

Kohta Ueno

Unvented Roofs Without Spray Foam:  
The Latest Building America Research

**BUILDINGENERGY BOSTON**

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

# Background

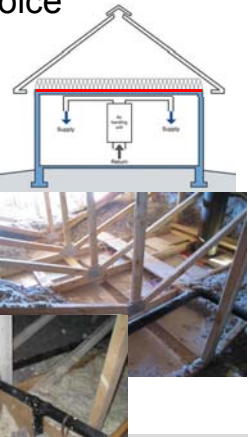
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2

## 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)



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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



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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

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### 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

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### 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

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### 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)


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### 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



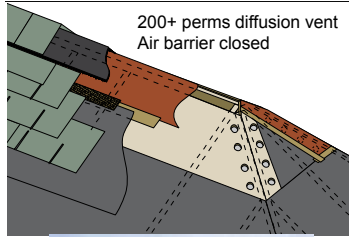



Chicago roof disassembly



Houston roof w. diffusion vent

### Diffusion Vent Prototype (Houston)

200+ perms diffusion vent  
Air barrier closed

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### Diffusion Vent Prototype (Orlando-Tile)

200+ perms diffusion vent  
Air barrier closed

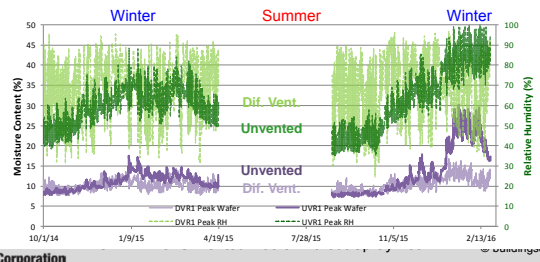





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### Houston/Orlando Results

- 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



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### Orlando Decommissioning



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

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## “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”

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### "Ping Pong" Water

- Shingles
- Roofing paper
- Wood based roof sheathing
- Open cell low density spray foam

“Pong”

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

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“Ping”

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### "Ping Pong" Water

- Shingles
- Roofing paper
- Wood based roof sheathing
- Open cell low density spray foam

Each “Ping” and “Pong” bounces the water molecules up the slope

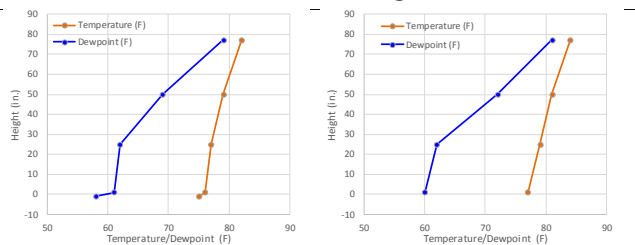
- “Gas separation process similar to pressure swing adsorption”
- Solar-powered moisture concentration machine

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### Orlando Decommissioning

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### Orlando Decommissioning



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



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## Test Hut Approach & Construction

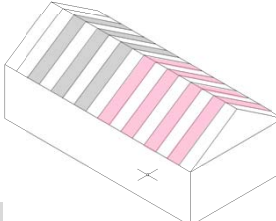

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### Test Hut Experimental Approach

- Climate Zone 5A test hut
- Eight north-south roof bays
- ±R-50 (14-3/4" 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





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### Test Hut Construction



- Walls 2x6, ccSPF, ZIP sheathing, 4" Roxul, 1x3s
- Roof cavity 14-3/4" deep, ~R-50 (2x12 + 2x4)
- 8:12 roof pitch


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### Test Hut Construction



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

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### 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

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### 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)

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### Test Hut Construction




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

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### Test Hut Construction



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

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### Test Hut Construction



- Instrumentation completion

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### Test Hut Construction



- ccSPF in guard bays and walls

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### Test Hut Construction



- Fibrous insulation installed

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### Test Hut Construction



- Interior air/vapor control installed

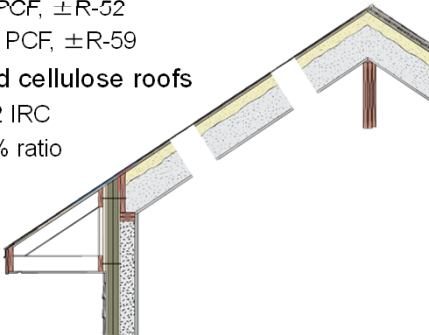

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### Experimental Approach


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### Experimental Approach: Insulation Mat'ls

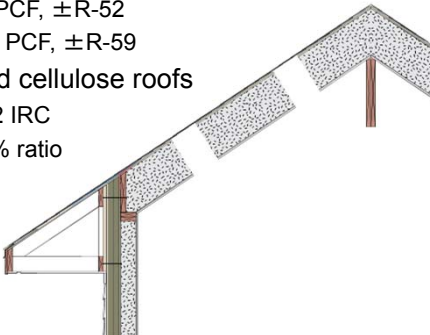
- Rafter bay insulation materials
  - Cellulose @ 3.5 PCF,  $\pm R-52$
  - Fiberglass @ 1.4 PCF,  $\pm R-59$
- Hybrid ccSPF and cellulose roofs
  - § R806.5 in 2012 IRC
  - $\pm R-63$ , 40%-60% ratio





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### Experimental Approach: Insulation Mat'ls

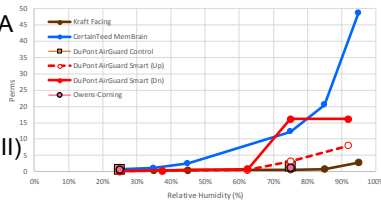
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### Experimental Approach: Vapor Control

- 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



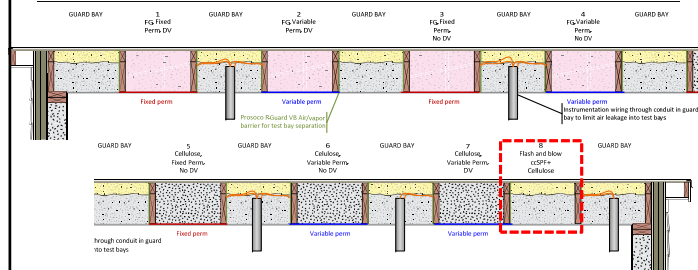
- ± 5 in. opening (fits under typical ridge cap)
- Cosella-Dörken Delta-Foxx
  - 214 perms dry cup
  - 550 perms wet cup

### 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

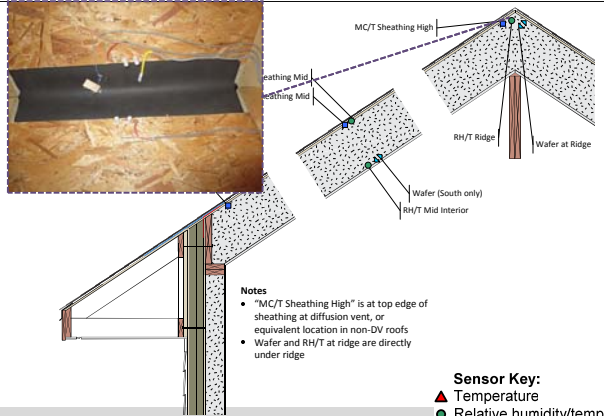
# Instrumentation Design



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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

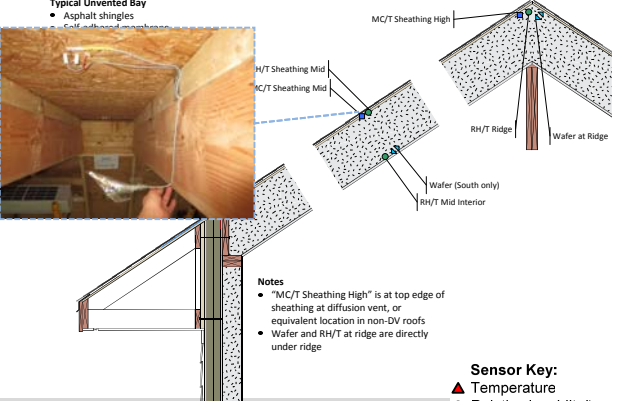


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## Instrumentation Design: Fibrous Insulation

**Typical Unvented Bay**

- Asphalt shingles
- Gelfoam insulation




**Notes**

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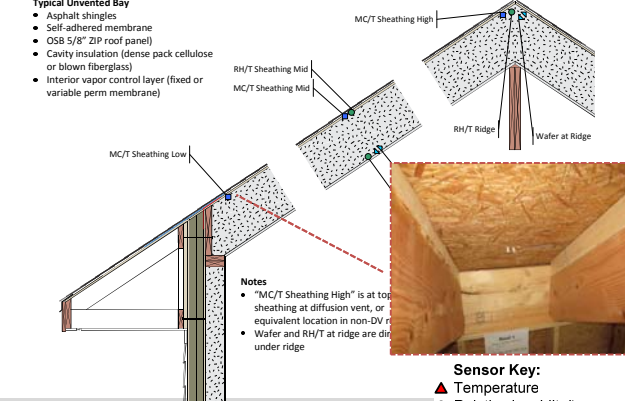


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## Instrumentation Design: Fibrous Insulation

**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)




**Notes**

- "MC/T Sheathing High" is at top sheathing at diffusion vent, or equivalent location in non-DV roofs
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- Relative humidity/temperature
- Moisture content/temperature
- Moisture content block

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### Instrumentation Design: Flash & Blow

**Control "Flash and Blow" Bay**

- Asphalt shingles
- Self-adhered membrane
- OSB 5/8" ZIP roof panel
- 4" ccSPF insulation
- Dense pack cellulose (-10°)
- Interior gypsum board

**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
- "Interface" denotes spray foam-to-fibrous insulation interface

**Sensor Key:**

- Relative humidity/temperature
- Moisture content/temperature
- Moisture content block "wafer"

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

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### Instrumentation Design: Interior T/RH

■ Interior temperature/RH measurements

- Low/high, east/west (4 total)

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### Instrumentation Design: Exterior

■ Exterior temperature/RH (north side)

■ Solar radiation (north and south roofs)

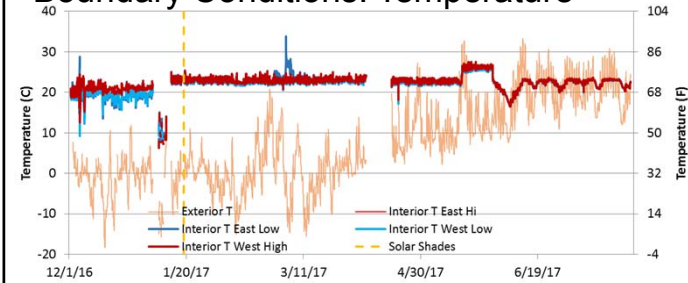
■ Data collected hourly on Campbell CR1000

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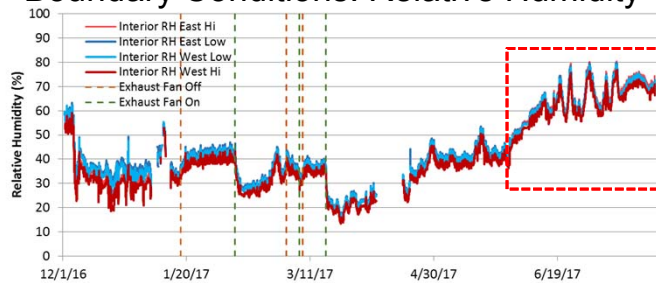
# Year One Results: Boundary Conditions

## Boundary Conditions: Temperature



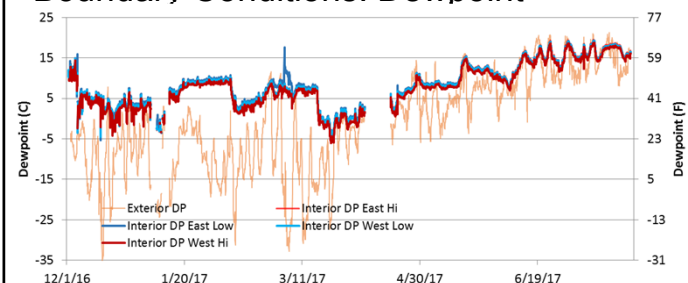
- Data from December 2016-July 2017
- Loss of data in January (power loss, flood), April (GFCI tripping)

## 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 cellulose	Fixed perm	No
7	Dense pack cellulose	Fixed perm	Yes
8	ccSPF + cellulose and blow" §R8	Fixed perm	No

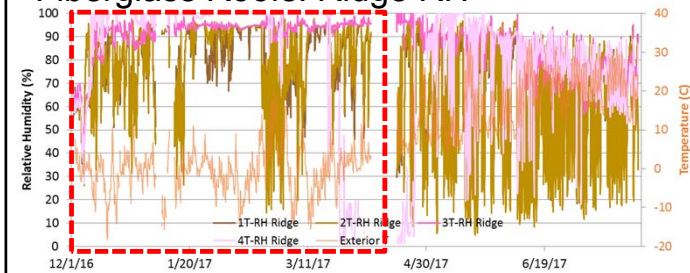
Roof	Short Name
1	FG-VB-DV
2	FG-SVR-DV
3	FG-VB-nDV
4	FG-SVR-nDV

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

## Interpreting the Data (Moisture Risks)

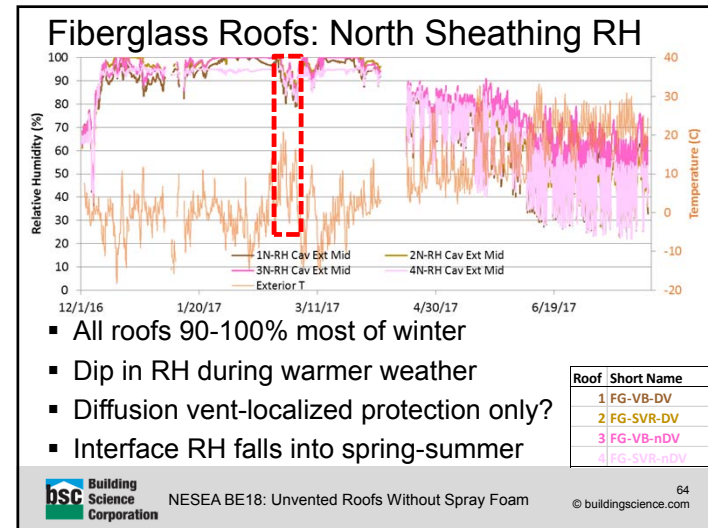
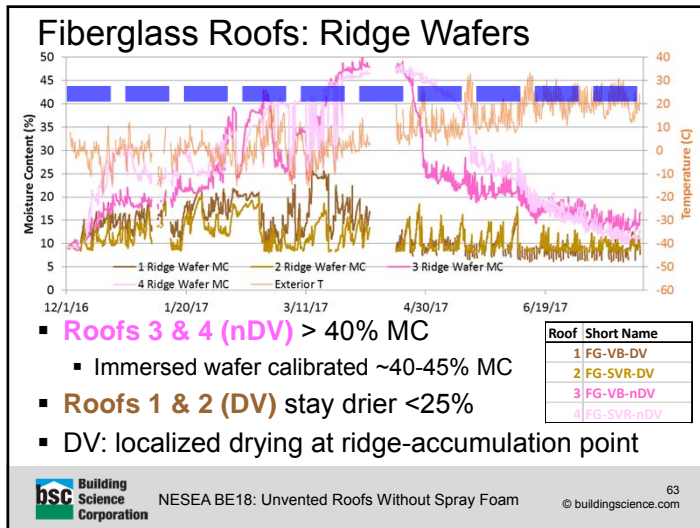
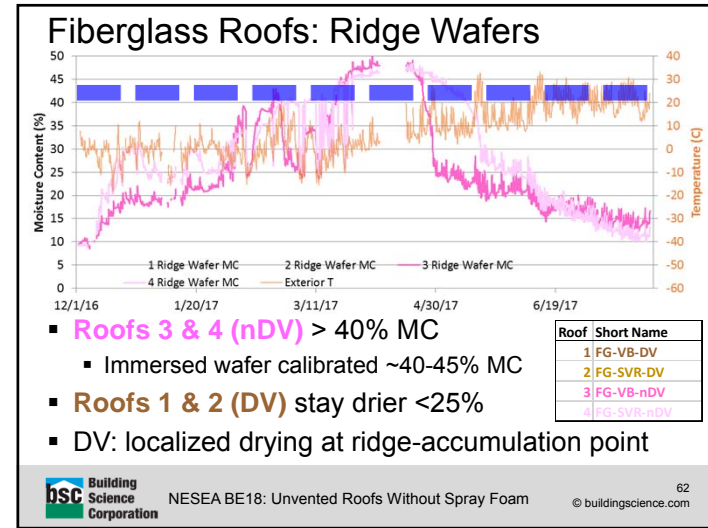
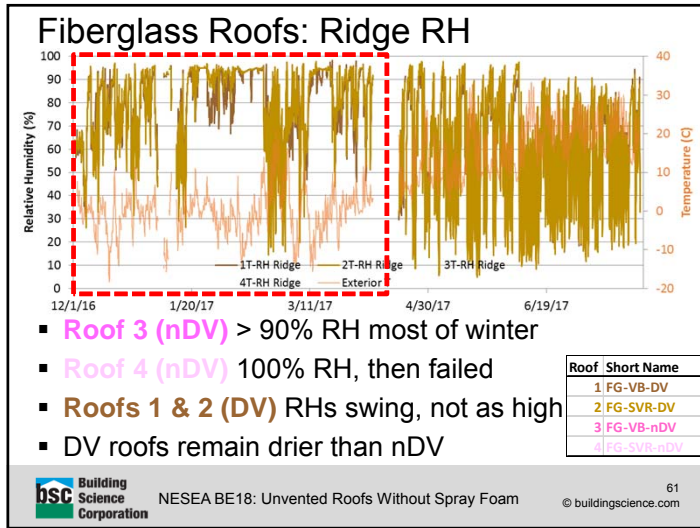
- Relative Humidity (RH)
  - 80% RH: conservative/unrealistic threshold
  - 90%-100% RH: mold risks, but temperature effects
  - Condensation (liquid water): mold growth kickstarter
- Wood Moisture Content (MC)
  - Under 20% MC safe
  - 25%-30% MC ideal for mold growth
  - 28%+ MC decay fungi.... BUT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

## Fiberglass Roofs: Ridge RH

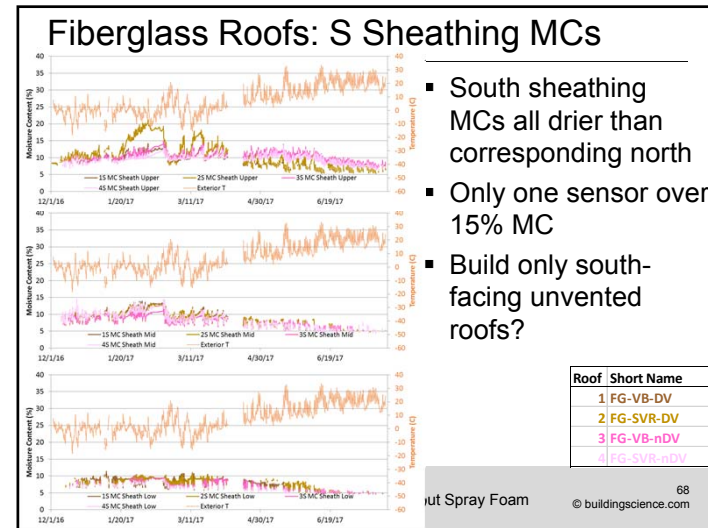
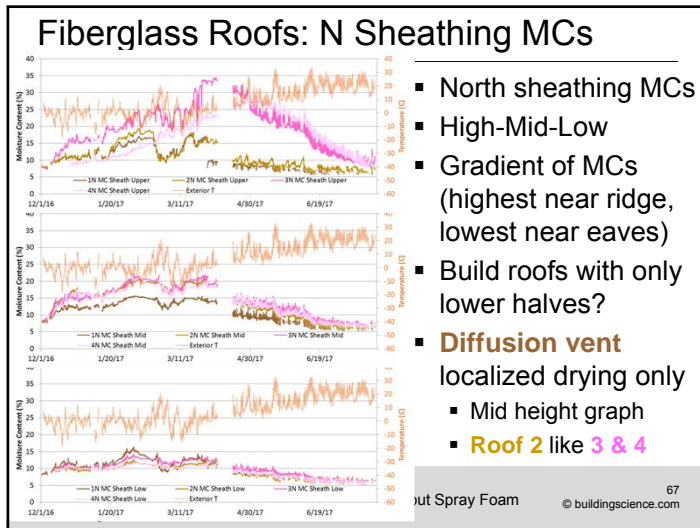
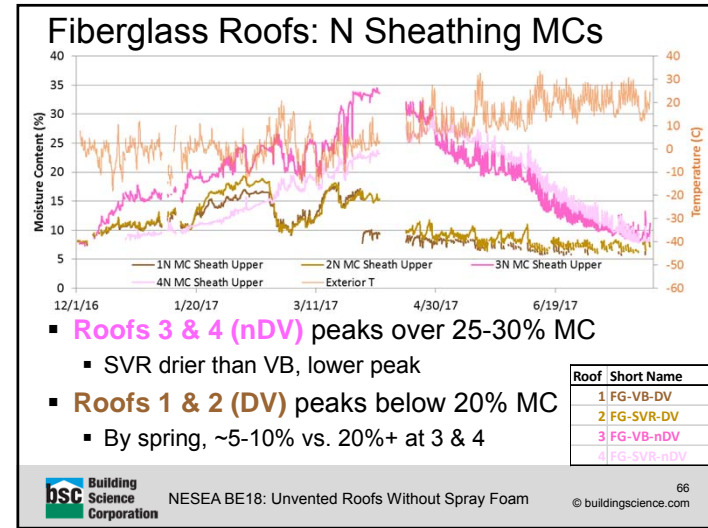
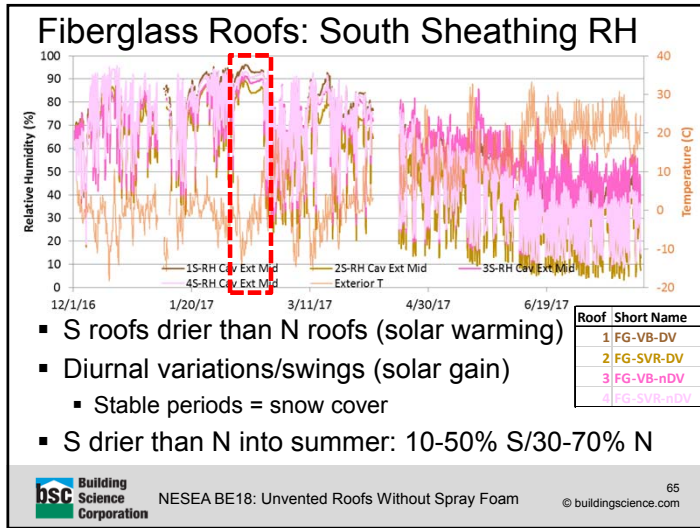


- **Roof 3 (nDV)** > 90% RH most of winter
- **Roof 4 (nDV)** 100% RH, then failed
- **Roofs 1 & 2 (DV)** RHs swing, not as high
- DV roofs remain drier than nDV


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







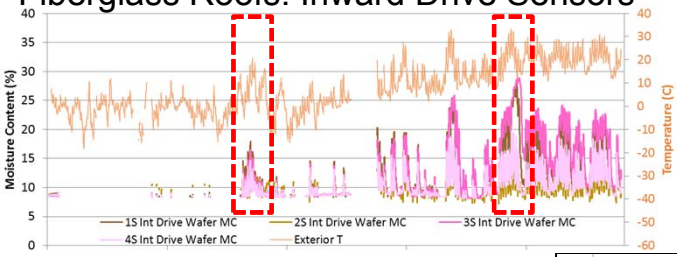
# Year One Results: Fiberglass Inward Drive



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## Fiberglass Roofs: Inward Drive Sensors



- 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

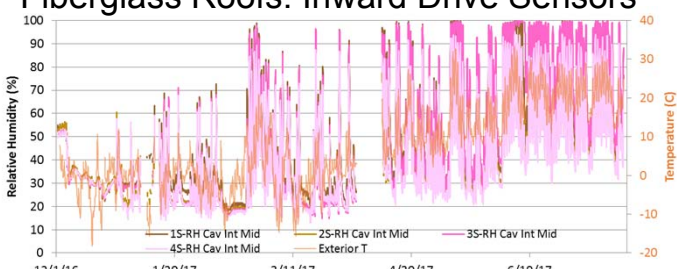
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3	FG-VB-nDV
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## Fiberglass Roofs: Inward Drive Sensors



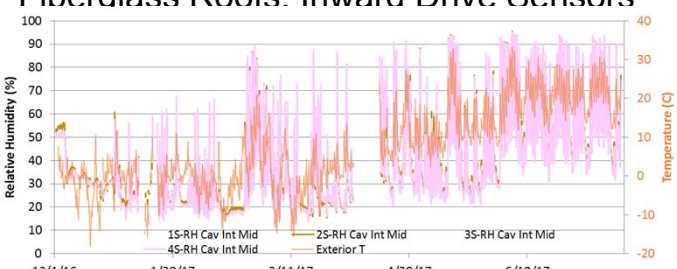
- South side RH sensors
- Roofs **1 & 3** (VB) stay wetter than **2 & 4** (SVR)
- SVRs do what they're supposed to do

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




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## Fiberglass Roofs: Inward Drive Sensors

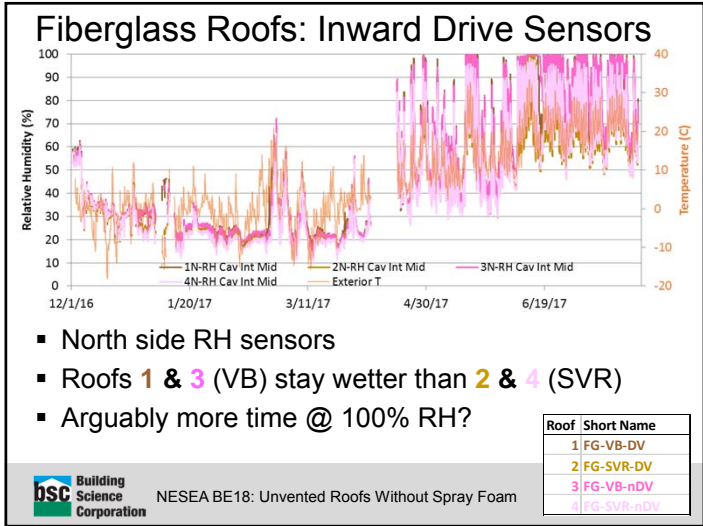


- South side RH sensors
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- SVRs do what they're supposed to do

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



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## Year One Results: Fiberglass Mold Index

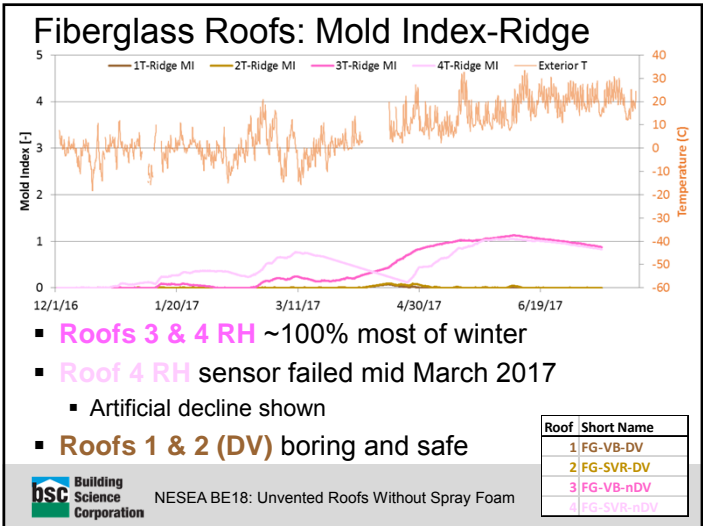
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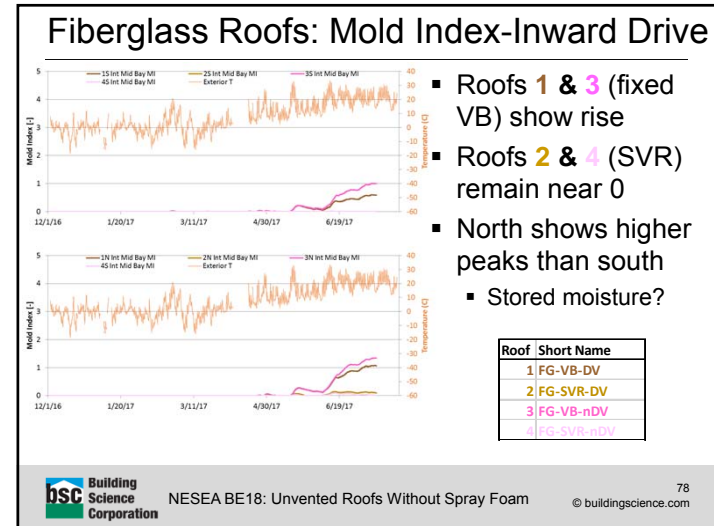
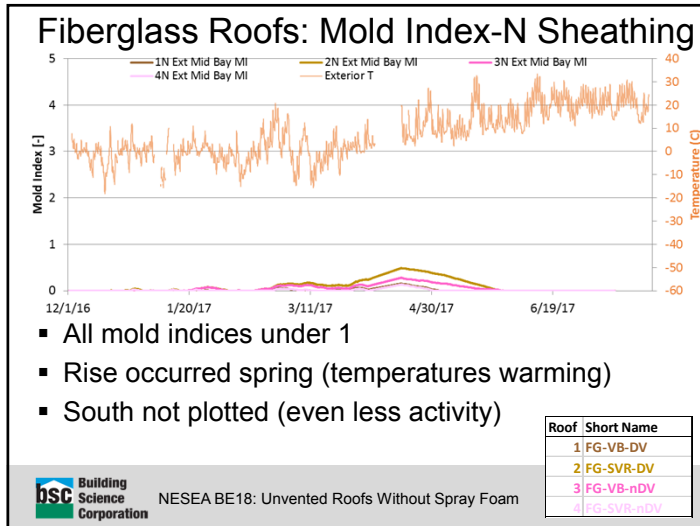
### Fiberglass Roofs: Mold Index Calculations

- 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%

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### 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

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# Year One Results: Cellulose Roofs

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### 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

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### 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

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### Cellulose Roofs: Ridge RH

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

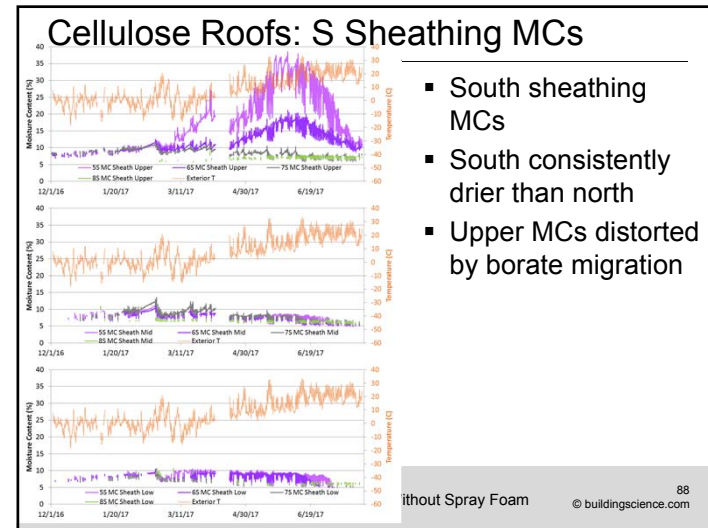
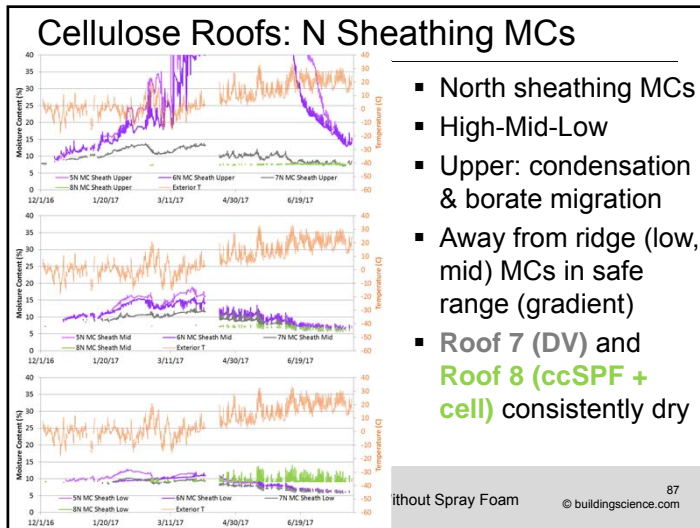
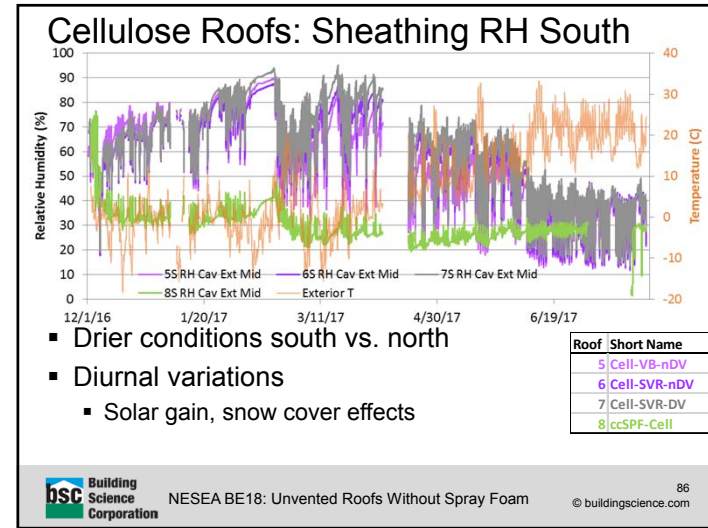
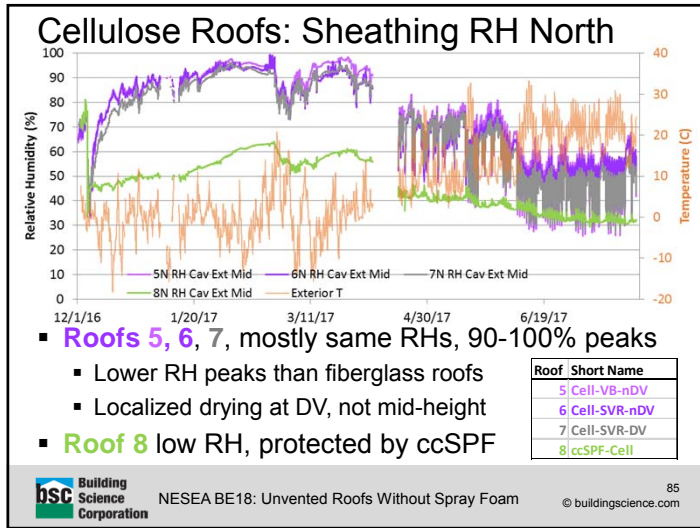
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### Cellulose Roofs: Ridge Wafer


- 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

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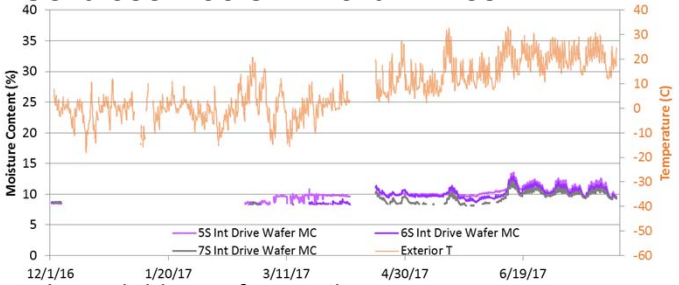


# Year One Results: Cellulose Inward Drive




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## Cellulose Roofs: Inward Drives



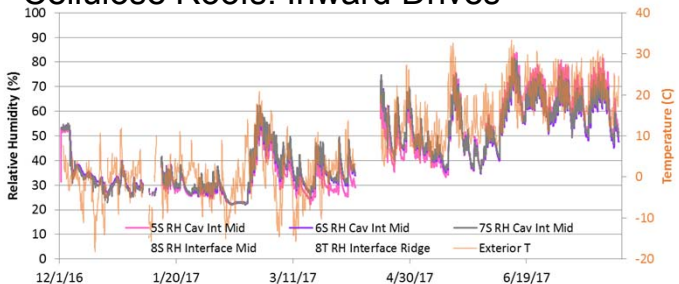
- Inward drive wafer, south
- All well below 15% MC (safe)

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




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## Cellulose Roofs: Inward Drives



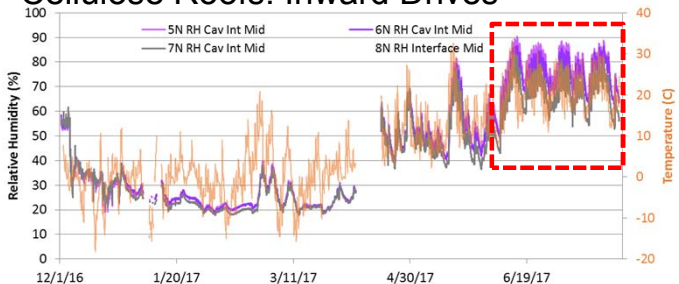
- Inward drive RH, south
- Peaks barely over 80% RH

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




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## Cellulose Roofs: Inward Drives



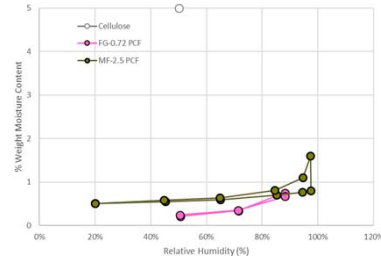
- Inward drive RH, north
- Peaks mostly under 90% RH
- Higher than south-stored moisture?

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



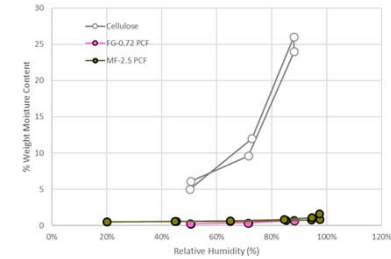
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### Cellulose vs. Fiberglass Moisture Storage



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

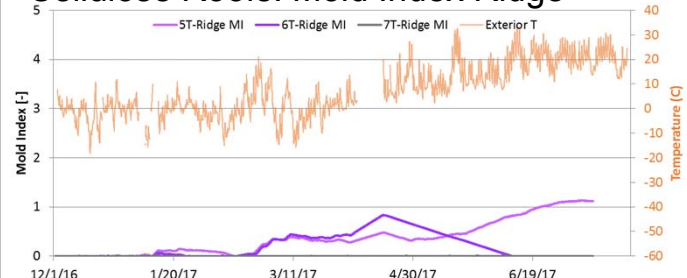
### Cellulose vs. Fiberglass Moisture Storage



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

## Year One Results: Cellulose Mold Index

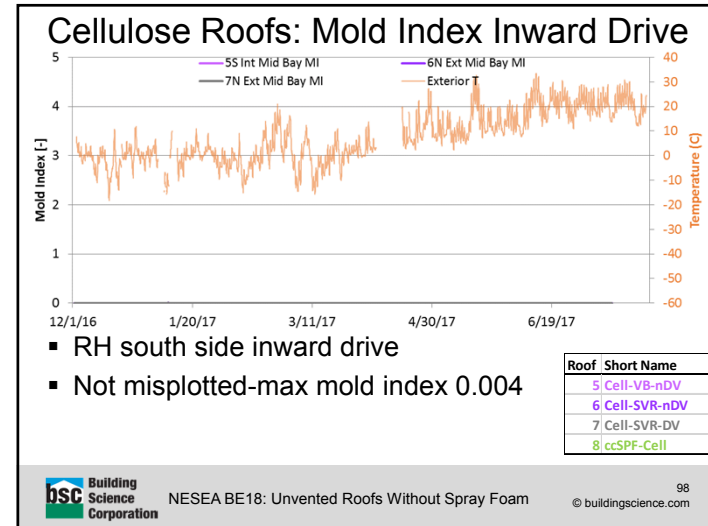
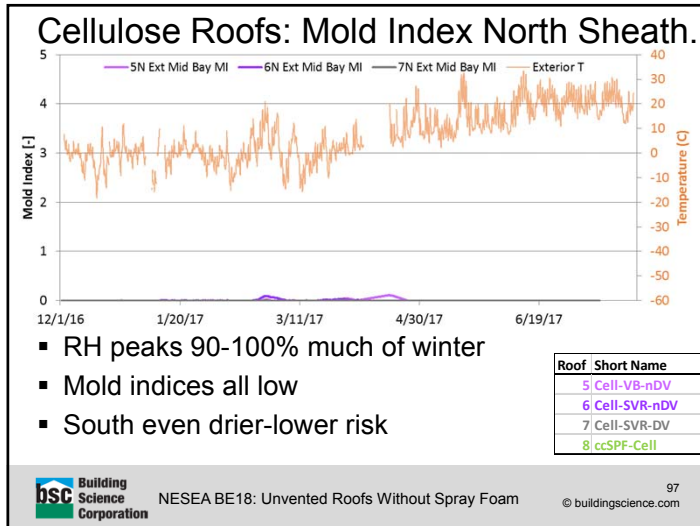
### Cellulose Roofs: Mold Index Ridge



- **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





### 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

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# Year Two: Humidification and New Assemblies

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### 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) <b>Fixed perm-(OC 1 perm)</b>	2"/±25 perm <b>No</b>	FG-SVR-tDV <b>FG-VB-tDV</b>
4	Fiberglass	Variable perm (MemBrain)	2"/±300 perm <b>No</b>	FG-SVR-sDV <b>FG-SVR-tDV</b>
5	Dense pack cellulose	Variable perm (DuPont Variable) <b>Fixed perm-(OC 1 perm)</b>	2"/±25 perm <b>No</b>	Cell-SVR-tDV <b>Cell-VB-tDV</b>
6	Dense pack cellulose	Variable perm (DuPont Variable)	2"/±300 perm <b>No</b>	Cell-SVR-sDV <b>Cell-SVR-tDV</b>
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

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### Summertime Inward Drive

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### Summertime Inward Drive

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

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### Retrofit Work, Fiberglass Settling

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### Retrofit Work, Cellulose Settling

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### Retrofit Work, Cellulose Settling

**Settling along entire roof length only occurred on north side**

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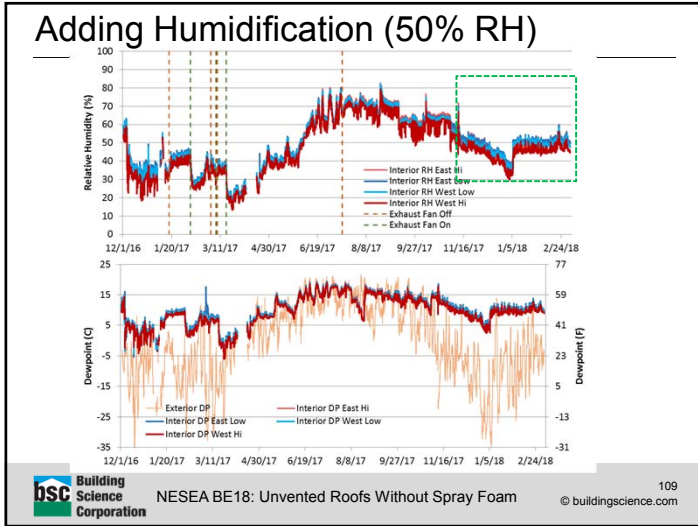
### Retrofit Work, Moisture Evidence

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### Adding Humidification (50% RH)

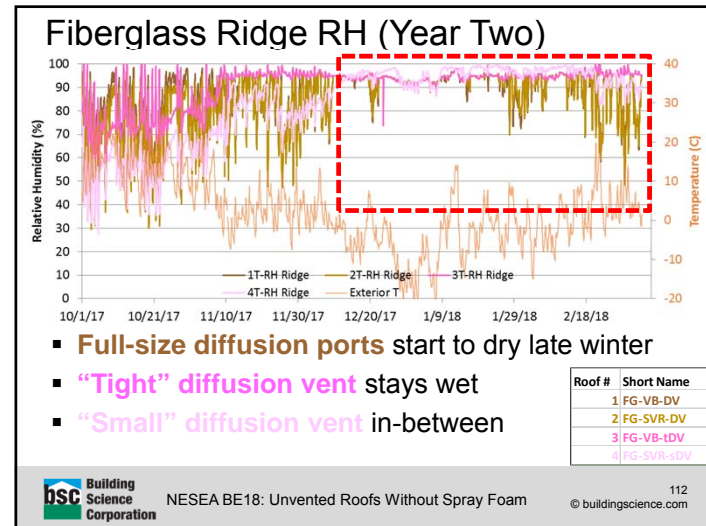
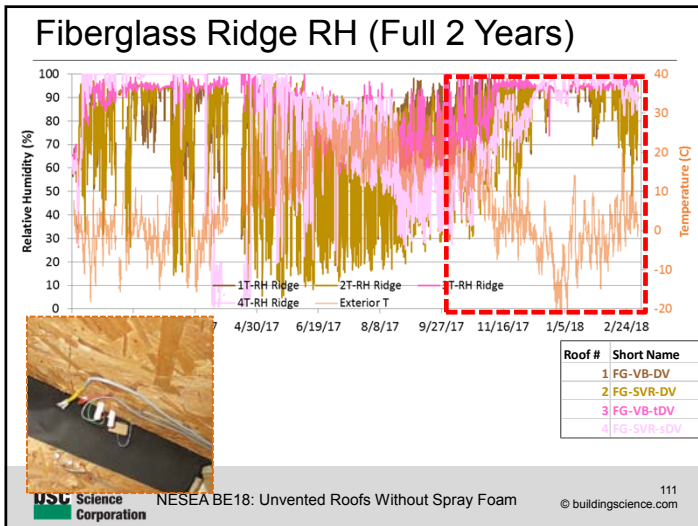
- Insulated heated “bucket”
- Heater & fan operate on call for humidification
- “Bucket” refilled by reservoir/float switch

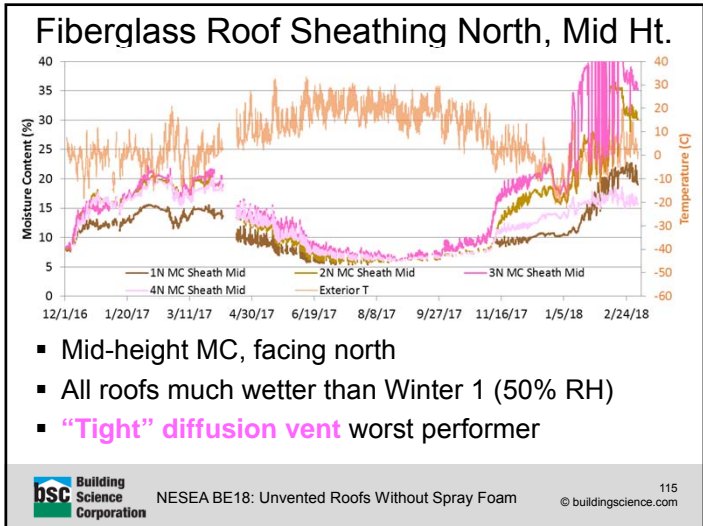
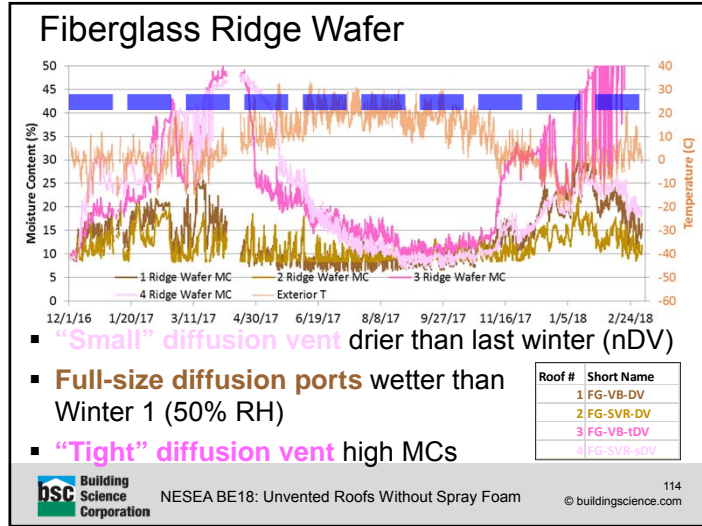
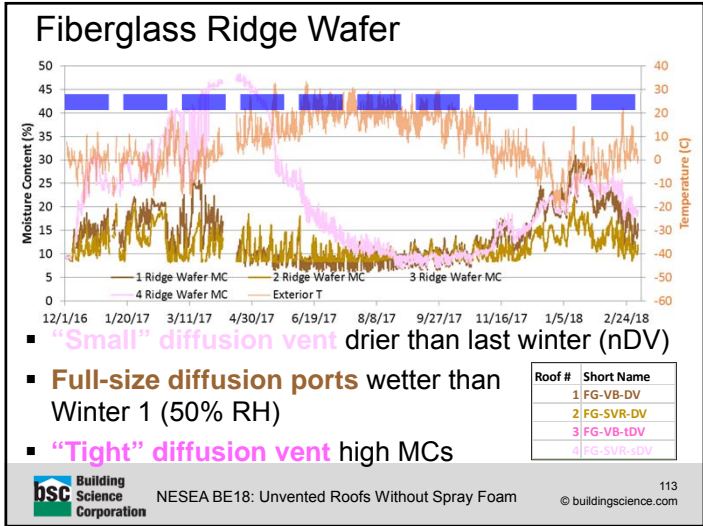
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# Year Two Results: Fiberglass Roofs

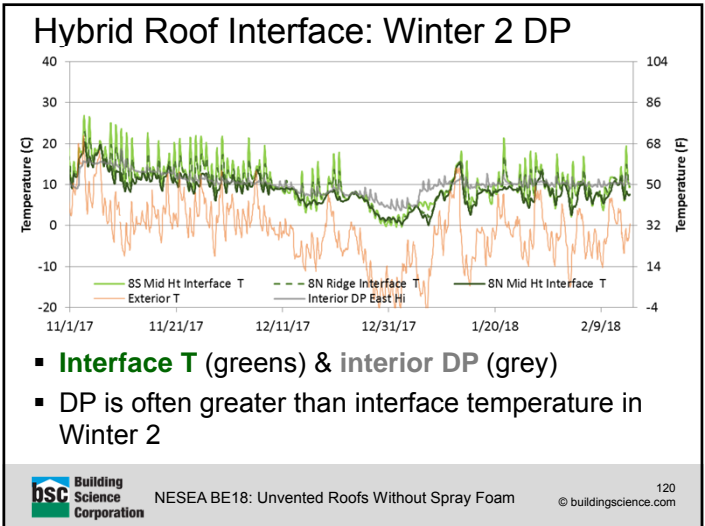
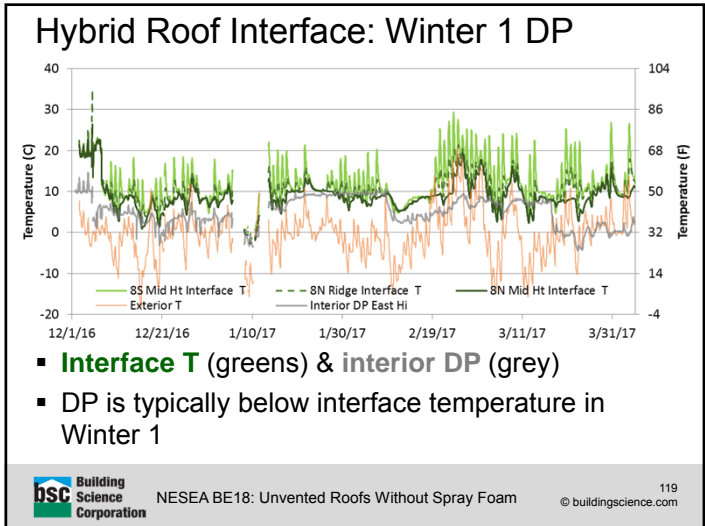
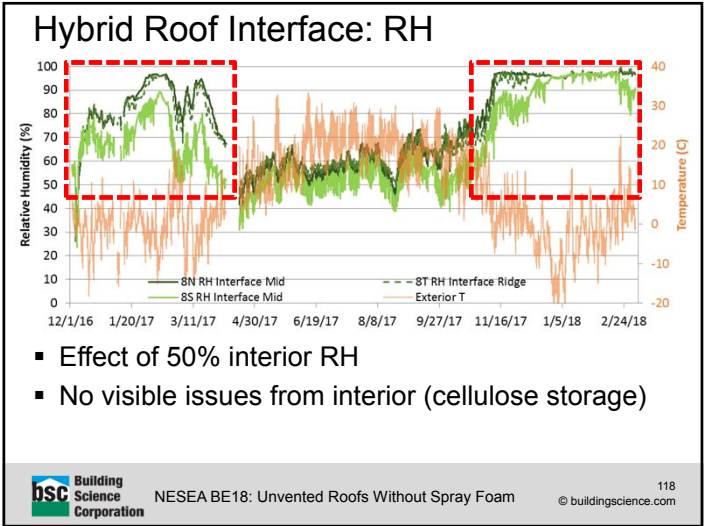
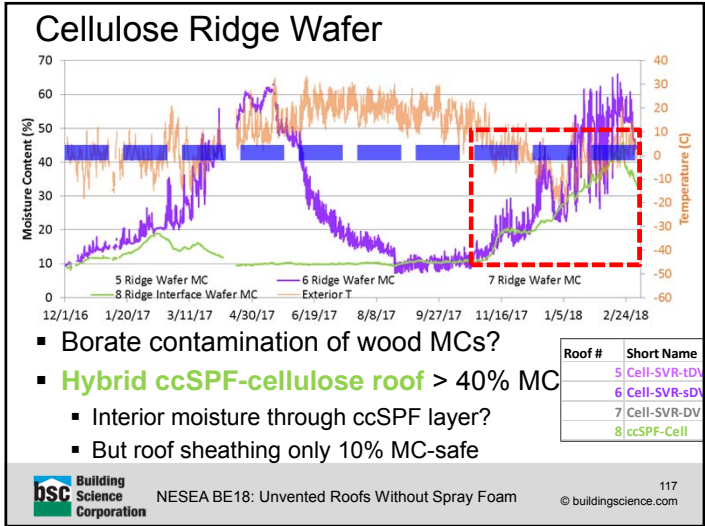
110  
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## Year Two Results: Cellulose & Hybrid Roofs

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# Year Two Conclusions and Recommendations

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## Conclusions & Further Work

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- 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




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## Conclusions & Further Work

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- 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



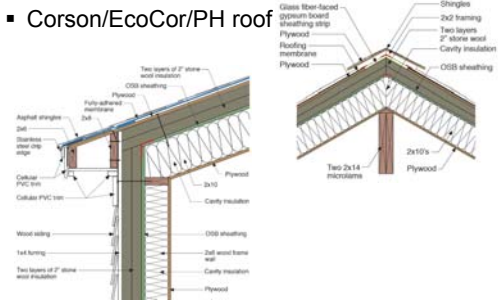
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## Recommendations

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- 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

- 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

Labels in diagram: Asphalt shingles, OSB, Gypsum board sheathing strip, Glass fiber-faced gypsum board sheathing strip, 2x2 framing, 1/2 inch insulation, 1/2 inch sheathing, Wood siding, 1x4 batten, Two layers of 2 inch water insulation.

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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—for life of building
  - 20-30% RH maximum in worst of winter?
- Complete cavity fills safer
- Cellulose moisture storage capacity
- Retrofit/remediation applications?

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### 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 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

Labels in diagram: 1/2 inch air space, 1/2 inch sheathing, 1/2 inch insulation, LIVING AREA, 1/2 inch air space.

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### Questions?

kohta Ueno  
kohta [at] buildingscience [dot] com

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

Logos: NAIMA (North American Insulation Manufacturers Association), NU-WOOL (Premium Cellulose Insulation, Green Since 1949), COSELLA DÖRKEN, DUPONT, U.S. DEPARTMENT OF ENERGY (Energy Efficiency & Renewable Energy), Building AMERICA (U.S. Department of Energy), OWENS CORNING (The miracles of science®)

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