Kohta Ueno

Unvented Roofs Without Spray Foam:

The Latest Building America Research

Building Science Corporation

BUILDINGENERGY BOSTON
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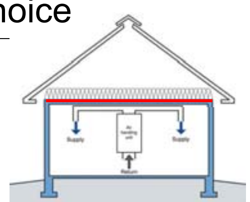
Conference • Trade Show of the Northeast Sustainable Energy Association (NESEA)

Background

Ventilated Attics—Best Choice

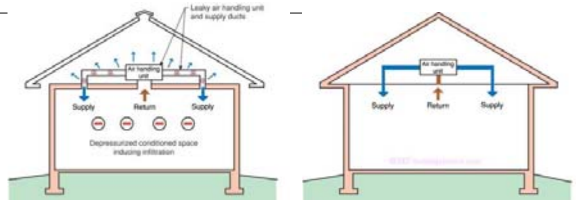
- Roof sheathing dries to ventilated attic-moisture safe
- Interior moisture (air leaks) ventilated away in winter
- Air sealing at ceiling critical for best performance
  - (e.g., spray foam air barrier, detail with sealant)



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

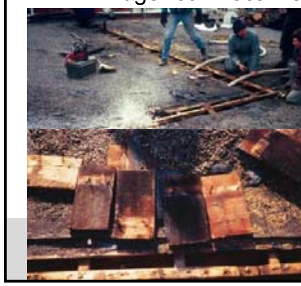

Unvented Roofs & HVAC Placement



- 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

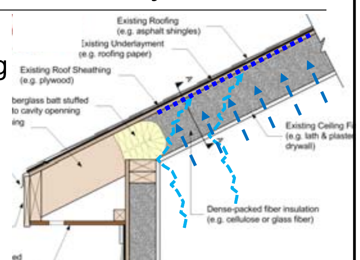
Fibrous Insulation Unvented Roofs

- 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)



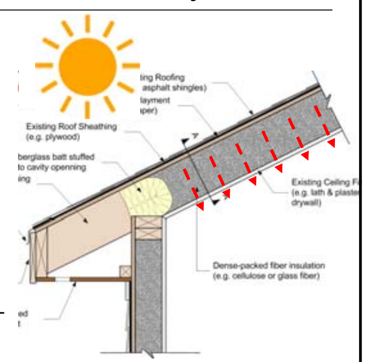
Why Unvented + Fibrous Risky?

- 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)

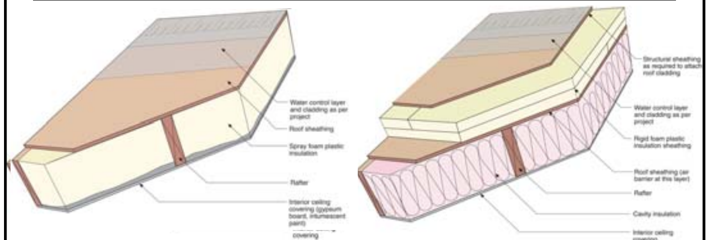


Why Unvented + Loose Fill Risky?

- 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

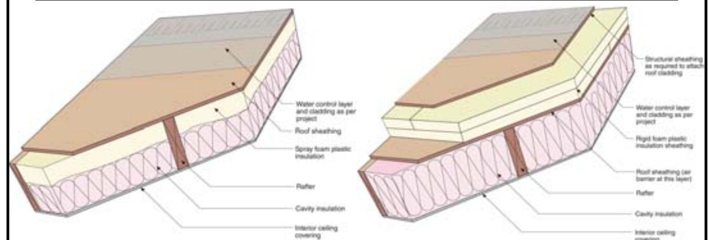


Spray Foam/Exterior Insulation Roofs



- 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

Spray Foam/Exterior Insulation Roofs



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Why Fibrous Fill Unvented Roofs?

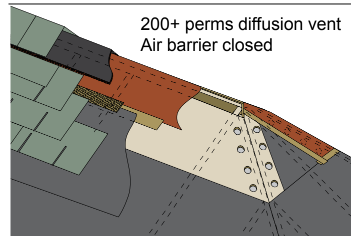
- Unvented roofs without spray/board foams could reduce costs and increase market penetration… IF moisture damage risks are addressed
- Retrofit opportunities (existing uninsulated living space at roof line, without removing finishes)

Previous Building America Research

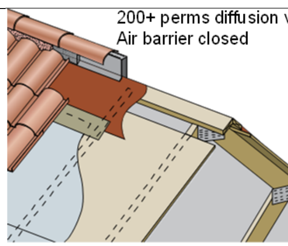
Previous Building America Research

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

Diffusion Vent Prototype (Houston)

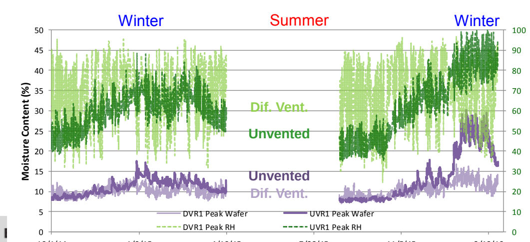


Diffusion Vent Prototype (Orlando-Tile)



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



Orlando Decommissioning

- Some bays still full
- Others fiberglass settling and minor mold growth

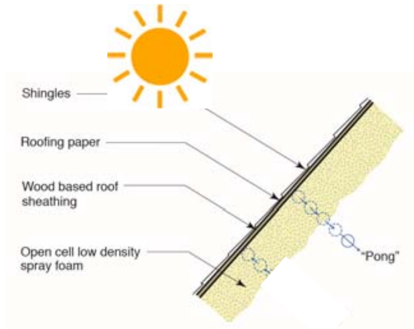
“Ridge Rot” and Moisture Buoyancy

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

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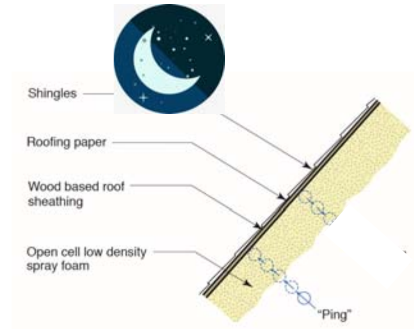

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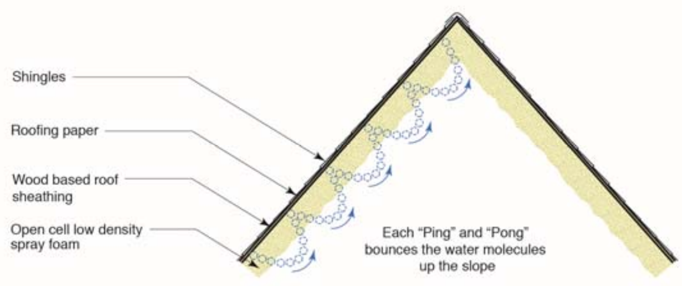

- "Gas separation process similar to pressure swing adsorption"
- Solar-powered moisture concentration machine

Orlando Decommissioning

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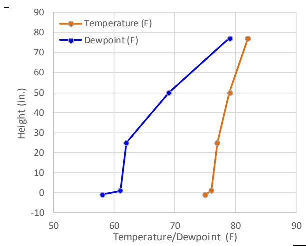
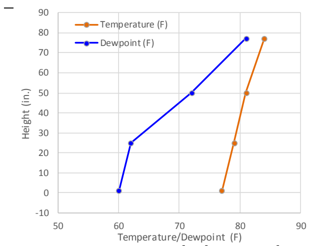




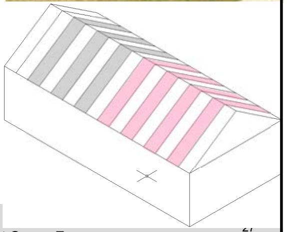
- Temperature and dewpoint stratification directly measured
- 90%+ RH near ridge
- System is not in equilibrium

Test Hut Approach & Construction

Test Hut Experimental Approach

- Climate Zone 5A test hut
- Eight north-south roof bays
- ±R-50 (14-¾" framing, 2012 IECC)
- Test variables (Winter 1 2016-2017):
  - Vapor retarder: variable perm vs. fixed perm
  - Diffusion vent at ridge vs. no diffusion vent
  - 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



Test Hut Construction

- Walls 2x6, ccSPF, ZIP sheathing, 4" Roxul, 1x3s
- Roof cavity 14-¾" deep, ~R-50 (2x12 + 2x4)
- 8:12 roof pitch

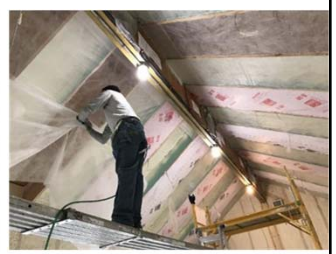
Test Hut Construction

- Adhered membrane connection roof-to-wall
- Overhangs (eave & rake) attached outboard of air barrier layer
- Self-adhered membrane on entire roof

Test Hut Construction

- Roof bays 24” o.c.
- Guard bays between experimental bays (“flash and blow” ccSPF + cellulose)
- Fluid-applied air and vapor barrier at guard bays

Test Hut Construction



- Flash and blow bays (ccSPF shown)
  - ccSPF completes air barrier between bays, wiring holes
- Insulation netted & blown (fiberglass complete in image; cellulose installation)

Test Hut Construction

- Interior air barrier & vapor retarder membrane
- Double tape seal (double-sided tape + housewrap tape)

Test Hut Construction


- Space conditioning with MSHP (heating & cooling)
- Ventilation via wall-mounted exhaust fan
- Solar control with roll-down shades (all-south glazing)

Test Hut Construction

- Instrumentation completion

Test Hut Construction

- ccSPF in guard bays and walls

Test Hut Construction

- Fibrous insulation installed

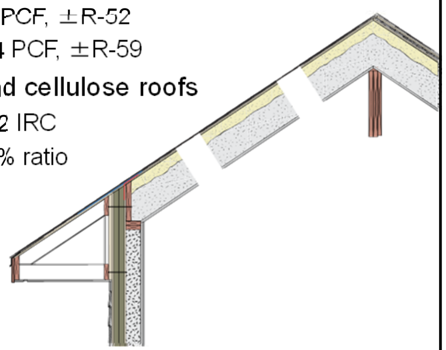
Test Hut Construction

- Interior air/vapor control installed

Experimental Approach

Experimental Approach: Insulation Mat'ls

- Rafter bay insulation materials
  - Cellulose @ 3.5 PCF, ±R-52
  - Fiberglass @ 1.4 PCF, ±R-59
- Hybrid ccSPF and cellulose roofs
  - § R806.5 in 2012 IRC
  - ±R-63, 40%-60% ratio



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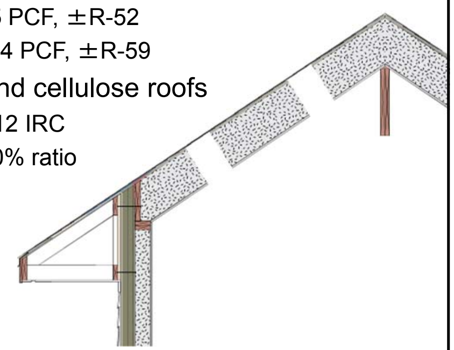
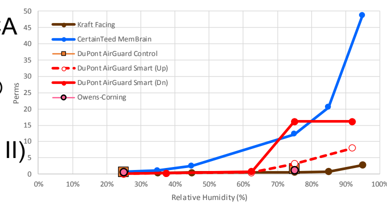


Experimental Approach: Vapor Control

- Fixed perm:
  - Owens Corning HPCA (0.8 dry/1.4 wet)
  - DuPont™ AirGuard® Control (0.7 perm)
  - About 1 perm (Class II)
- Variable perm
  - CertainTeed MemBrain
  - DuPont™ AirGuard Smart Gen2



Experimental Approach: Diffusion Vent

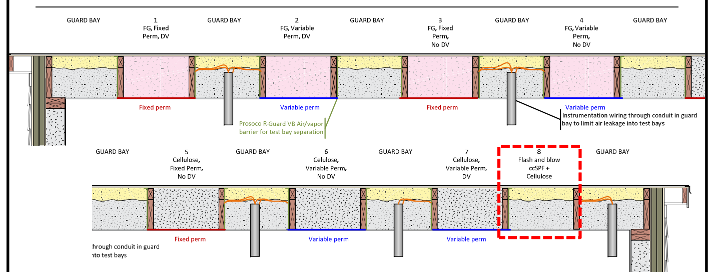
- ±5 in. opening (fits under typical ridge cap)
- Cosella-Dörken Delta-Foxx
  - 214 perms dry cup
  - 550 perms wet cup

Experimental Approach: Test Roof IDs

Roof #	Insulation	Interior VB	Diffusion Vent
1	Fiberglass	Fixed perm	Yes
2	Fiberglass	Variable perm	Yes
3	Fiberglass	Fixed perm	No
4	Fiberglass	Variable perm	No
5	Dense pack cellulose	Fixed perm	No
6	Dense pack cellulose	Variable perm	No
7	Dense pack cellulose	Variable perm	Yes
8	ccSPF + cellulose "flash and blow" §R806.4	Latex paint on GWB	No

- 4 fiberglass bays
- 3 cellulose bays
- 1 "flash and blow" control comparison

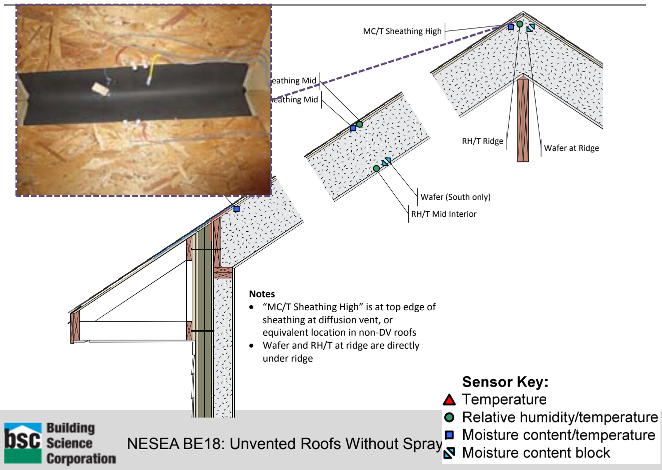
Experimental Approach: Roof Section



- 4 fiberglass bays
- 3 cellulose bays
- 1 "flash and blow" control comparison

Instrumentation Design

Instrumentation Design: Fibrous Insulation



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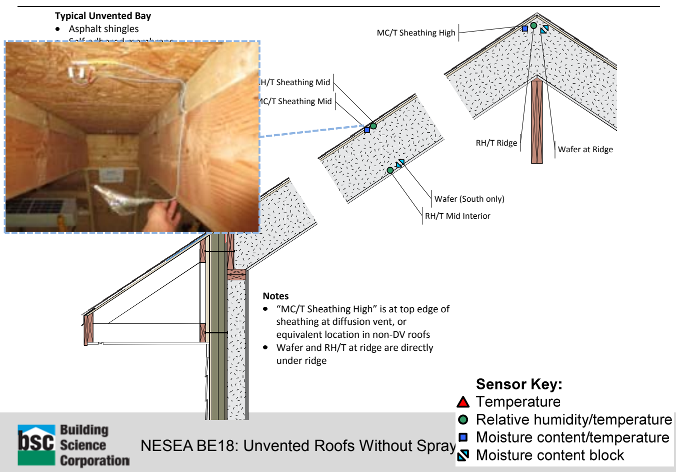

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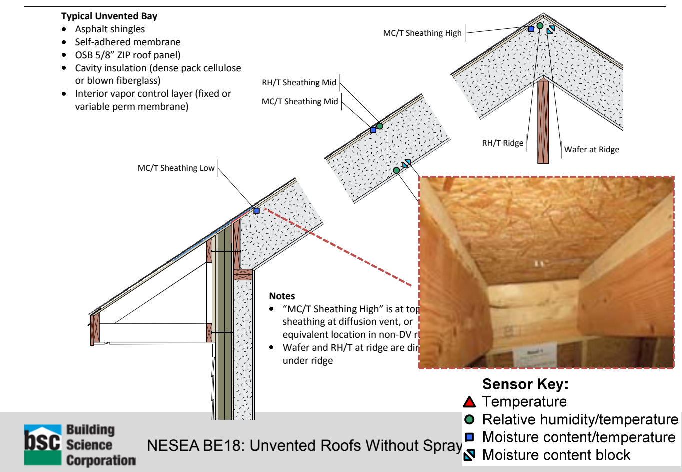

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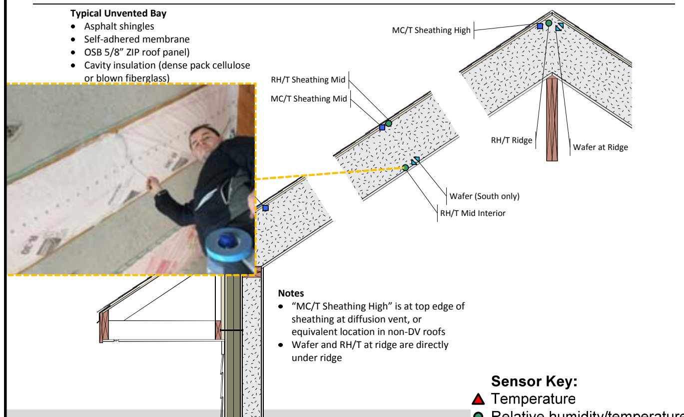
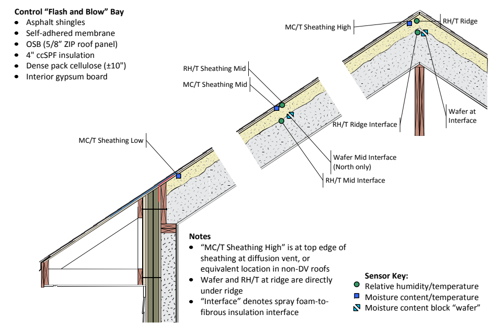


Instrumentation Design: Flash & Blow



- "Flash and blow" roof: instruments shifted to ccSPF/cellulose interface

Instrumentation Design: Interior T/RH

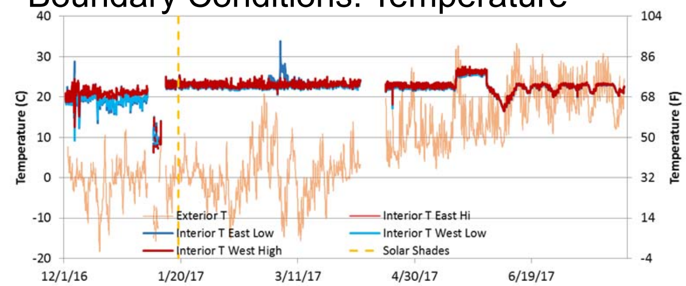

- Interior temperature/RH measurements
  - Low/high, east/west (4 total)

Instrumentation Design: Exterior


- Exterior temperature/RH (north side)
- Solar radiation (north and south roofs)
- Data collected hourly on Campbell CR1000

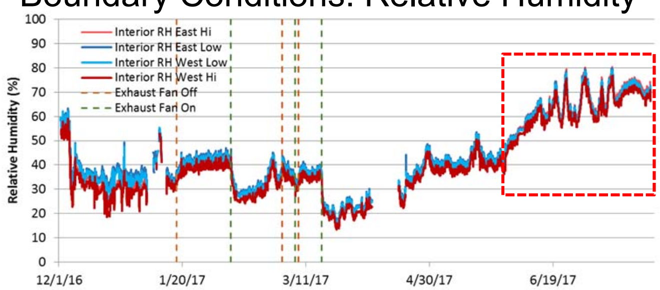
Year One Results: Boundary Conditions

Boundary Conditions: Temperature



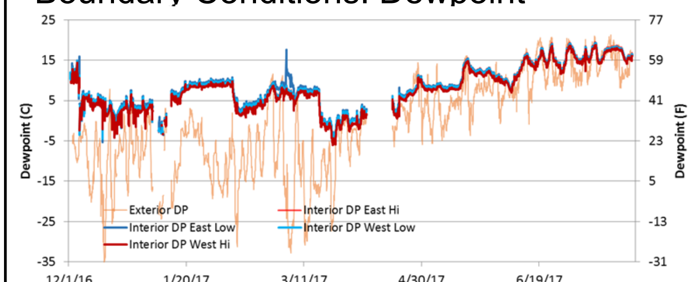
- Data from December 2016-July 2017
- Loss of data in January (power loss, flood), April (GFCI tripping)

Boundary Conditions: Relative Humidity



- RHs in winter 25% to 45%
- Exhaust fan operation affects interior RH levels and building depressurization
- Interior RH in summer 60-80%: MSHP cooling

Boundary Conditions: Dewpoint



- Dewpoint variations→exterior DP, exhaust fan
- Wintertime DP ~10 C/50 F during non-fan periods
- DP tracking exterior in summertime

Year One Results: Fiberglass Roofs

Fiberglass Roofs: Color Codes

Roof #	Insulation	Interior VB	Diffusion Vent
1	Fiberglass	Fixed perm	Yes
2	Fiberglass	Variable perm	Yes
3	Fiberglass	Fixed perm	No
4	Fiberglass	Variable perm	No
5	Dense pack cellulose	Fixed perm	No
6	Dense pack cellu		No
7	Dense pack cellu		Yes
8	ccSPF + cellulose and blow" §R8(	/B	No

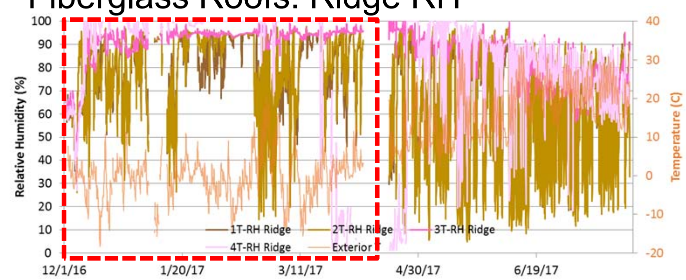
Roof	Short Name
1	FG-VB-DV
2	FG-SVR-DV
3	FG-VB-nDV
4	FG-SVR-nDV

- VB = fixed perm vapor retarder
- SVR = variable perm "smart" vapor retarder
- nDV/DV = no diffusion vent/diffusion vent

Interpreting the Data (Moisture Risks)

- Relative Humidity (RH)
  - 80% RH: conservative/unrealistic threshold
  - 90%-100% RH: mold risks, but temperature effects
  - Condensation (liquid water): mold growth kickstarter
- Wood Moisture Content (MC)
  - Under 20% MC safe
  - 25%-30% MC ideal for mold growth
  - 28%+ MC decay fungi…. BUT
  - Previous work (double stud walls): high MCs, no damage
- Mold Index
  - Combines RH, temperature, and time

Fiberglass Roofs: Ridge RH



- **Roof 3 (nDV)** > 90% RH most of winter
- **Roof 4 (nDV)** 100% RH, then failed
- **Roofs 1 & 2 (DV)** RHs swing, not as high
- DV roofs remain drier than nDV

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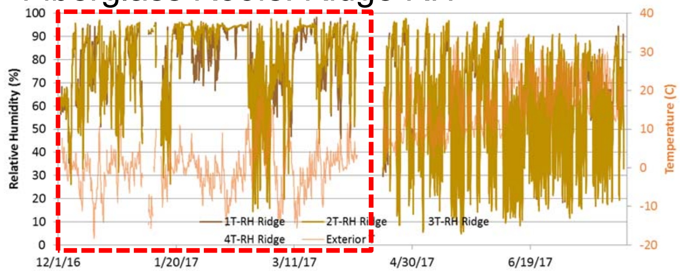
Fiberglass Roofs: Ridge RH



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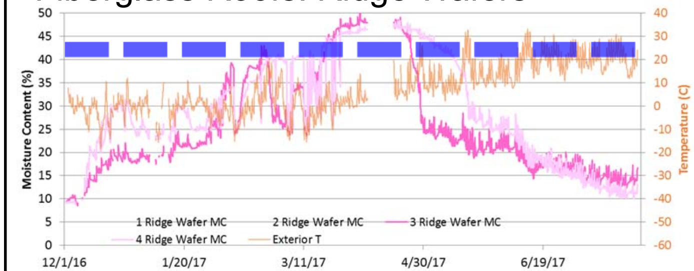
Fiberglass Roofs: Ridge Wafers



- **Roofs 3 & 4 (nDV)** > 40% MC
  - Immersed wafer calibrated ~40-45% MC
- **Roofs 1 & 2 (DV)** stay drier <25%
- DV: localized drying at ridge-accumulation point

Roof	Short Name
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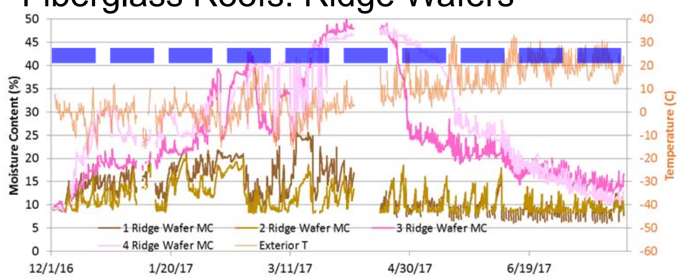
4	FG-SVR-nDV

Fiberglass Roofs: Ridge Wafers



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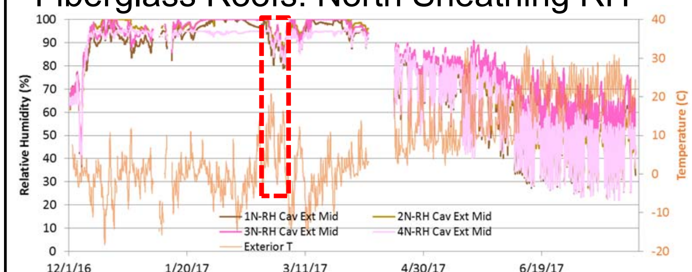
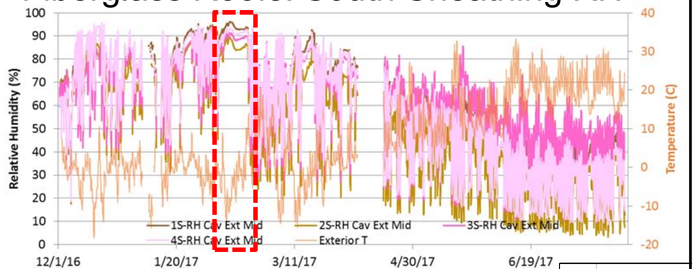
Fiberglass Roofs: North Sheathing RH



- All roofs 90-100% most of winter
- Dip in RH during warmer weather
- Diffusion vent-localized protection only?
- Interface RH falls into spring-summer

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

Fiberglass Roofs: South Sheathing RH



Roof	Short Name
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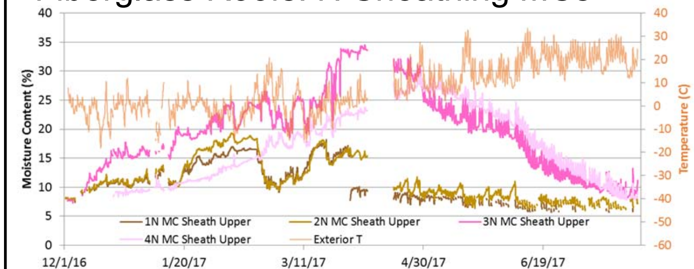
- S roofs drier than N roofs (solar warming)
- Diurnal variations/swings (solar gain)
  - Stable periods = snow cover
- S drier than N into summer: 10-50% S/30-70% N

Fiberglass Roofs: N Sheathing MCs



- Roofs 3 & 4 (nDV) peaks over 25-30% MC
  - SVR drier than VB, lower peak
- Roofs 1 & 2 (DV) peaks below 20% MC
  - By spring, ~5-10% vs. 20%+ at 3 & 4

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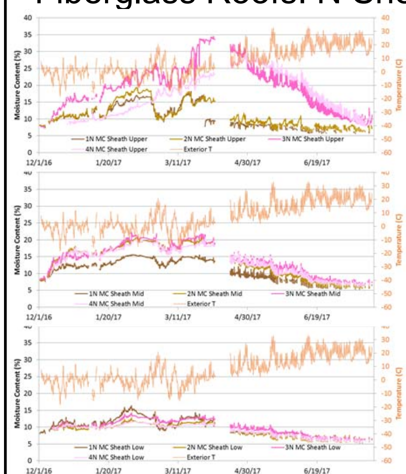
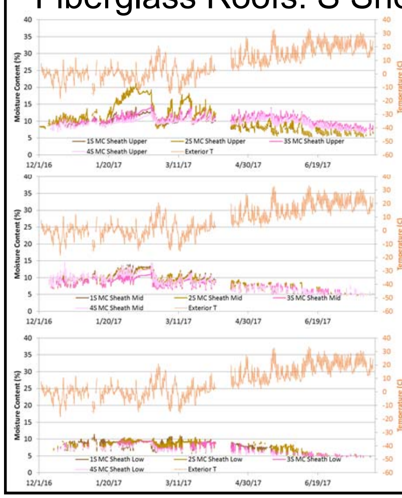
Fiberglass Roofs: N Sheathing MCs



- North sheathing MCs
- High-Mid-Low
- Gradient of MCs (highest near ridge, lowest near eaves)
- Build roofs with only lower halves?
- Diffusion vent localized drying only
  - Mid height graph
  - Roof 2 like 3 & 4

Fiberglass Roofs: S Sheathing MCs



- South sheathing MCs all drier than corresponding north
- Only one sensor over 15% MC
- Build only south-facing unvented roofs?

Roof	Short Name
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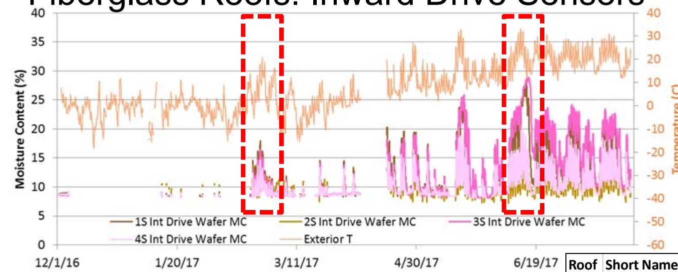
3	FG-VB-nDV
4	FG-SVR-nDV

Year One Results: Fiberglass Inward Drive

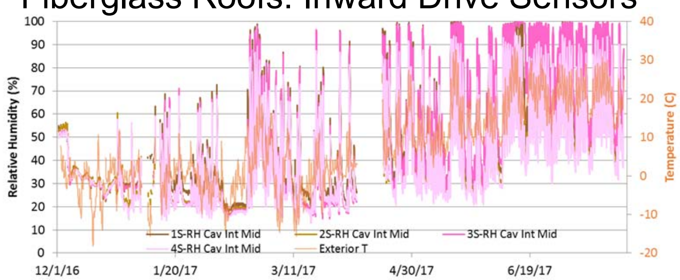
Fiberglass Roofs: Inward Drive Sensors



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

- South side wafer sensors
- Tracks to outdoor T-MC spikes
- Roofs 1 & 3 (VB) stay wetter than 2 & 4 (SVR)
- Peaks 25-30%, not condensation

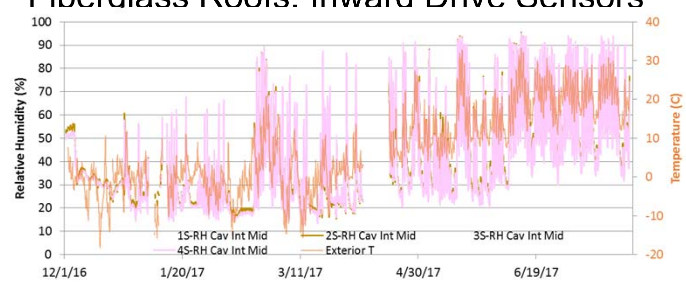
Fiberglass Roofs: Inward Drive Sensors



- South side RH sensors
- Roofs 1 & 3 (VB) stay wetter than 2 & 4 (SVR)
- SVRs do what they're supposed to do

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

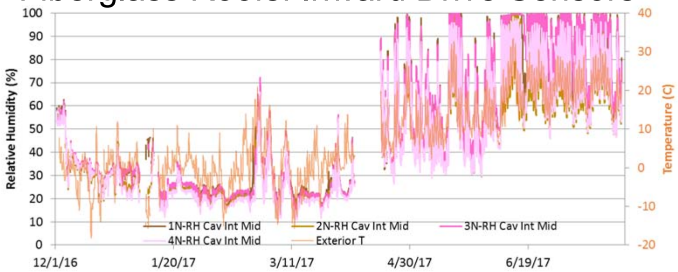
Fiberglass Roofs: Inward Drive Sensors



- South side RH sensors
- Roofs 1 & 3 (VB) stay wetter than 2 & 4 (SVR)
- SVRs do what they're supposed to do

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

Fiberglass Roofs: Inward Drive Sensors



- North side RH sensors
- Roofs 1 & 3 (VB) stay wetter than 2 & 4 (SVR)
- Arguably more time @ 100% RH?

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

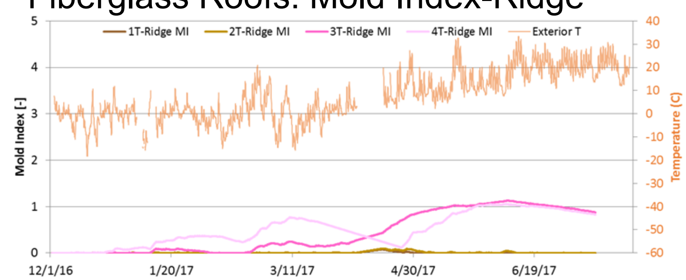
Year One Results: Fiberglass Mold Index

Fiberglass Roofs: Mold Index Calculations

- Viitanen Mold Index (time, temp., RH, substrate)
- Consistent with ASHRAE 160 Addendum e (2016)
- Mold index over 3.0 (visible mold growth 10%) constitutes failure

Index	Description of Growth Rate
0	No growth
1	Small amounts of mold on surface (microscope), initial stages of local growth
2	Several local mold growth colonies on surface (microscope)
3	Visual findings of mold on surface, < 10% coverage, or **< 50% coverage of mold (microscope)**
4	Visual findings of mold on surface, 10%–50% coverage, or **> 50% coverage of mold (microscope)**
5	Plenty of growth on surface, > 50% coverage (visual)
6	Heavy and tight growth, coverage about 100%

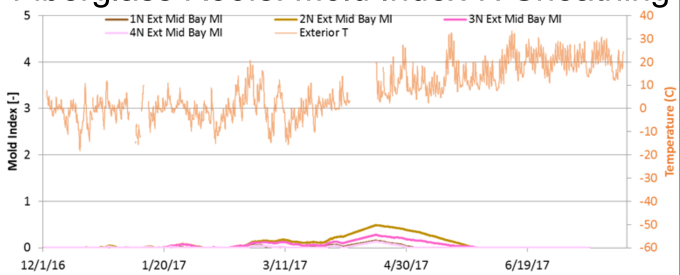
Fiberglass Roofs: Mold Index-Ridge



- Roofs 3 & 4 RH ~100% most of winter
- Roof 4 RH sensor failed mid March 2017
  - Artificial decline shown
- Roofs 1 & 2 (DV) boring and safe

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

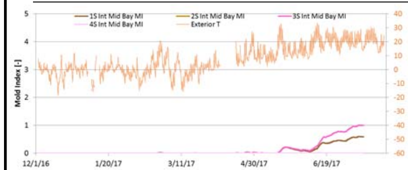
Fiberglass Roofs: Mold Index-N Sheathing

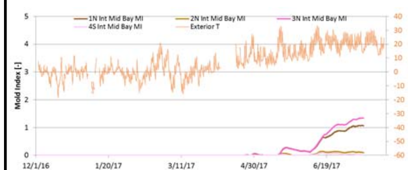


- All mold indices under 1
- Rise occurred spring (temperatures warming)
- South not plotted (even less activity)

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

Fiberglass Roofs: Mold Index-Inward Drive





- Roofs 1 & 3 (fixed VB) show rise
- Roofs 2 & 4 (SVR) remain near 0
- North shows higher peaks than south
  - Stored moisture?

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

Conclusions: Fiberglass

- All roofs show mold indices under 3.0: would pass ASHRAE 160… BUT
- Ridge at Roofs 3 & 4 (no diffusion vent)
  - Wafers indicating condensation
  - Sheathing MCs > 25-30%
- Inward drive sensors Roofs 1 & 3 (fixed VB)
  - Extended 100% RH peaks
- Roof 2 (smart vapor retarder + diffusion vent) overall safest
- Winter 1 of 3 test results

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

Year One Results: Cellulose Roofs

Cellulose Roofs: Color Codes

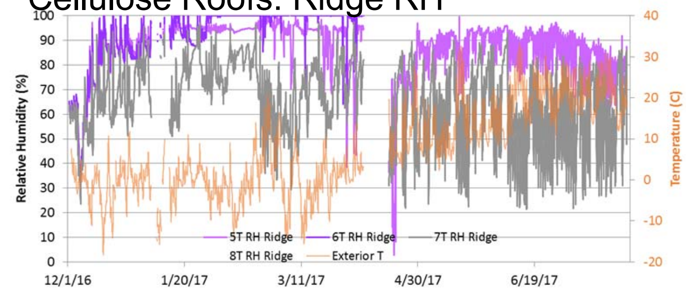
Roof #	Insulation	Interior VB	Diffusion Vent
1	Fiberglass	Fixed perm	Yes
2	Fiberglass	Variable perm	Yes
3	Fiberglass	Fixed perm	No
4	Fiberglass	Variable perm	No
5	Dense pack cellulose	Fixed perm	No
6	Dense pack cellulose	Variable perm	No
7	Dense pack cellulose	Variable perm	Yes
8	ccSPF + cellulose "flash and blow" §R806.4	Latex paint on GWB	No

- VB = fixed perm vapor retarder
- SVR = variable perm "smart" vapor retarder
- nDV/DV = (no) diffusion vent

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Building Science Corporation NESEA BE18: Unvented Roofs Without Spray Foam 81 © buildingscience.com

Cellulose Roofs: Ridge RH

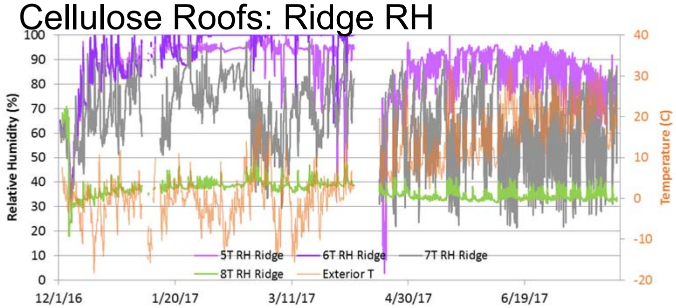


- **Roofs 5 & 6 (nDV)** RHs 95-100% RH thru winter
  - Roof 6 RH sensor failure 4/2017
- **Roof 7 (DV)** RHs seldom over 90% RH
- **Roof 8 (ccSPF + cell)** 30-40% RH

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Building Science Corporation NESEA BE18: Unvented Roofs Without Spray Foam 82 © buildingscience.com

Cellulose Roofs: Ridge RH

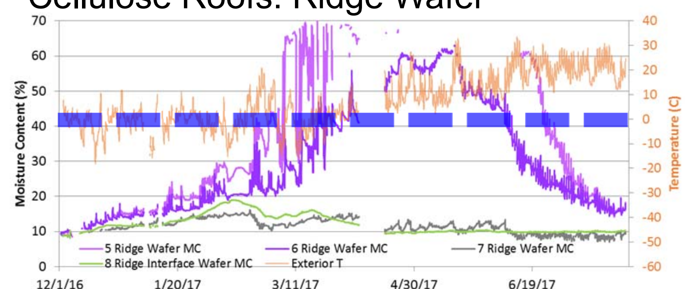


- **Roofs 5 & 6 (nDV)** RHs 95-100% RH thru winter
  - Roof 6 RH sensor failure 4/2017
- **Roof 7 (DV)** RHs seldom over 90% RH
- **Roof 8 (ccSPF + cell)** 30-40% RH

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Building Science Corporation NESEA BE18: Unvented Roofs Without Spray Foam 83 © buildingscience.com

Cellulose Roofs: Ridge Wafer

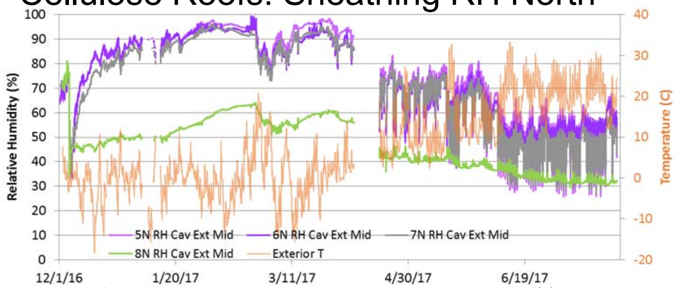


- **Roofs 5 & 6 (nDV)** over 60% MC (?!?)
  - Condensation, migration of borates, not real MC
- **Roof 7 (DV)** wafer peak under 15% MC
- **Roof 8 (ccSPF + cell)** under 20% MC

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Building Science Corporation NESEA BE18: Unvented Roofs Without Spray Foam 84 © buildingscience.com

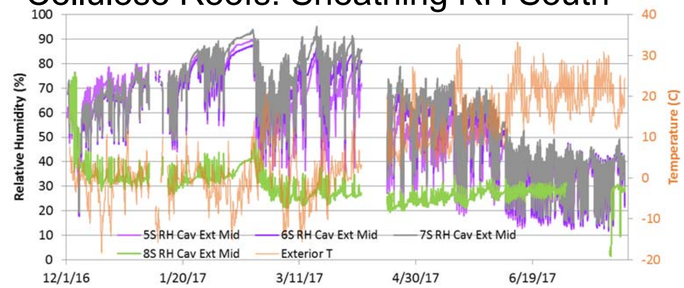
Cellulose Roofs: Sheathing RH North



- **Roofs 5, 6**, 7, mostly same RHs, 90-100% peaks
  - Lower RH peaks than fiberglass roofs
  - Localized drying at DV, not mid-height
- **Roof 8** low RH, protected by ccSPF

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

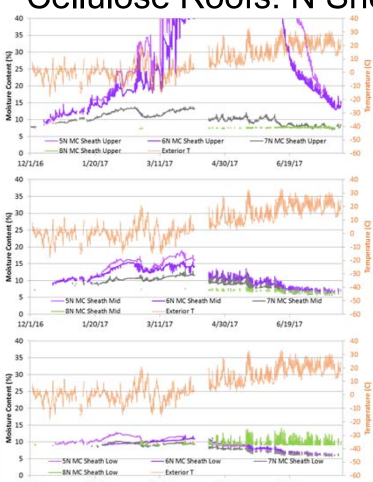
Cellulose Roofs: Sheathing RH South



- Drier conditions south vs. north
- Diurnal variations
  - Solar gain, snow cover effects

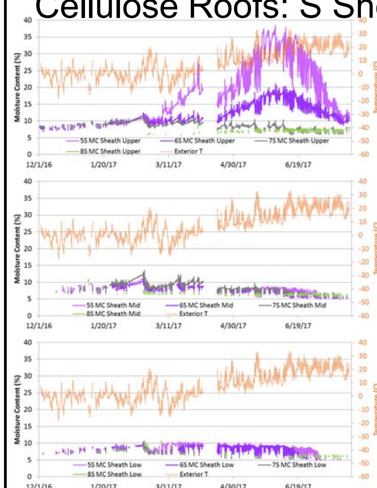
Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Cellulose Roofs: N Sheathing MCs



- North sheathing MCs
- High-Mid-Low
- Upper: condensation & borate migration
- Away from ridge (low, mid) MCs in safe range (gradient)
- **Roof 7 (DV)** and **Roof 8 (ccSPF + cell)** consistently dry

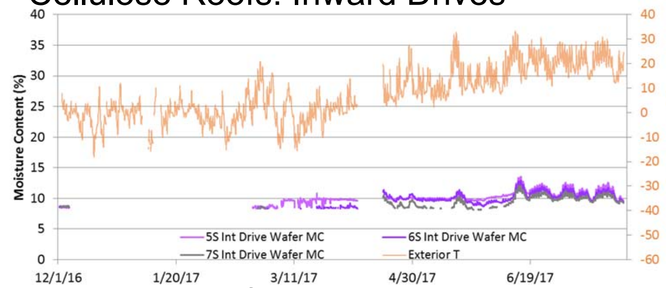
Cellulose Roofs: S Sheathing MCs



- South sheathing MCs
- South consistently drier than north
- Upper MCs distorted by borate migration

Year One Results: Cellulose Inward Drive

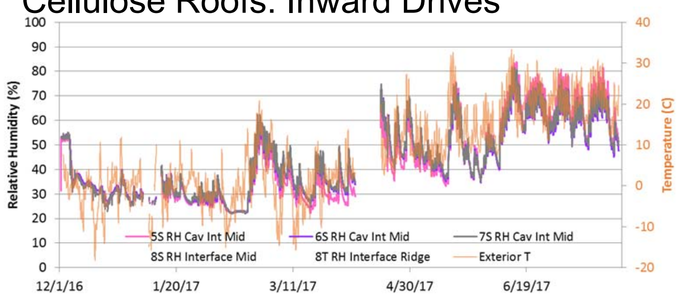
Cellulose Roofs: Inward Drives



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

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

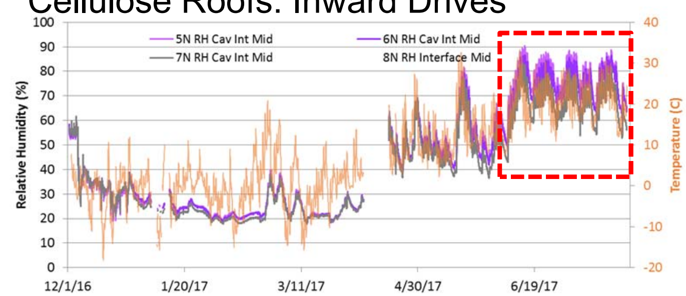
Cellulose Roofs: Inward Drives



- Inward drive RH, south
- Peaks barely over 80% RH

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

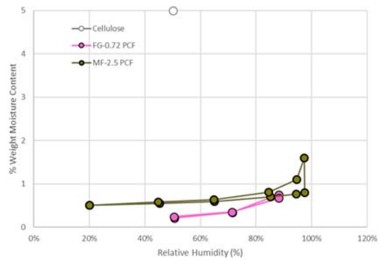
Cellulose Roofs: Inward Drives



- Inward drive RH, north
- Peaks mostly under 90% RH
- Higher than south-stored moisture?

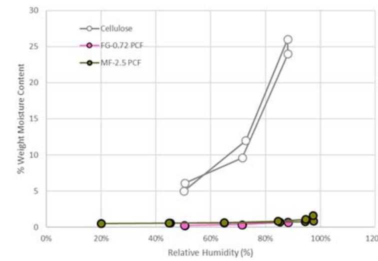
Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Cellulose vs. Fiberglass Moisture Storage



- ASHRAE Fundamentals data (Kumaran, Burch)
- Moisture buffering/storage ability of cellulose
- Raw data, shown by weight (not volume)

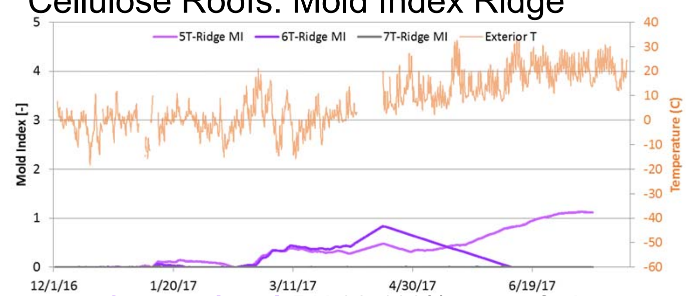
Cellulose vs. Fiberglass Moisture Storage



- ASHRAE Fundamentals data (Kumaran, Burch)
- Moisture buffering/storage ability of cellulose
- Raw data, shown by weight (not volume)

Year One Results: Cellulose Mold Index

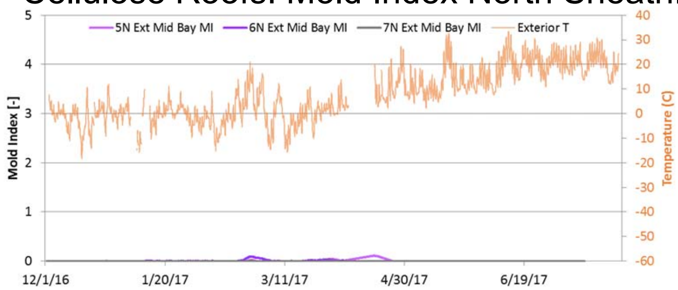
Cellulose Roofs: Mold Index Ridge



- **Roofs 5 & 6 (nDV)** RH 90-100% most of winter
- **Roofs 6** RH sensor failed mid April 2017
  - Artificial decline shown

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

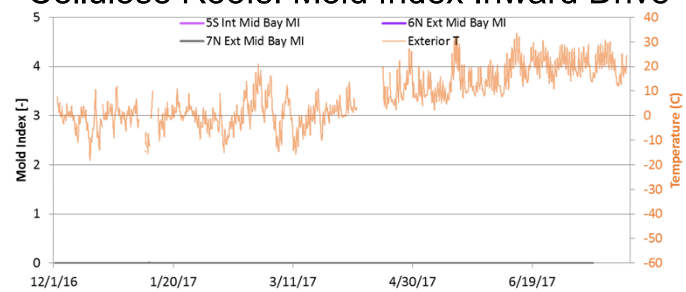
Cellulose Roofs: Mold Index North Sheath.



- RH peaks 90-100% much of winter
- Mold indices all low
- South even drier-lower risk

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Cellulose Roofs: Mold Index Inward Drive



- RH south side inward drive
- Not misplotted-max mold index 0.004

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Conclusions: Cellulose

- All roofs show mold indices under 3.0: would pass ASHRAE 160… BUT
- Ridge at **Roofs 5 & 6** (no diffusion vent)
  - Wafers indicating condensation
  - Sheathing MCs high (uncertainty-borate migration)
- Inward drive sensors non-issue in cellulose roofs
- **Roof 7** (smart vapor retarder + diffusion vent) overall safest
- **Roof 8 (ccSPF + cell)** boring and safe (did not bother calculating Mold Index)

Roof	Short Name
5	Cell-VB-nDV
6	Cell-SVR-nDV
7	Cell-SVR-DV
8	ccSPF-Cell

Year Two: Humidification and New Assemblies

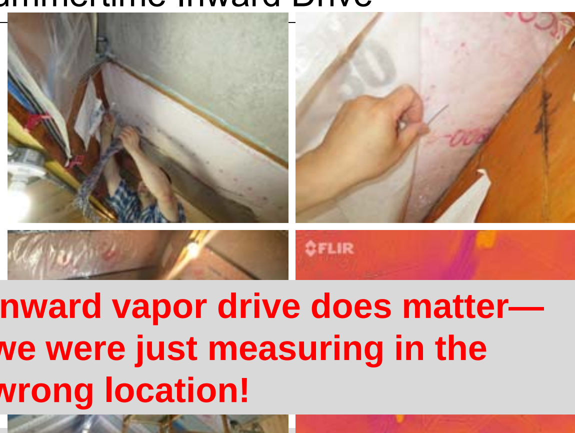
New Assemblies-Replace Poor Performers

tDV = "tight" diffusion vent (25 perms vs. 300+ perms)
sDV = "small" diffusion vent (2" wide vs. 6" wide)

Roof	Insulation	Interior VB	Diffusion Vent	Short Name
1	Fiberglass	Fixed perm (OC 1 perm)	6"/±300 perm (Yes)	FG-VB-DV
2	Fiberglass	Variable perm (MemBrain)	6"/±300 perm (Yes)	FG-SVR-DV
3	Fiberglass	**Variable perm (MemBrain)** ~~Fixed perm (OC 1 perm)~~	**2"/±25 perm** ~~No~~	FG-**SVR-tDV** ~~FG-VB-nDV~~
4	Fiberglass	Variable perm (MemBrain)	**2"/±300 perm** ~~No~~	FG-SVR-**sDV** ~~FG-SVR-nDV~~
5	Dense pack cellulose	**Variable perm (DuPont Variable)** ~~Fixed perm (OC 1 perm)~~	**2"/±25 perm** ~~No~~	Cell-**SVR-tDV** ~~Cell-VB-nDV~~
6	Dense pack cellulose	Variable perm (DuPont Variable)	**2"/±300 perm** ~~No~~	Cell-SVR-**sDV** ~~Cell-SVR-nDV~~
7	Dense pack cellulose	Variable perm (DuPont Variable)	6"/300 perm (Yes)	Cell-SVR-DV
8	ccSPF + cellulose "flash and blow"	None	No	ccSPF-Cell

Summertime Inward Drive

Summertime Inward Drive



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

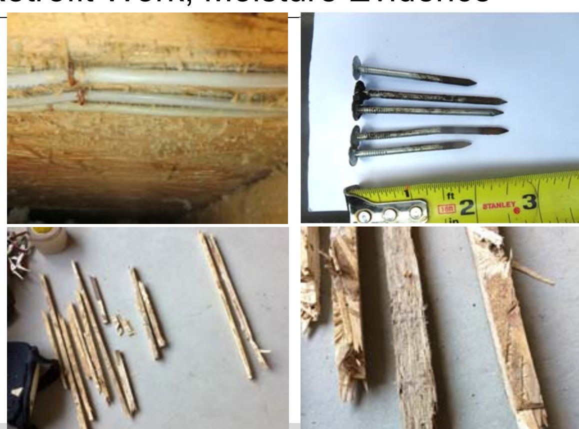
Retrofit Work, Fiberglass Settling

Retrofit Work, Cellulose Settling

Retrofit Work, Cellulose Settling

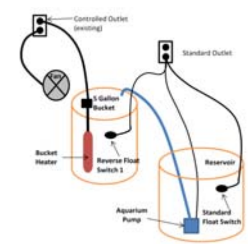
Settling along entire roof length <u>only</u> occurred on north side

Retrofit Work, Moisture Evidence

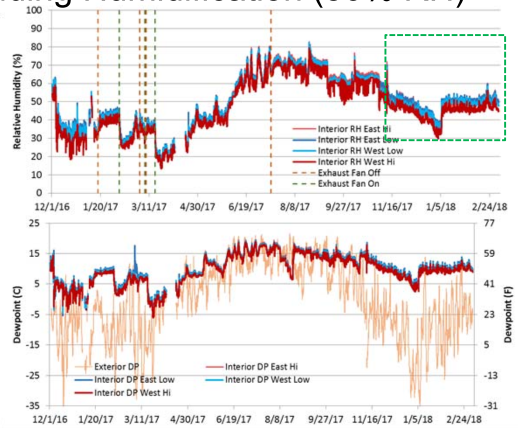


Adding Humidification (50% RH)

- Insulated heated "bucket"
- Heater & fan operate on call for humidification
- "Bucket" refilled by reservoir/float switch

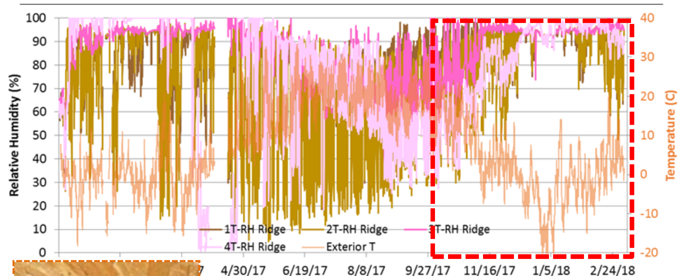


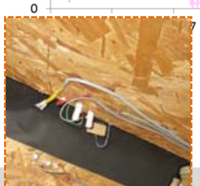
Adding Humidification (50% RH)



Year Two Results: Fiberglass Roofs

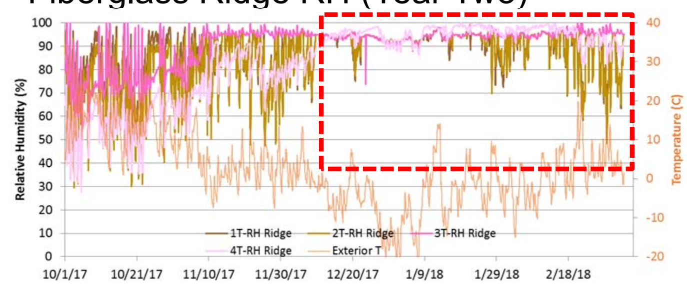
Fiberglass Ridge RH (Full 2 Years)





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

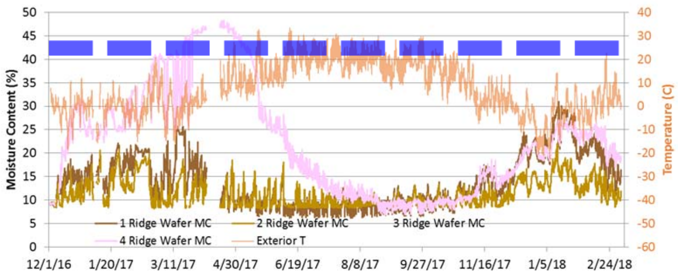
Fiberglass Ridge RH (Year Two)



- **Full-size diffusion ports** start to dry late winter
- **"Tight" diffusion vent** stays wet
- **"Small" diffusion vent** in-between

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

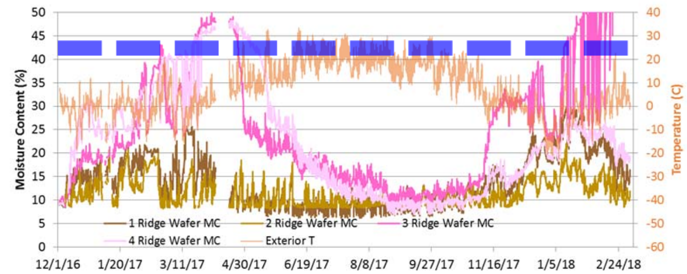
Fiberglass Ridge Wafer



- "Small" diffusion vent drier than last winter (nDV)
- **Full-size diffusion ports** wetter than Winter 1 (50% RH)
- **"Tight" diffusion vent** high MCs

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

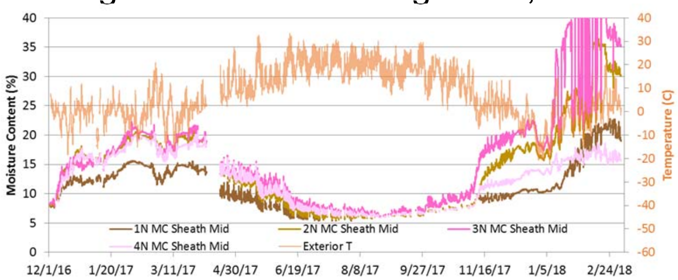
Fiberglass Ridge Wafer



- "Small" diffusion vent drier than last winter (nDV)
- **Full-size diffusion ports** wetter than Winter 1 (50% RH)
- **"Tight" diffusion vent** high MCs

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

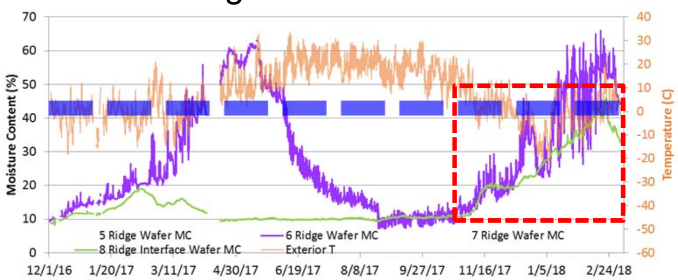
Fiberglass Roof Sheathing North, Mid Ht.



- Mid-height MC, facing north
- All roofs much wetter than Winter 1 (50% RH)
- **"Tight" diffusion vent** worst performer

Year Two Results: Cellulose & Hybrid Roofs

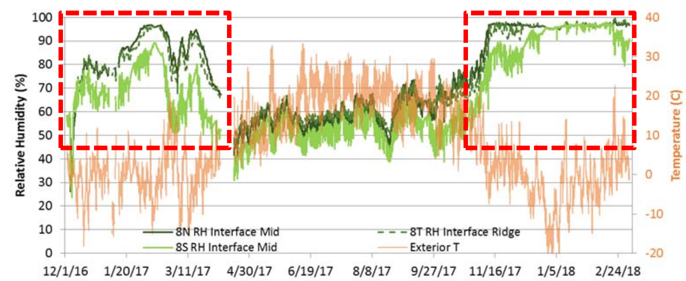
Cellulose Ridge Wafer



- Borate contamination of wood MCs?
- **Hybrid ccSPF-cellulose roof** > 40% MC
  - Interior moisture through ccSPF layer?
  - But roof sheathing only 10% MC-safe

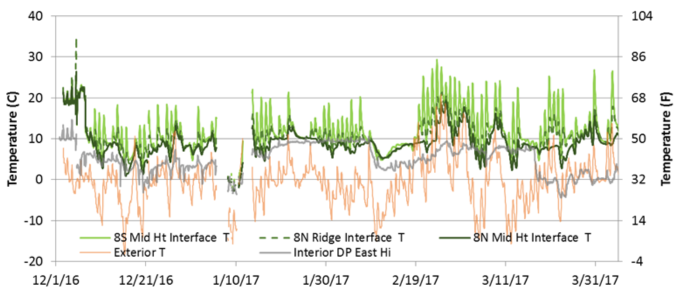
Roof #	Short Name
5	Cell-SVR-tD
6	Cell-SVR-sD
7	Cell-SVR-DV
8	ccSPF-Cell

Hybrid Roof Interface: RH



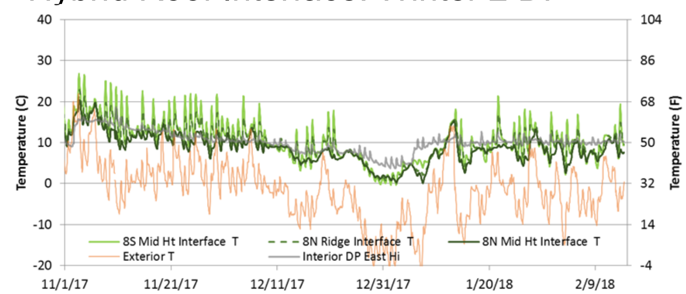
- Effect of 50% interior RH
- No visible issues from interior (cellulose storage)

Hybrid Roof Interface: Winter 1 DP



- **Interface T** (greens) & **interior DP** (grey)
- DP is typically below interface temperature in Winter 1

Hybrid Roof Interface: Winter 2 DP



- **Interface T** (greens) & **interior DP** (grey)
- DP is often greater than interface temperature in Winter 2

Year Two Conclusions and Recommendations

Conclusions & Further Work

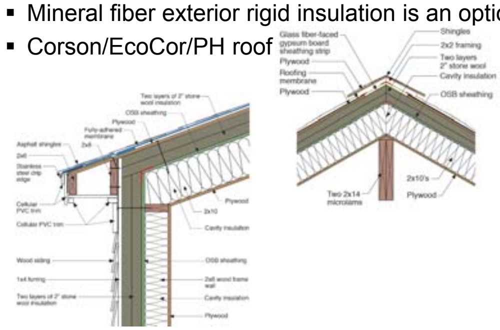
- Roofs with diffusion vent & variable-perm vapor consistently safest, BUT
- Interior at 50% RH creates much more challenging conditions: many at risk of failure
- "Tight" diffusion vent (25 perms vs. 500 perms) did not work acceptably
- "Small" diffusion vent: better than nothing, but larger allows more drying
- 50% RH pushes limits of "flash and blow" ratios—safe storage saves cellulose roof

Conclusions & Further Work

- Year 2 of 3-year project
- Planned interior conditions:
  - Winter 1: "Normal" interior conditions
  - Winter 2: Elevated RH (50% constant)
  - Winter 3: Air leakage into rafter bays
- Possibly change experimental program based on Year 2 results

Recommendations

- Code-compliant (IRC § R806.5) still safest (spray foam or exterior rigid insulation)
  - Mineral fiber exterior rigid insulation is an option
  - Corson/EcoCor/PH roof



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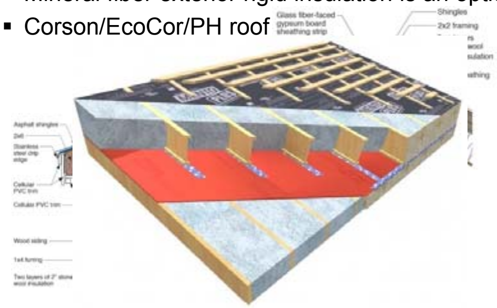
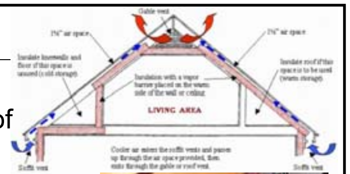


Recommendations

- Fibrous-only insulation (no exterior insulation) roof assemblies are "off-label" (against code)
- Diffusion vent + variable-perm vapor retarder safest
  - "Least bad" if choosing this option
- Test airtightness of interior membrane
  - Workmanship sensitive: project type? (e.g., public bid)
- Control interior RH—<u>for life of building</u>
  - 20-30% RH maximum in worst of winter?
- Complete cavity fills safer
- Cellulose moisture storage capacity
- Retrofit/remediation applications?

Recommendations



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

Questions?

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

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