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
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

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)

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 + 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

Unvented Roofs & HVAC Placement

Fibrous Insulation Unvented Roofs
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

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)
- 200+ perms diffusion vent
- Air barrier closed

Diffusion Vent Prototype (Orlando-Tile)
- 200+ perms diffusion vent
- Air barrier closed

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

- 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

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

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

Test Hut Approach & Construction

- Climate Zone 5A test hut
- Eight north-south roof bays
- ±R-50 (14-½” 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 Construction

- Walls 2x6, ccSPF, ZIP sheathing, 4” Roxul, 1x3s
- Roof cavity 14-3/8” 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: 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

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
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

<table>
<thead>
<tr>
<th>Roof #</th>
<th>Insulation</th>
<th>Interior VB</th>
<th>Diffusion Vent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>fiberglass</td>
<td>Fixed perm</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>fiberglass</td>
<td>Variable perm</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>fiberglass</td>
<td>Fixed perm</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>fiberglass</td>
<td>Variable perm</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>dense pack cellulose</td>
<td>Fixed perm</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>dense pack cellulose</td>
<td>Variable perm</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>dense pack cellulose</td>
<td>Variable perm</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>ccSPF + cellulose “flash and blow”</td>
<td>Latex paint on GWB</td>
<td>No</td>
</tr>
</tbody>
</table>

- 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: Fibrous Insulation

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

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 edge are directly under ridge.

Typical Unvented Bay
- Asphalt shingles
- Self-adhered membrane
- 2½" ZIP roof panel
- Cavity insulation (dense pack cellulose or blown fiberglass)
- Interior vapor control layer (fixed or variable perm membrane)

MC/T Sheathing
- High
- Mid
- Low

RH/T Sheathing
- Mid
- Low

Wafer at Ridge
- (South only)
Instrumentation Design: Fibrous Insulation

Typical Unvented Bay
- Asphalt shingles
- Self-adhered membrane
- OSI/ZIP/RP (zip panel)
- Cavity insulation (dense pack cellulose or blown fiberglass)
- Interior vapor control layer (fixed or variable perm 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

Instrumentation Design: Flash & Blow

- "Flash and blow" roof: instruments shifted to ccSPF/cellulose interface
  - Flash and Blow Bay
    - Asphalt shingles
    - Self-adhered membrane
    - OSI/ZIP/RP (zip panel)
    - Dense pack insulation/blend
    - Interior vapor barrier
  - 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 edge are directly under ridge
    - RH/T Ridge Interface denotes spray foam to fibrous insulation interface

Instrumentation Design: Interior T/RH

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

Instrumentation Design: Exterior

- Exterior temperature/KH (north side)
- Solar radiation (north and south roofs)
- Data collected hourly on Campbell CR1000
Year One Results: Boundary Conditions

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

Boundary Conditions: Temperature

- 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: Relative Humidity

- 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

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: Color Codes

<table>
<thead>
<tr>
<th>Roof #</th>
<th>Insulation</th>
<th>Interior VB</th>
<th>Diffusion Vent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>fiberglass</td>
<td>fixed perm</td>
<td>yes</td>
</tr>
<tr>
<td>2</td>
<td>fiberglass</td>
<td>variable perm</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>fiberglass</td>
<td>fixed perm</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>fiberglass</td>
<td>variable perm</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>dense pack cellulose</td>
<td>fixed perm</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>dense pack cellulose</td>
<td>variable perm</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>dense pack cellulose</td>
<td>variable perm</td>
<td>yes</td>
</tr>
<tr>
<td>8</td>
<td>ccSPF + cellulose and blow&quot; [R806.4]</td>
<td>FG-VB-DV</td>
<td>no</td>
</tr>
<tr>
<td>9</td>
<td>ccSPF + cellulose and blow&quot; [R806.4]</td>
<td>FG-SVR-DV</td>
<td>no</td>
</tr>
<tr>
<td>10</td>
<td>ccSPF + cellulose and blow&quot; [R806.4]</td>
<td>FG-VB-nDV</td>
<td>no</td>
</tr>
</tbody>
</table>

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

### 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 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

- 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

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

- 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

- 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?
Year One Results: Fiberglass Inward Drive

- South side RH sensors
- Roofs 1 & 3 (VB) stay wetter than 2 & 4 (SVR)
- SVRs do what they’re supposed to do
Fiberglass Roofs: Inward Drive Sensors

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

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

<table>
<thead>
<tr>
<th>Index</th>
<th>Description of Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No growth</td>
</tr>
<tr>
<td>1</td>
<td>Small amount of mold on surface (microscope), initial stages of growth</td>
</tr>
<tr>
<td>2</td>
<td>Several local mold growth colonies on surface (microscope)</td>
</tr>
<tr>
<td>3</td>
<td>Visual findings of mold on surface, &lt; 10% coverage, or &lt; 50% coverage of mold (microscope)</td>
</tr>
<tr>
<td>4</td>
<td>Visual findings of mold on surface, 10%–30% coverage, or &gt; 50% coverage of mold (microscope)</td>
</tr>
<tr>
<td>5</td>
<td>Fuzzy growth on surface, &gt; 30% coverage (visual)</td>
</tr>
<tr>
<td>6</td>
<td>Ropy and tight growth, coverage about 100%</td>
</tr>
</tbody>
</table>

Year One Results: Fiberglass Mold Index

- 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

<table>
<thead>
<tr>
<th>Roof Short Name</th>
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<tbody>
<tr>
<td>1F-VG-DV</td>
</tr>
<tr>
<td>2F-SVR-DV</td>
</tr>
<tr>
<td>3F-VG-nDV</td>
</tr>
<tr>
<td>4F-SVR-nDV</td>
</tr>
</tbody>
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<td>1F-VG-DV</td>
</tr>
<tr>
<td>2F-SVR-DV</td>
</tr>
<tr>
<td>3F-VG-nDV</td>
</tr>
</tbody>
</table>
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
1F G‐VB‐DV
2F G‐SVR‐DV
3F G‐VB‐nDV
4F G‐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

Year One Results: Cellulose Roofs
Cellulose Roofs: Color Codes

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

<table>
<thead>
<tr>
<th>Roof #</th>
<th>Insulation</th>
<th>Interior VB</th>
<th>Diffusion Vent</th>
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<tr>
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<td>Variable perm</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Fiberglass</td>
<td>Fixed perm</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Dense pack cellulose</td>
<td>Fixed perm</td>
<td>No</td>
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<tr>
<td>5</td>
<td>Dense pack cellulose</td>
<td>Variable perm</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Dense pack cellulose</td>
<td>Variable perm</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>ccSPF + cellulose “flash and blow” §R006.4</td>
<td>Latex paint on GWB</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>ccSPF + cellulose “flash and blow” §R006.4</td>
<td>Latex paint on GWB</td>
<td>No</td>
</tr>
</tbody>
</table>

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

- **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

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
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

<table>
<thead>
<tr>
<th>Roof Short Name</th>
<th>Roof Name</th>
<th>Sheathing RH North</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Cell-VB-nDV</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cell-SVR-nDV</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cell-SVR-DV</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>ccSPF-Cell</td>
<td></td>
</tr>
</tbody>
</table>

Cellulose Roofs: Sheathing RH South

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

<table>
<thead>
<tr>
<th>Roof Short Name</th>
<th>Roof Name</th>
<th>Sheathing RH South</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Cell-VB-nDV</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cell-SVR-nDV</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cell-SVR-DV</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>ccSPF-Cell</td>
<td></td>
</tr>
</tbody>
</table>

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

- Inward drive RH, south
- Peaks barely over 80% RH
- Inward drive wafer, south
- All well below 15% MC (safe)

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

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

Cellulose Roofs: Mold Index Ridge
Cellulose Roofs: Mold Index North Sheath.

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

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)

Cellulose Roofs: Mold Index Inward Drive

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

Year Two: Humidification and New Assemblies
### New Assemblies—Replace Poor Performers

<table>
<thead>
<tr>
<th>Roof Insulation</th>
<th>Interior VB</th>
<th>Diffusion Vent</th>
<th>Short Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fiberglass</td>
<td>Fixed perm (OC 1 perm) 6&quot;/±300 perm</td>
<td>Yes</td>
<td>FG-VB-DV</td>
</tr>
<tr>
<td>2 Fiberglass</td>
<td>Variable perm (MemBrain) 6&quot;/±300 perm</td>
<td>Yes</td>
<td>FG-SVR-DV</td>
</tr>
<tr>
<td>3 Fiberglass</td>
<td>Variable perm (MemBrain) 2&quot;/±25 perm</td>
<td>No</td>
<td>FG-DB-VB-DV</td>
</tr>
<tr>
<td>4 Fiberglass</td>
<td>Variable perm (MemBrain) 2&quot;/±300 perm</td>
<td>No</td>
<td>FG-SVR-nDV</td>
</tr>
<tr>
<td>5 Dense pack cellulose</td>
<td>Variable perm (DuPont Variable) 2&quot;/±300 perm</td>
<td>No</td>
<td>Cell-SVR-nDV</td>
</tr>
<tr>
<td>6 Dense pack cellulose</td>
<td>Variable perm (DuPont Variable) 2&quot;/±300 perm</td>
<td>No</td>
<td>Cell-SVR-DV</td>
</tr>
<tr>
<td>7 Dense pack cellulose</td>
<td>Variable perm (DuPont Variable) 6&quot;/300 perm</td>
<td>Yes</td>
<td>Cell-SVR-DV</td>
</tr>
<tr>
<td>8 ccSPF + cellulose</td>
<td>None</td>
<td>No</td>
<td>ccSPF-Cell</td>
</tr>
</tbody>
</table>

**tDV** = “tight” diffusion vent (25 perms vs. 300+ perms)

**sDV** = “small” diffusion vent (2” wide vs. 6” wide)

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### Summertime Inward Drive

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

### Retrofit Work, Fiberglass Settling
Retrofit Work, Cellulose Settling

Settling along entire roof length only 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)

<table>
<thead>
<tr>
<th>Date</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1/18</td>
<td>20%</td>
</tr>
<tr>
<td>1/15/18</td>
<td>30%</td>
</tr>
<tr>
<td>1/20/18</td>
<td>40%</td>
</tr>
<tr>
<td>1/25/18</td>
<td>50%</td>
</tr>
<tr>
<td>1/30/18</td>
<td>60%</td>
</tr>
<tr>
<td>2/05/18</td>
<td>70%</td>
</tr>
<tr>
<td>2/10/18</td>
<td>80%</td>
</tr>
<tr>
<td>2/15/18</td>
<td>90%</td>
</tr>
<tr>
<td>2/20/18</td>
<td>100%</td>
</tr>
</tbody>
</table>

Year Two Results: Fiberglass Roofs

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

Fiberglass Ridge RH (Full 2 Years)

Fiberglass Ridge RH (Year Two)
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

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

- Mid-height MC, facing north
- All roofs much wetter than Winter 1 (50% RH)
- “Tight” diffusion vent worst performer
- Borate contamination of wood MCs?
- Hybrid ccSPF-cellulose roof > 40% MC
  - Interior moisture through ccSPF layer?
  - But roof sheathing only 10% MC-safe

### Cellulose Ridge Wafer

<table>
<thead>
<tr>
<th>Roof #</th>
<th>Short Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Cell-SVR-tD</td>
</tr>
<tr>
<td>6</td>
<td>Cell-SVR-sD</td>
</tr>
<tr>
<td>7</td>
<td>Cell-SVR-DV</td>
</tr>
<tr>
<td>8</td>
<td>ccSPF-Cell</td>
</tr>
</tbody>
</table>

### 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

- 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

- 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

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 assembly
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 assembly

- 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

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?

Questions?

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