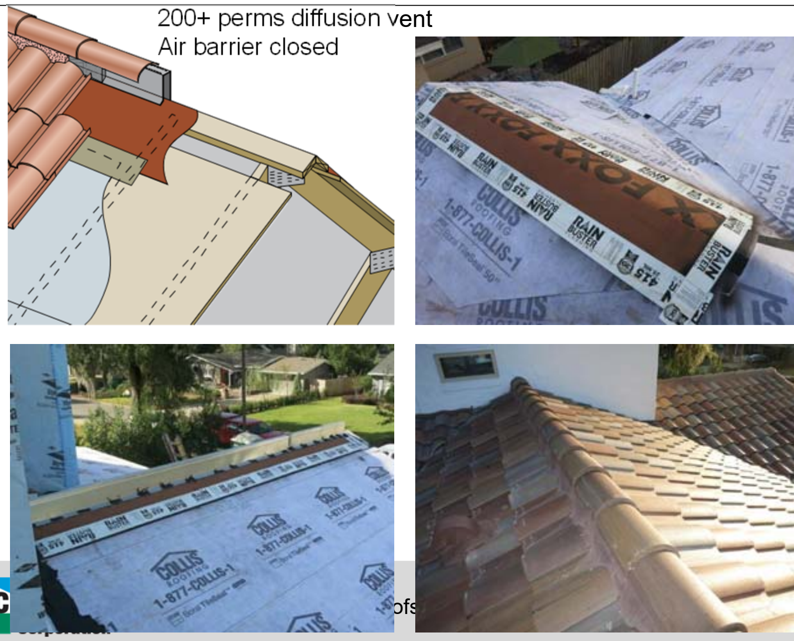
- Chicago (CZ 5A):
  - One winter, 50% RH
  - Unvented roofs-high risk
  - Cellulose lower risk than FG batt
  - Vented compact roof (chute) safe-but poor air leakage
- Houston/Orlando (CZ 2A):
  - 2 attics, multiple seasons
  - Diffusion vents allow greater drying, avoid moisture problems





14

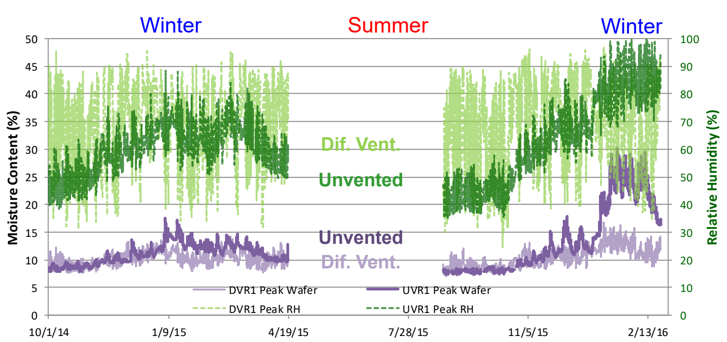
Diffusion Vent Prototype (Orlando-Tile)



15

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



16

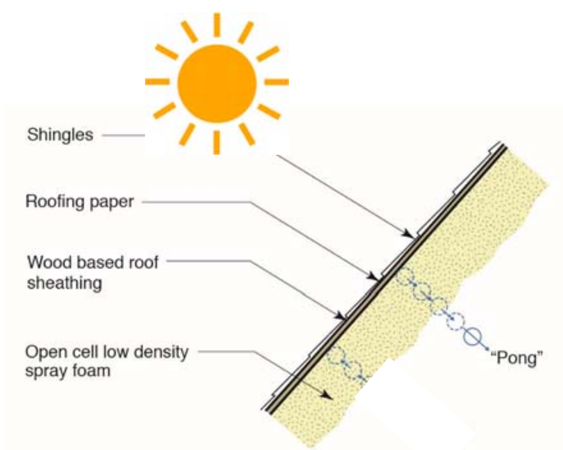
“Ridge Rot” and Moisture Buoyancy

Houston and Jacksonville (CZ 2A) 2001

Moisture Buoyancy

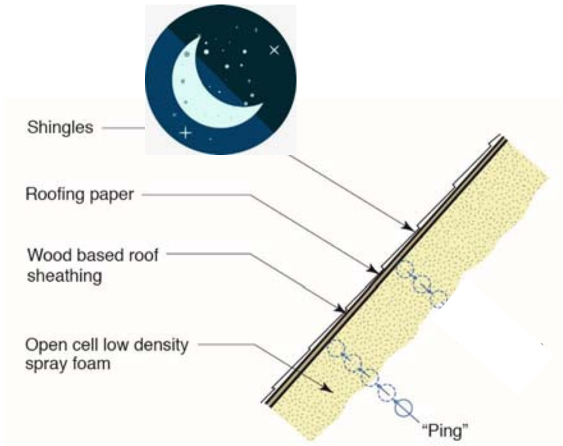
- Moisture concentrated at highest point in conditioned attic (ridge)
- Not a simple one-dimensional problem
- Not a straight-up air leakage problem
- Problem with open-cell spray foam (ocSPF) unvented roofs (high RHs in attic)-many climates
  - But not ccSPF—lower vapor permeance
- Concentration of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

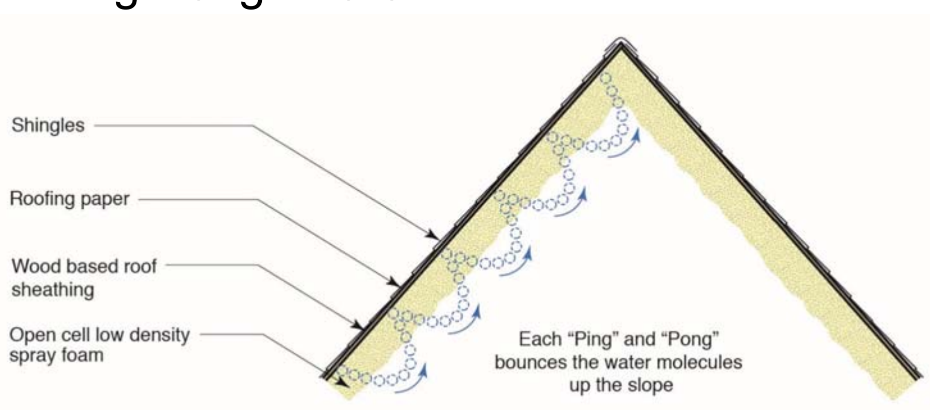
"Ping Pong" Water



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

21

"Ping Pong" Water

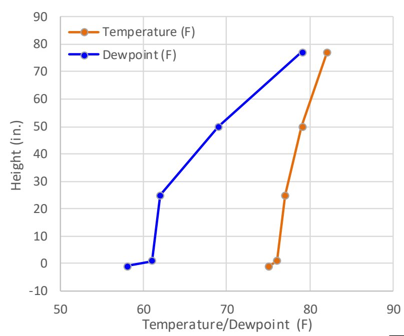


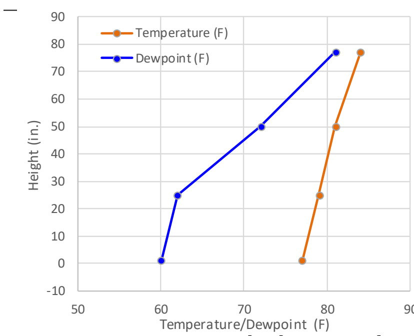
- "Gas separation process similar to pressure swing adsorption"
- Solar-powered moisture concentration machine

22

Orlando Decommissioning

Orlando Decommissioning





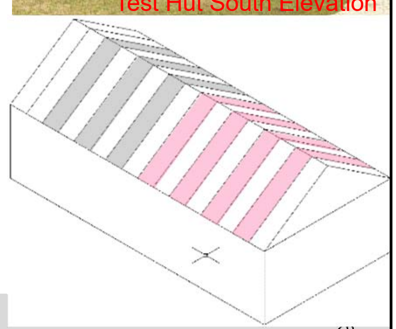
- Temperature and dewpoint stratification directly measured
- 90%+ RH near ridge
- System is not in equilibrium

Test Hut Approach & Construction

25

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



26

Test Hut Construction

- Flash and blow bays (ccSPF shown)
  - ccSPF completes air barrier between bays, wiring holes
- Insulation netted & blown

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 27

27

Test Hut Construction

- Interior air barrier & vapor retarder membrane
- Adhesive spray + double tape seal (double-sided tape + housewrap tape) plus mechanical fasteners

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 28

28

Test Hut Construction

- Instrumentation completion

Test Hut Construction

- ccSPF in guard bays and walls

Test Hut Construction

- Fibrous insulation installed

31

Test Hut Construction

- Interior air/vapor control installed

32

Experimental Approach: Diffusion Vent

- ~6 in. opening (fits under typical ridge cap)
- Dörken Delta-Foxx membrane
  - 214 perms dry cup, 550 perms wet cup

Research Findings

Year 1 Findings ("Normal" Conditions)

- Non-diffusion vent roofs worst; high moisture levels at ridge
- Roofs with diffusion vent & variable-perm vapor retarder safest
- 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 for Year 2 (added "small" & "tight" DVs)

Roof Insulation Settling (Fiberglass)

- Insulation settling noted during diffusion vent retrofit
- Fiberglass roof shown above

Retrofit Work, Cellulose Settling

Building Science Corporation

NESEA BE20: Unvented Roofs Without Spray Foam

37

37

Retrofit Work, Cellulose Settling

Settling along entire roof length <u>only</u> occurred on north side

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

Building Science Corporation

NESEA BE20: Unvented Roofs Without Spray Foam

38

© buildingscience.com

38

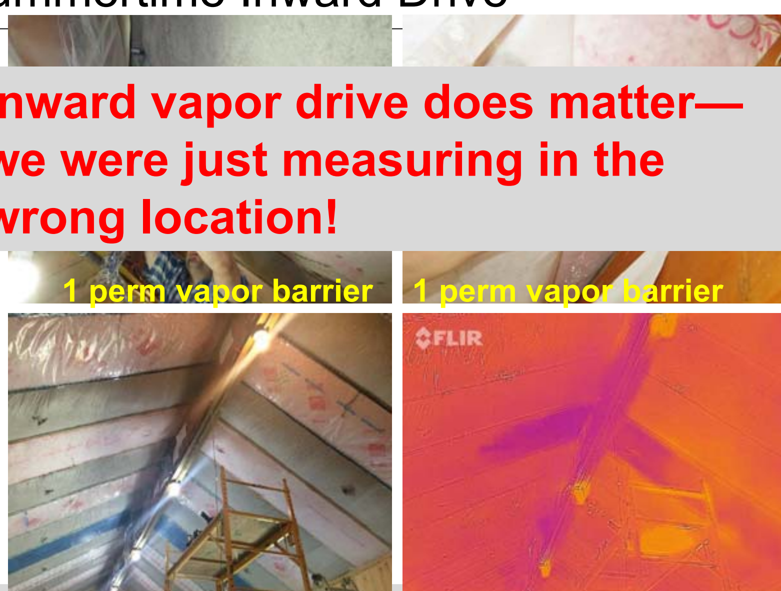
Summertime Inward Drive

Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam
39

39

Summertime Inward Drive

Inward vapor drive does matter—we were just measuring in the wrong location!



Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam
40

40

“Small” and “Tight” Diffusion Vents

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

43

Summer 2 Ridge Disassembly Work

- Cellulose: <u>worst</u> mold, settling (greater at north)

44

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

45

Air Injection System

46

Disassembly

No indication of moisture issues
(mold, staining, packy insulation

47

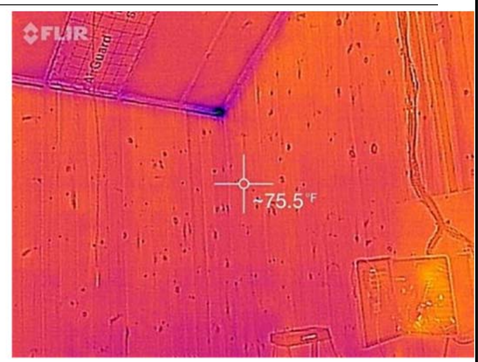
Miscellaneous Measurements

48

Air Leakage Testing

- Duct Blaster™ attached to exhaust opening
- Pressurization & depressurization
- ~50 CFM 50 (0.02 CFM 50/sf enclosure)
- Sliding door seal effect on airtightness

Air Leakage Testing: Infrared w. ΔP

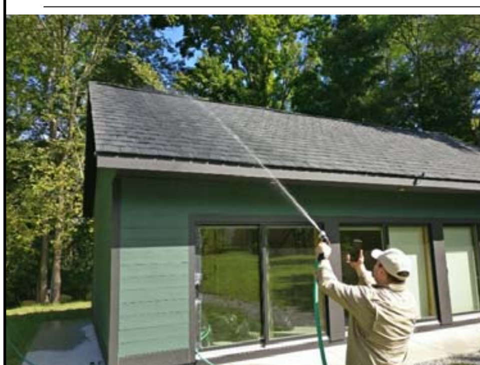


- Air leakage at 3-way intersection
- At guard bay, not test bay

Air Leakage Testing During Disassembly

- Depressurized to -75 Pascals
- No detectable air leakage
- No indication of tape seam failure

Water Leakage Testing



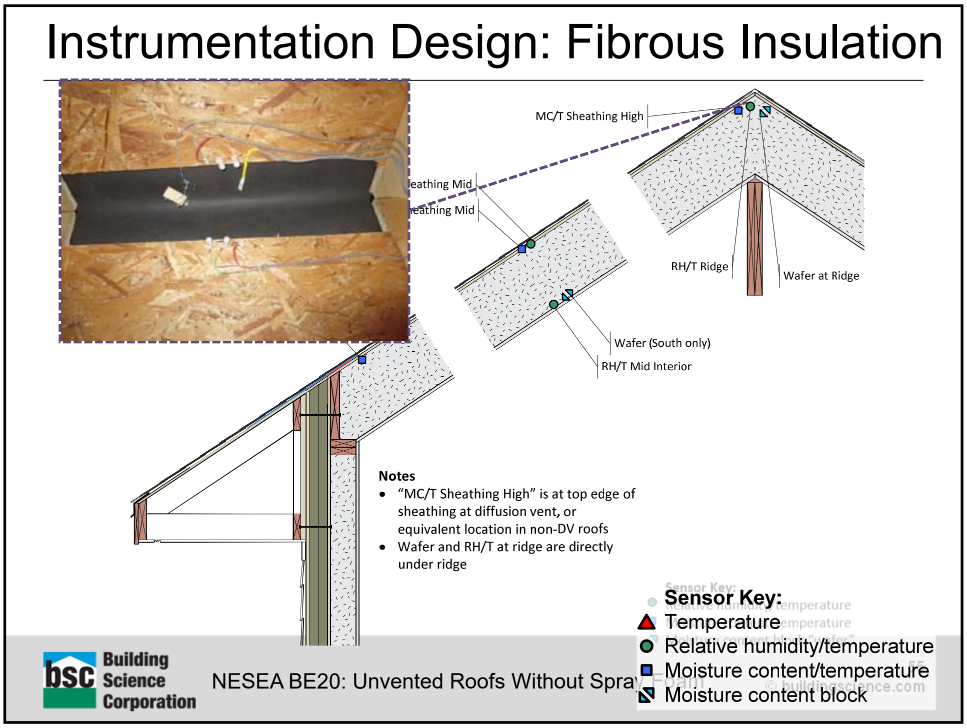
- Insulation removed from interior
- -75 Pascal depressurization, 10 minutes water spraying each side
- No sign of water leakage

Density Measurements

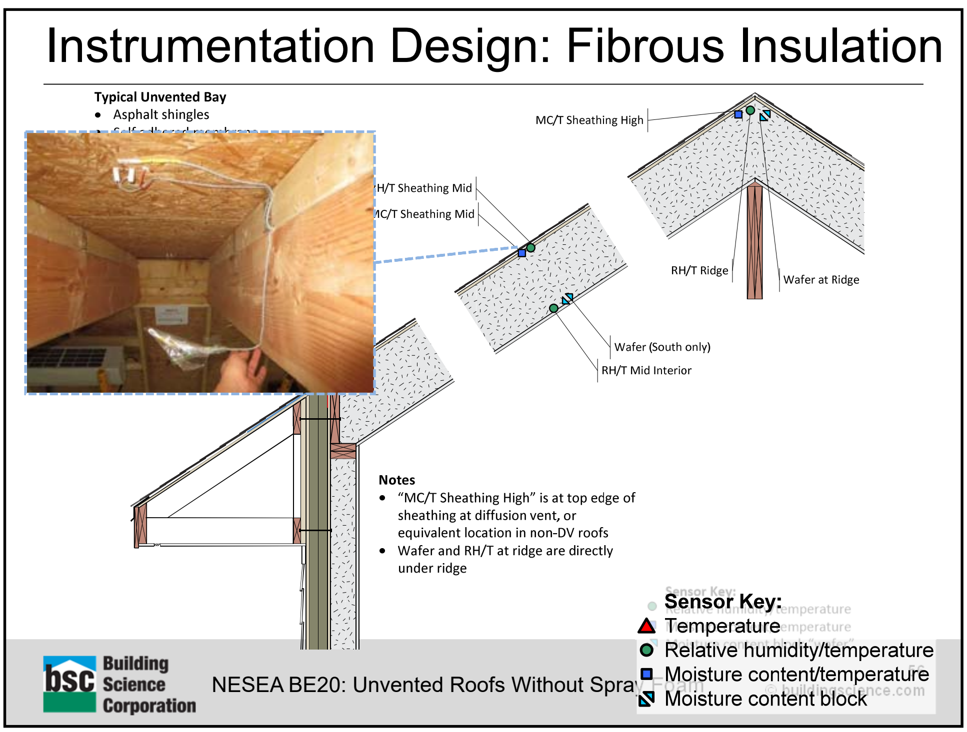
- Insulation weighed, density calc
- Average 1.5 PCF (fiberglass) & 4.0 PCF (cellulose)
- Higher density @ FG ridge

Roof	Total Lbs	Cubic Ft	PCF
1 FG-VB-DV	5.8	4.6	1.3
2 FG-SVR-DV	6.2	4.6	1.3
3 FG-VB-nDV (Low)	6.6	4.6	1.4
3 FG-VB-nDV (Hi)	5.0	2.3	2.2
4 FG-SVR-nDV	6.4	4.6	1.4
5 Cell-VB-nDV (Low)	19.2	4.6	4.1
5 Cell-VB-nDV (Hi)	10.0	2.3	4.3
6 Cell-SVR-nDV	10.6	2.3	4.6
7 Cell-SVR-DV	8.6	2.3	3.7

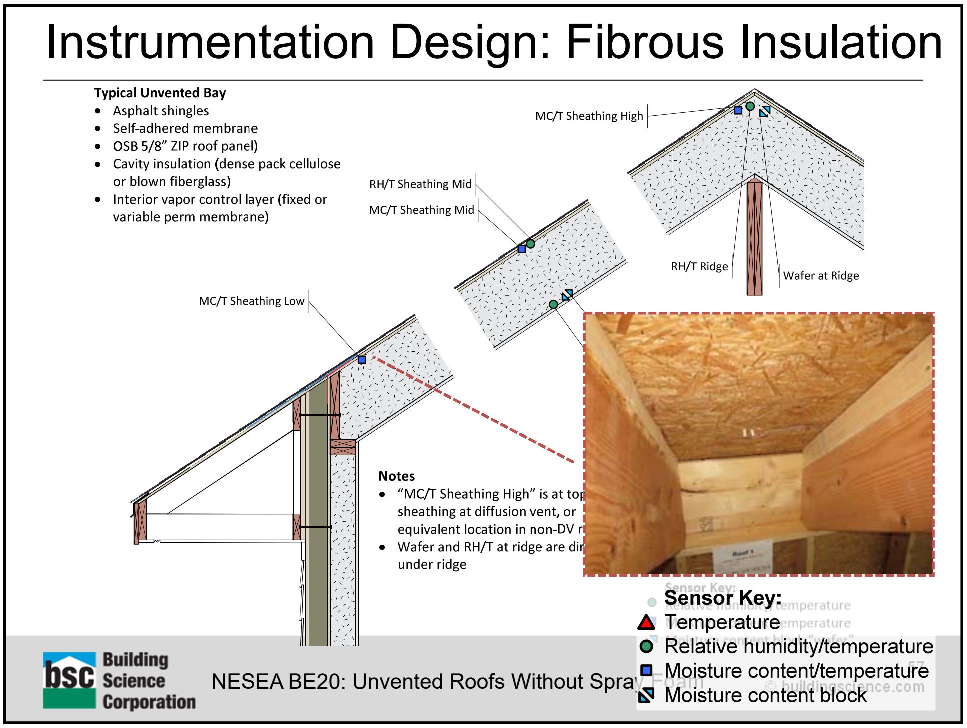
Data Results (Fiberglass Roofs)


Instrumentation Design: Fibrous Insulation
MC/T Sheathing High
RH/T Ridge
Wafer at Ridge
Wafer (South only)
RH/T Mid Interior
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
Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam

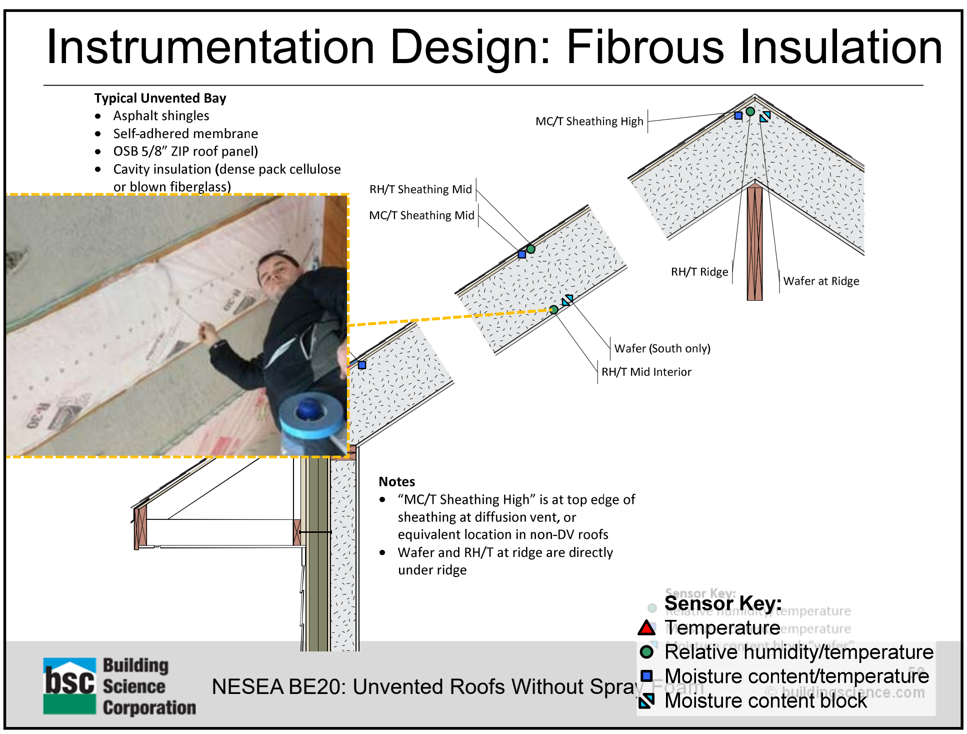
55


Instrumentation Design: Fibrous Insulation
Typical Unvented Bay
• Asphalt shingles
MC/T Sheathing High
RH/T Ridge
Wafer at Ridge
Wafer (South only)
RH/T Mid Interior
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
Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam

56

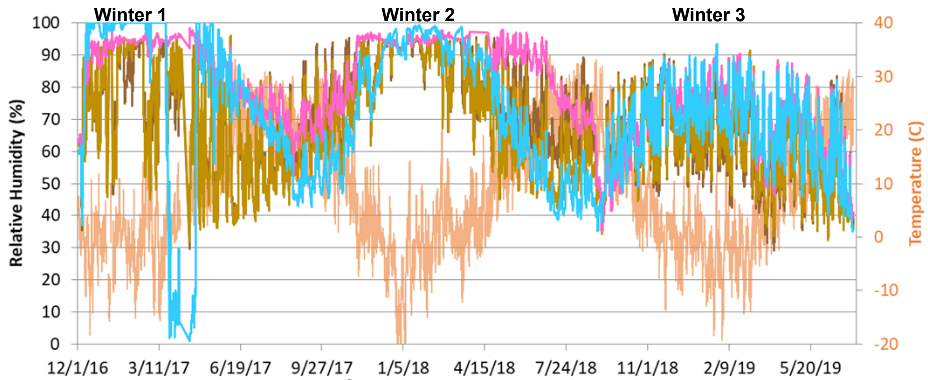

Instrumentation Design: Fibrous Insulation
Typical Unvented Bay
• Asphalt shingles
• Self-adhered membrane
• OSB 5/8” ZIP roof panel)
• Cavity insulation (dense pack cellulose or blown fiberglass)
• Interior vapor control layer (fixed or variable perm membrane)
MC/T Sheathing High
RH/T Sheathing Mid
MC/T Sheathing Mid
RH/T Ridge
Wafer at Ridge
MC/T Sheathing Low
Notes
• “MC/T Sheathing High” is at top
sheathing at diffusion vent, or
equivalent location in non-DV r
• Wafer and RH/T at ridge are dir
under ridge
Sensor Key:
Temperature
Relative humidity/temperature
Moisture content/temperature
Moisture content block
Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam

57


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)
MC/T Sheathing High
RH/T Sheathing Mid
MC/T Sheathing Mid
RH/T Ridge
Wafer at Ridge
Wafer (South only)
RH/T Mid Interior
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
Building Science Corporation
NESEA BE20: Unvented Roofs Without Spray Foam

58

Fiberglass Roofs: Ridge RH 24 hr Average



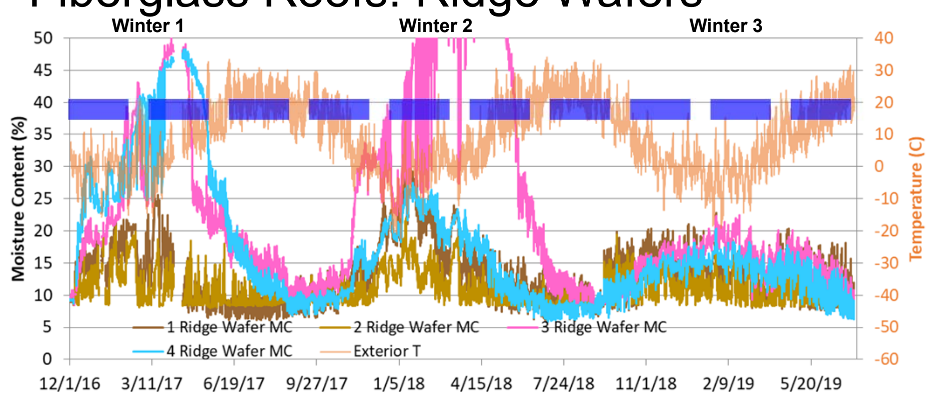
- 24 hr. averaging for readability
- Winter 1 compares DV vs. non-DV
- Winter 2 wetter than Winter 1
- Winter 3 much drier than Winter 2

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

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 59

59

Fiberglass Roofs: Ridge Wafers



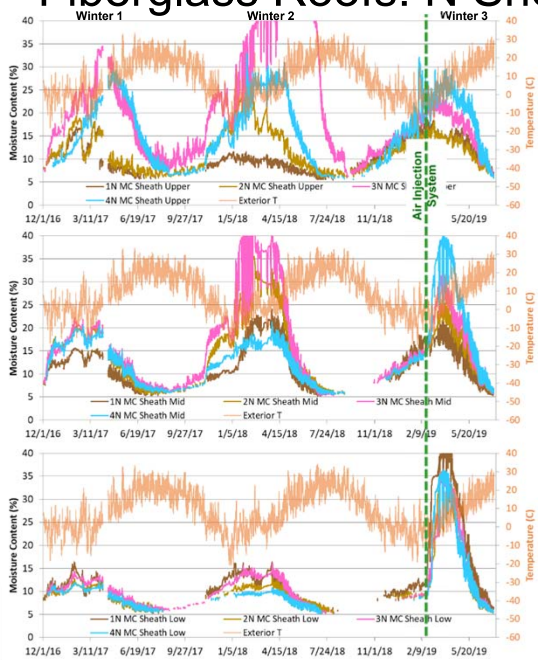
- Winter 1 Roof 3 & Roof 4 no DV
- Winter 1 vs Winter 2 (50% RH)
- Winter 3 also 50% RH-but low moisture
  - And wafer sensor replaced

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

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 60

60

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

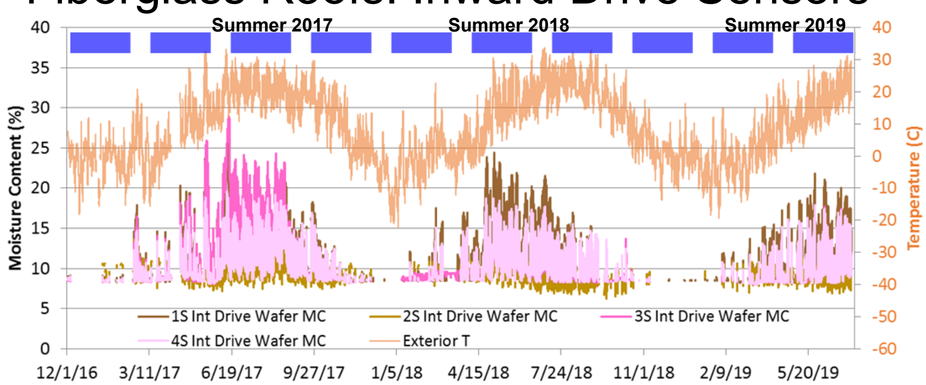
out Spray Foam

61

© buildingscience.com

61

Fiberglass Roofs: Inward Drive Sensors



- South side wafer sensors
- Summer 2018/2019: **Roofs 1** worst (fixed VB)
- All below 40-45% MC condensation level

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

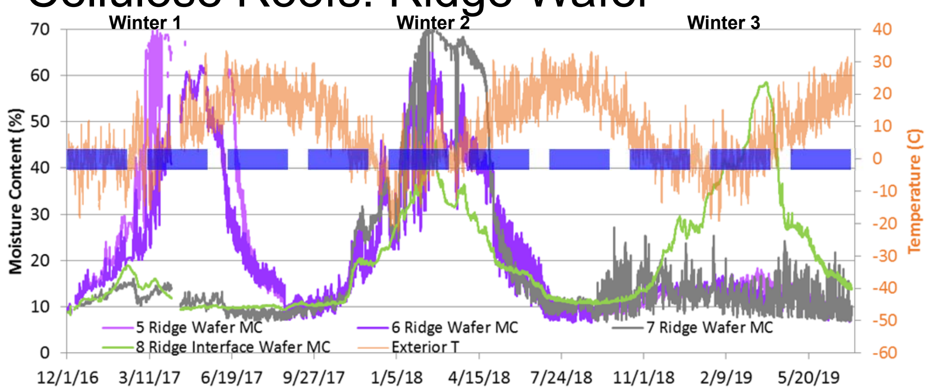
Building Science Corporation

NESEA BE20: Unvented Roofs Without Spray Foam

62

Data Results (Cellulose Roofs)

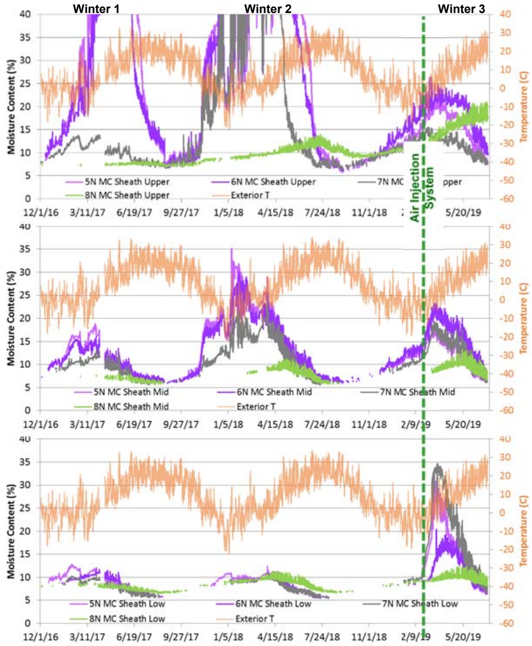
Cellulose Roofs: Ridge Wafer



- 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

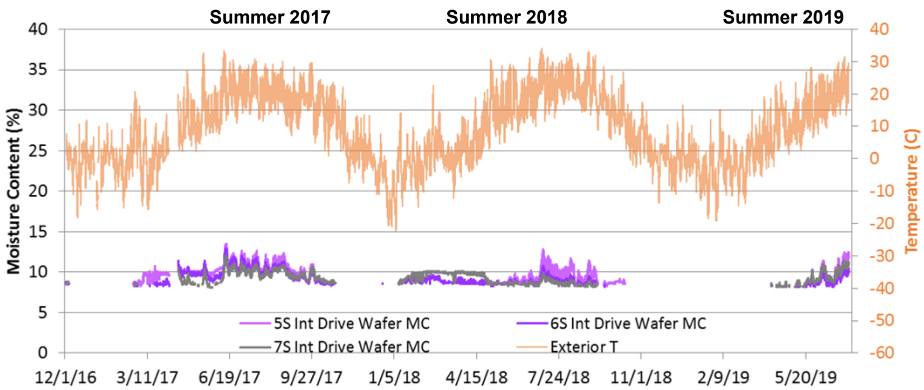
Cellulose Roofs: N Sheathing MCs



- 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

Cellulose Roofs: Inward Drives



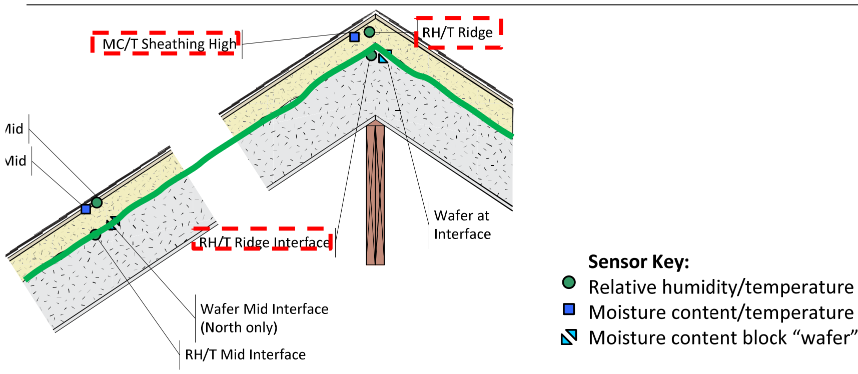
- Inward drive wafer, south
- All well below 15% MC (safe)

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

Hybrid Roofs (ccSPF & cellulose)

67

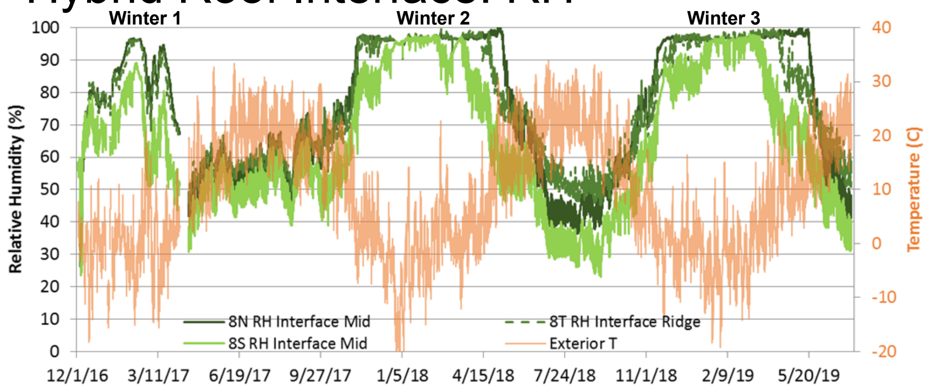
Rising RH Conditions @ Ridge



- Sensor at sheathing showed safe behavior
- Interface (ccSPF to cellulose) likely condensing surface

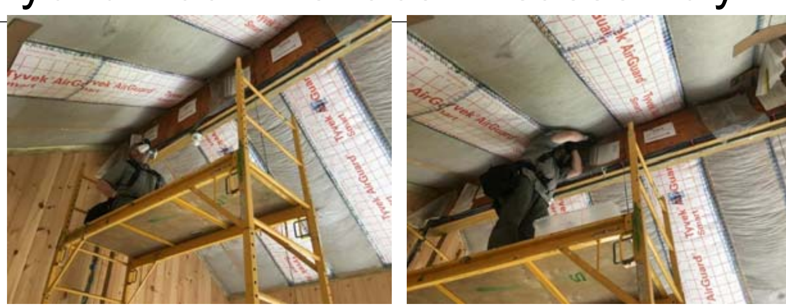
68

Hybrid Roof Interface: RH



- Winter 1: excursions to 90-95% RH
- Winters 2 & 3 (50% RH): 95-100% RH all winter
- No visible issues from interior (cellulose storage)

Hybrid Roof Interface: Disassembly



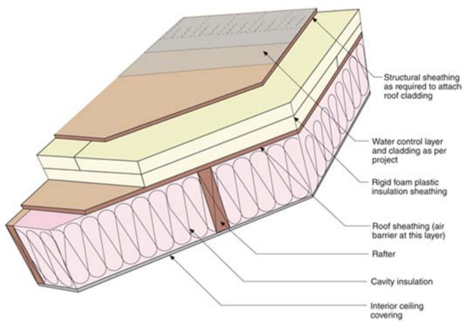
Conclusions and Recommendations

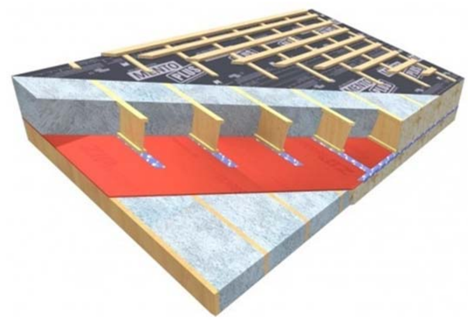
Recommendations and Further Work

- 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 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

Foam-free Unvented Roof Options

- Fibrous + continuous exterior insulation outside air barrier, per § R806.5
  - Mineral fiber, wood fiber board, etc.
- Ventilated cavity outboard of vapor-permeable air/water control membrane

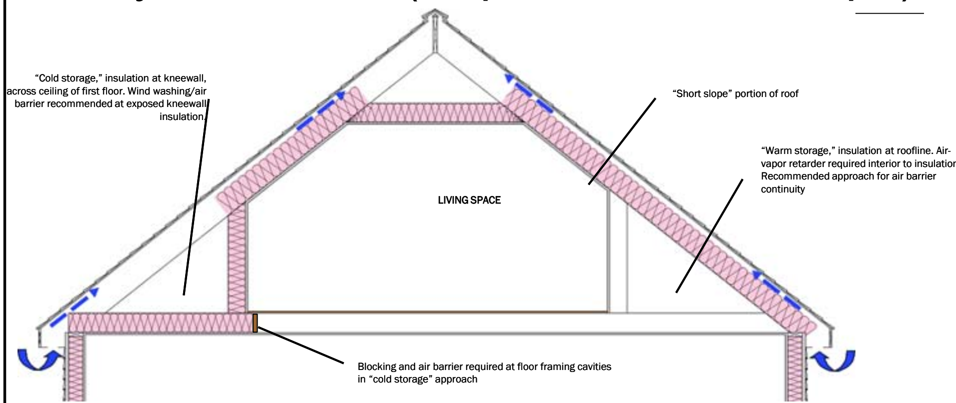




Recommendations and Further Work

- 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)

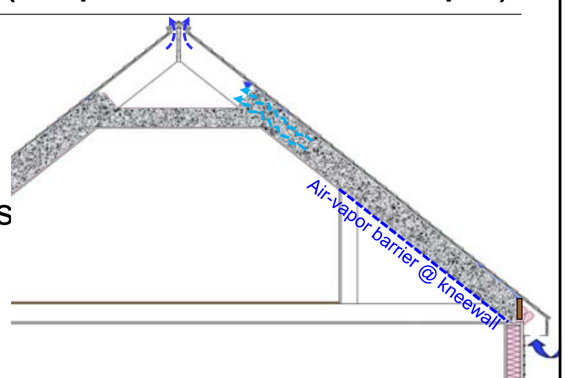


- Possible application to retrofitting "short slope" of kneewall attic geometry
- Eliminates "chute," possible to retrofit longer runs

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 75

75

Story and a Half (Cape Cod Short Slope)



- Higher R-value in limited cavity
- Not <u>proven</u> 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

Building Science Corporation NESEA BE20: Unvented Roofs Without Spray Foam 76

76

Questions?

Kohta Ueno
kohta [at] buildingscience [dot] com

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

NAIMA
NORTH AMERICAN INSULATION MANUFACTURERS ASSOCIATION

NU-WOOL®
PREMIUM CELLULOSE INSULATION
GREEN Since 1949

DÖRKEN

DUPONT®
The miracles of science™

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building America®
U.S. Department of Energy

OWENS CORNING®