Kohta Ueno and Joseph Lstiburek

# Unvented Roof Without Spray Foam:

# The Latest Building America Research

Building Science Corporation

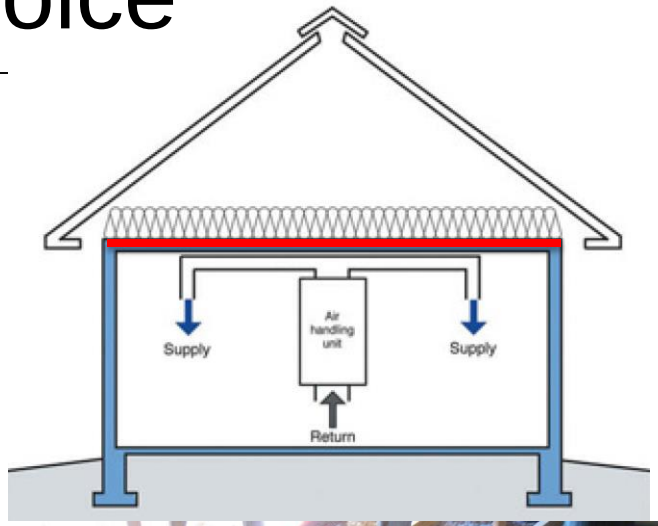


PHIUS 13th Annual North American Passive House Conference

# Background

# Ventilated Attics—Best Choice

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

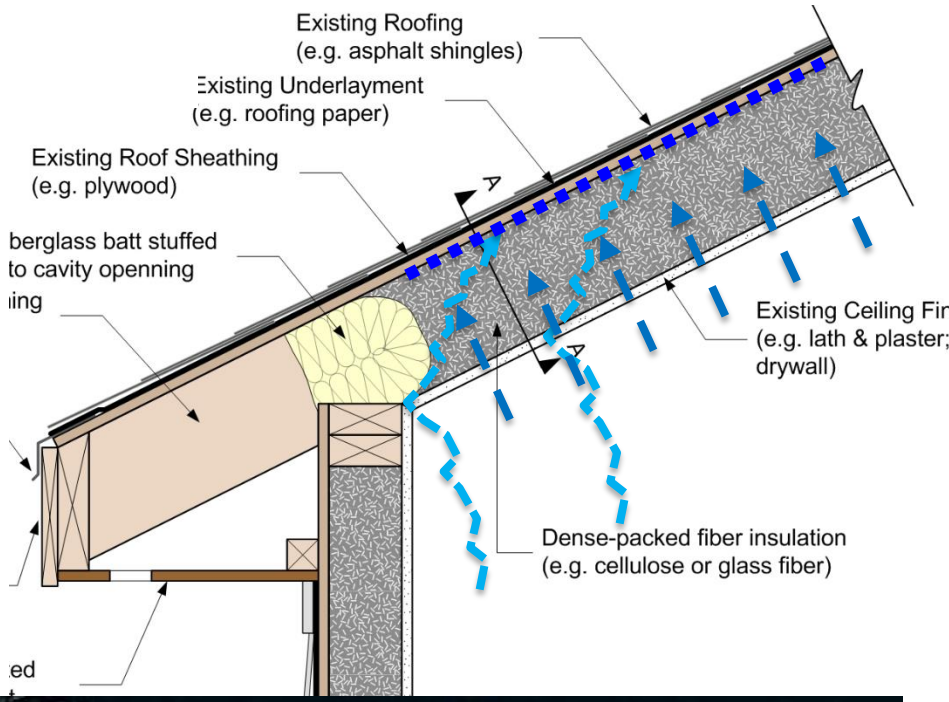



# Then Why Unvented Roofs?

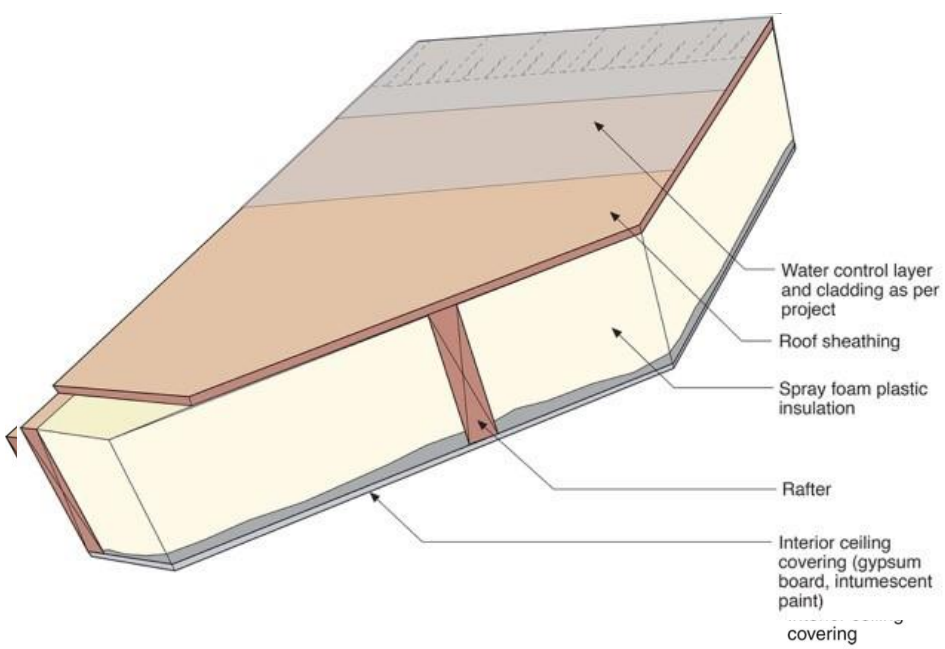
- Living space built into roof
- Vented cathedral assemblies—often poor performance
- Complicated rooflines, hip geometries—how to vent?
- Unworkable air barrier at ceiling line
- HVAC in vented attic

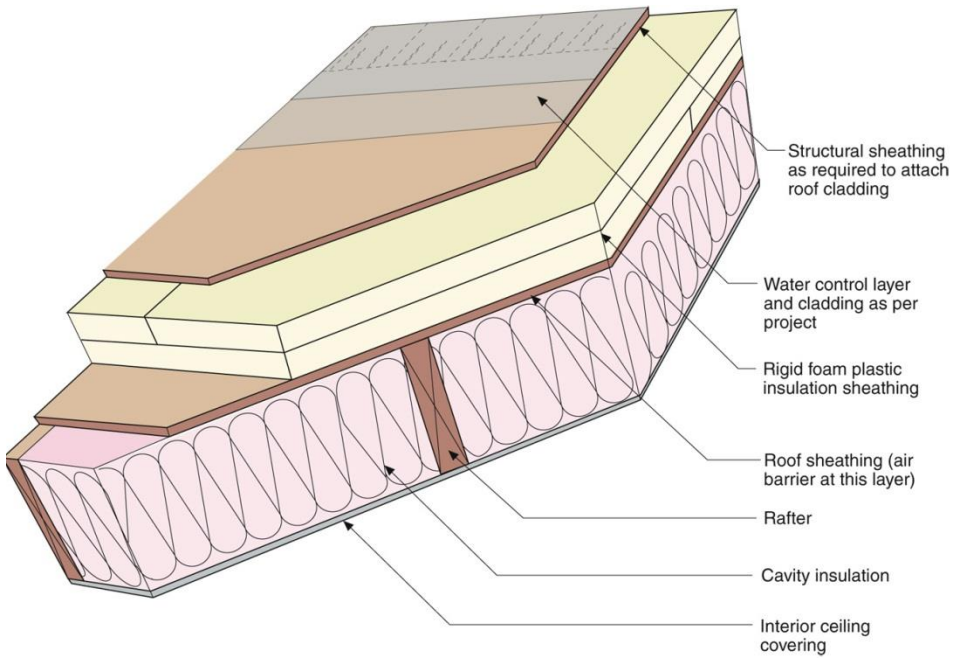

# Why Unvented + Fibrous Risky?

- 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)




# Spray Foam/Exterior Insulation Roofs




- 2006 IRC: § R806.4/5 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?

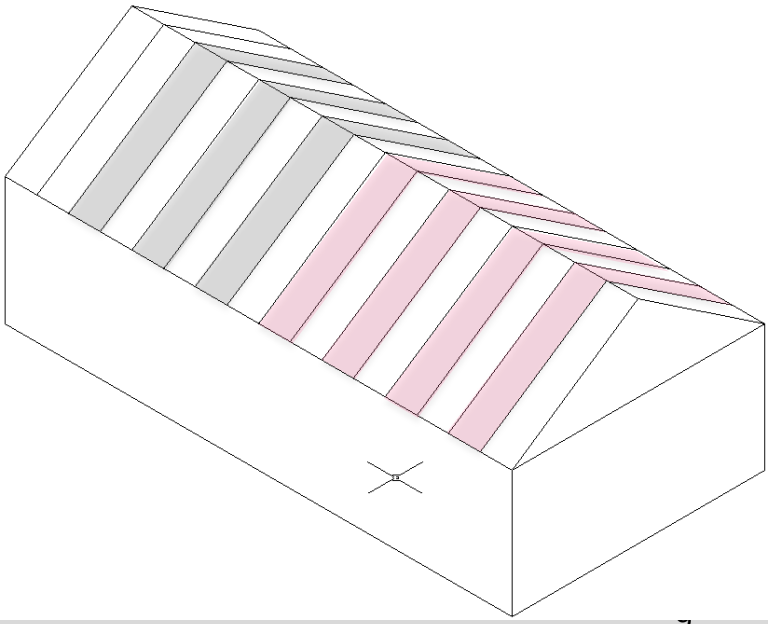
- Unvented roofs without spray/board foams could reduce costs and increase market penetration… IF moisture damage risks are addressed
- Retrofit opportunities (existing uninsulated living space at roof line, without removing finishes)

# Research Project Background

# Test Hut Experimental Approach

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


- 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

# Test Hut Construction


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

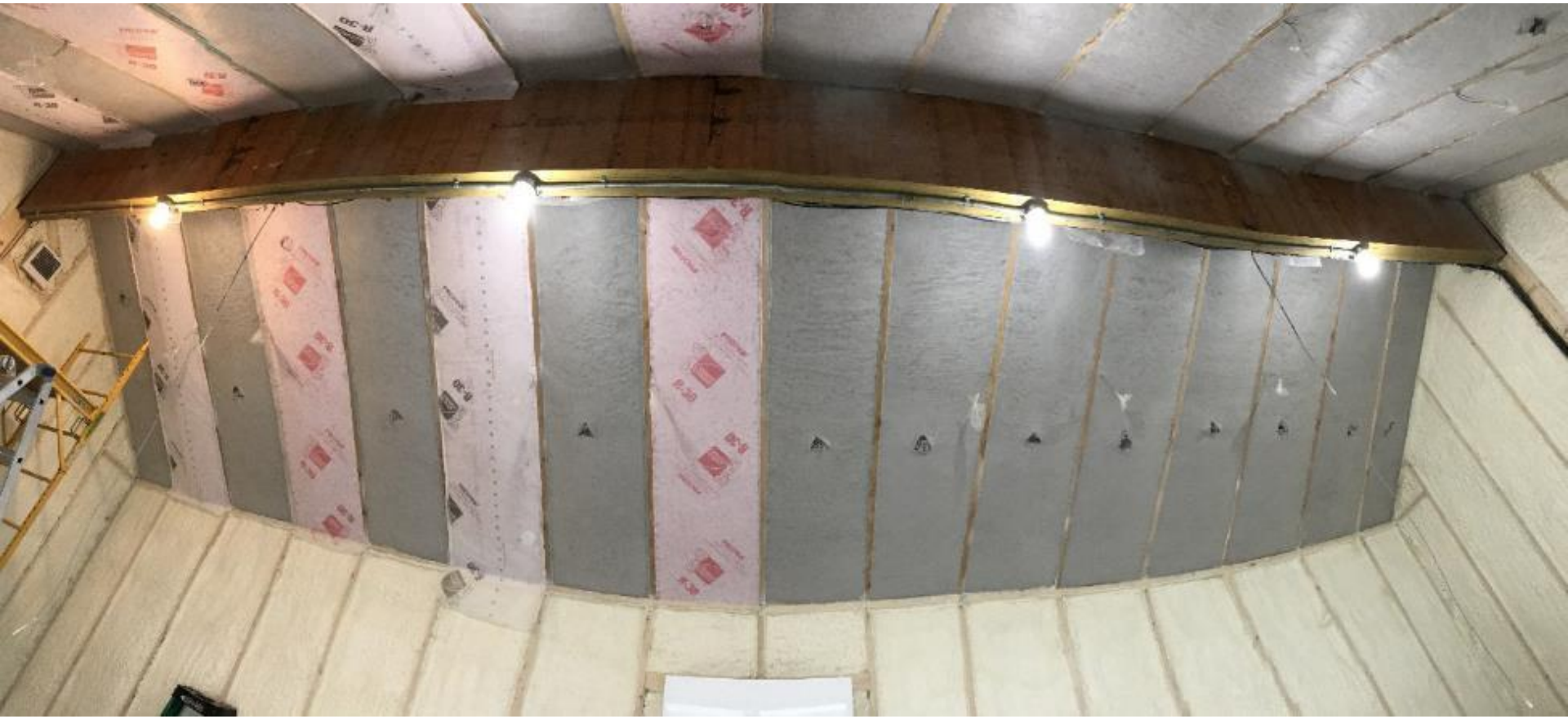
# Test Hut Construction

- 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: Diffusion Vent


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

# Test Roof IDs (Winter 1)

| Roof # | Insulation | Interior VB | Diffusion Vent |
|---|---|---|---|
| 1 | Fiberglass | Fixed perm (OC 1 perm) | Yes |
| 2 | Fiberglass | Variable perm (MemBrain) | Yes |
| 3 | Fiberglass | Fixed perm (OC 1 perm) | No |
| 4 | Fiberglass | Variable perm (MemBrain) | No |
| 5 | Dense pack cellulose | Fixed perm (DuPont 1 perm) | No |
| 6 | Dense pack cellulose | Variable perm (DuPont Variable) | No |
| 7 | Dense pack cellulose | Variable perm (DuPont Variable) | Yes |
| 8 | ccSPF + cellulose "flash and blow" | None | No |

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

# Winter 1 Conclusions

- Roofs with diffusion vent & variable-perm vapor consistently safest; ridge RHs and MCs controlled
- No diffusion vent → worst performance
- Year 1 of 3-year project; interior conditions:
  - Winter 1: “Normal” interior conditions
  - Winter 2: Elevated RH (50% constant)
  - Winter 3: Air leakage into rafter bays
- Modifications to existing assemblies
  - Winter 1 to Winter 2

# Winter 1-Winter 2 Roof Modifications

| 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 (DuPont 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 |

# Results: Fiberglass Roofs

# Warning on Presentation of Results

- Limited “soda straw” view of selected data
- 30 minute window to present
  - Too many roofs (mental gear-shifting)
  - Too many sensors (which one is that one?)
  - Too many sub-experiments

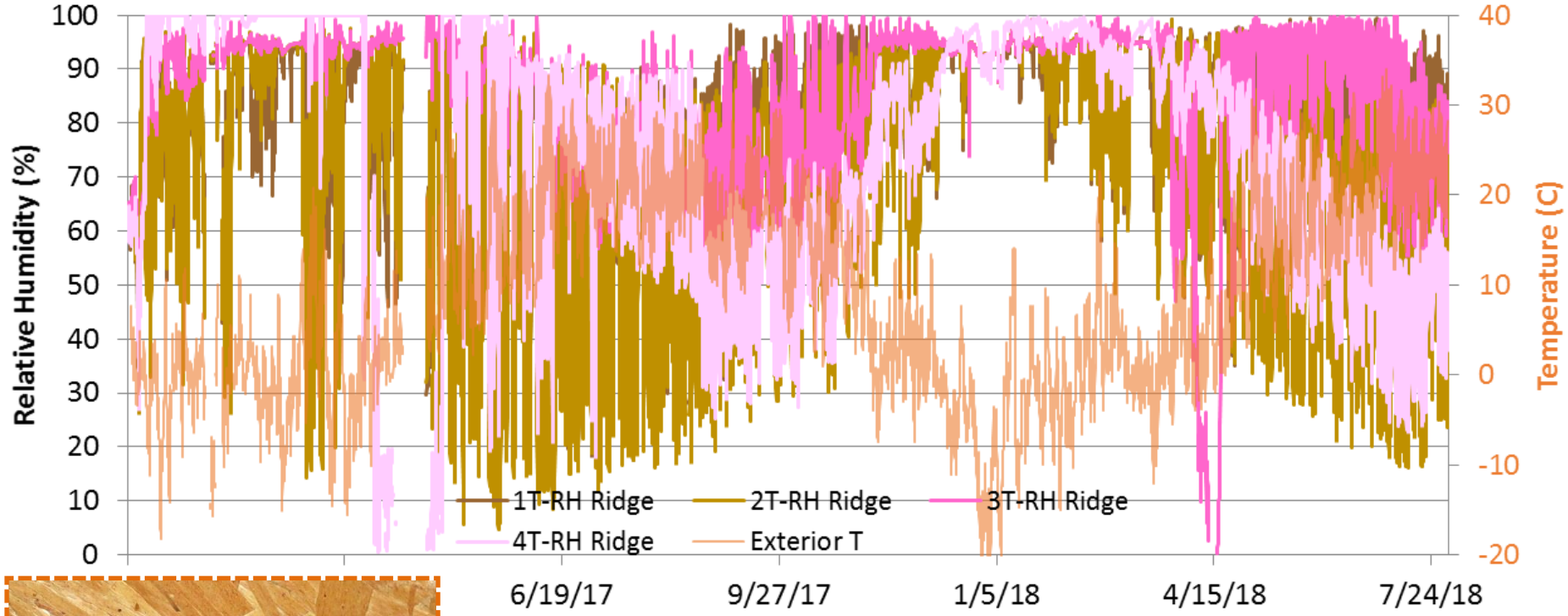
# Fiberglass Roofs: Color Codes

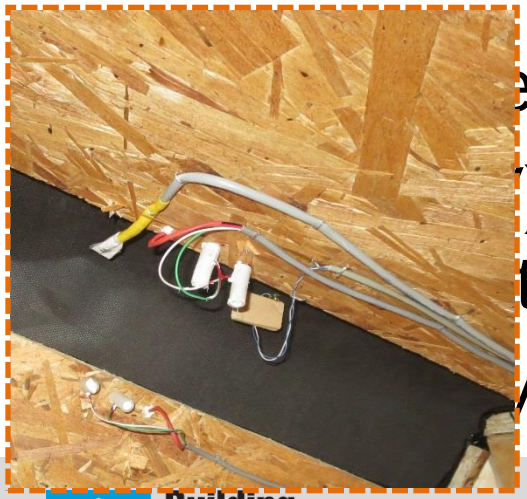
| Roof # | Insulation | Interior VB | Diffusion Vent |
|---|---|---|---|
| 1 | Fiberglass | Fixed perm (OC 1 perm) | 6"/±300 perm (Yes) |
| 2 | Fiberglass | Variable perm (MemBrain) | 6"/±300 perm (Yes) |
| 3 | Fiberglass | **Variable perm (MemBrain)** | **2"/±25 perm** |
| 4 | Fiberglass | Variable perm (MemBrain) | **2"/±300 perm** |
| 5 | Dense pack cellulose | **Variable perm (DuPont Variable)** | **2"/±25 perm** |
| 6 | Dense pack cellulose | Variable perm (DuPont | |
| 7 | Dense pack cellulose | Variable perm (DuPont | |
| 8 | ccSPF + cellulose "flash and blow" | None | |

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

- DV = Diffusion Vent
- nDV = no Diffusion Vent
- sDV = "small" Diffusion Vent (±300 perm, 2" wide)
- tDV = "tight" Diffusion Vent (±25 perm, 2" wide)

# Fiberglass Roofs: Ridge RH



esolve-variations

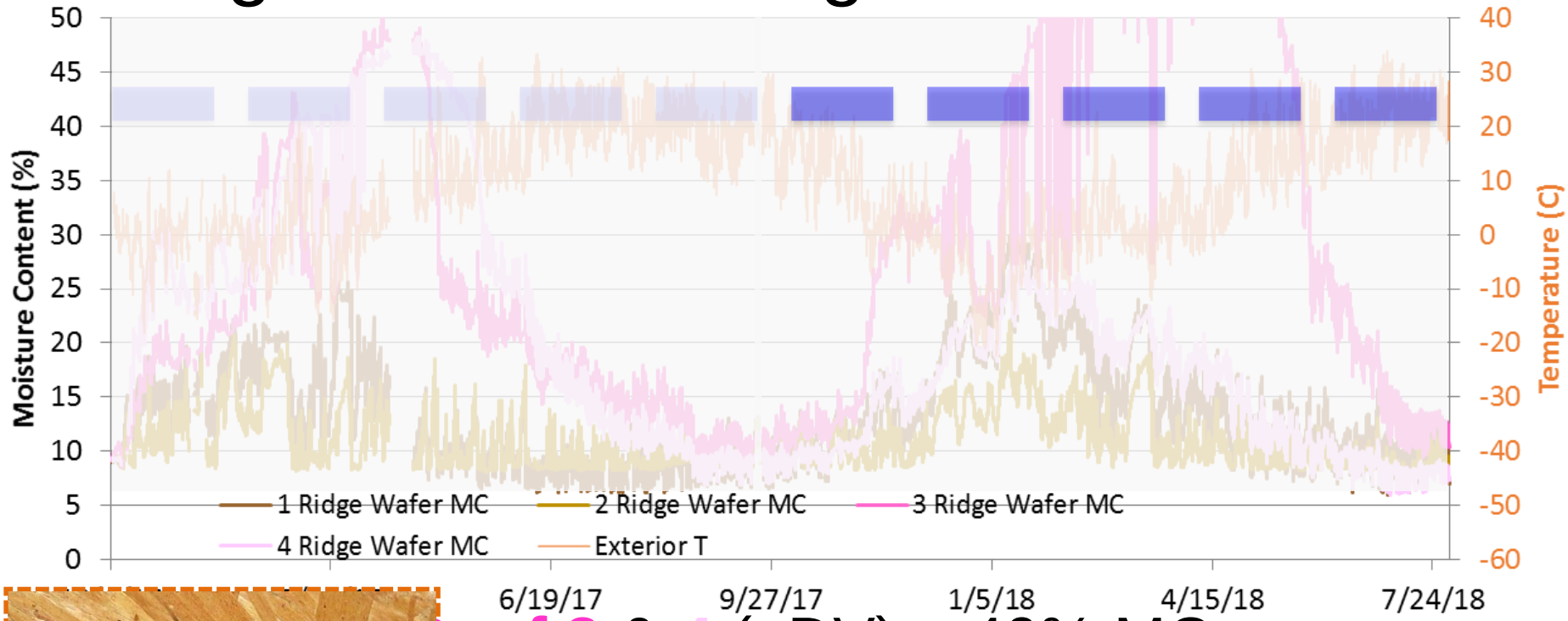
) > 95% RH most of Winter

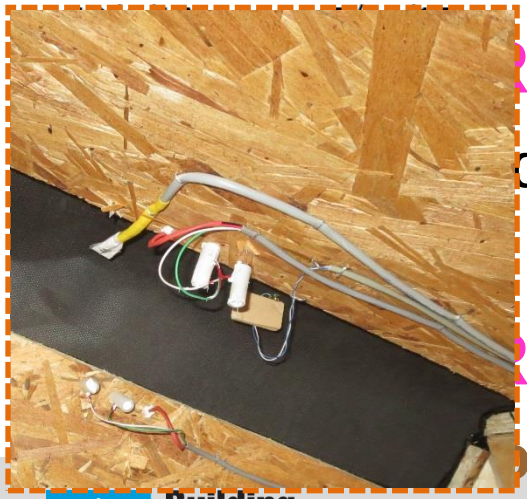
test into summer

/) next highest RHs

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

# Fiberglass Roofs: Ridge Wafers



oof 3 & 4 (nDV) > 40% MC

d wafer calibrated ~40-45% MC

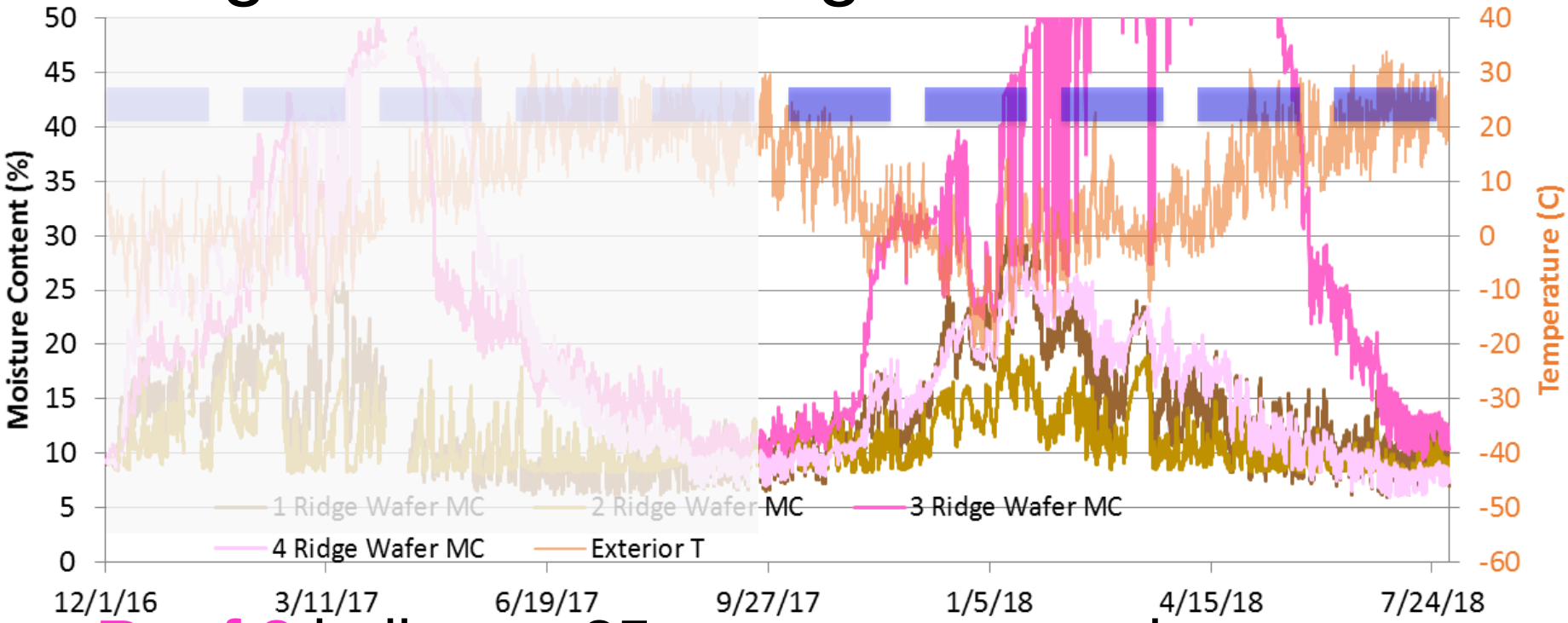
Vent Roofs 1 & 2 stay drier <25%

oof 3 (tDV) soaking wet ridge

ofs 1, 2 & 4 (DV) 20-30% MC

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

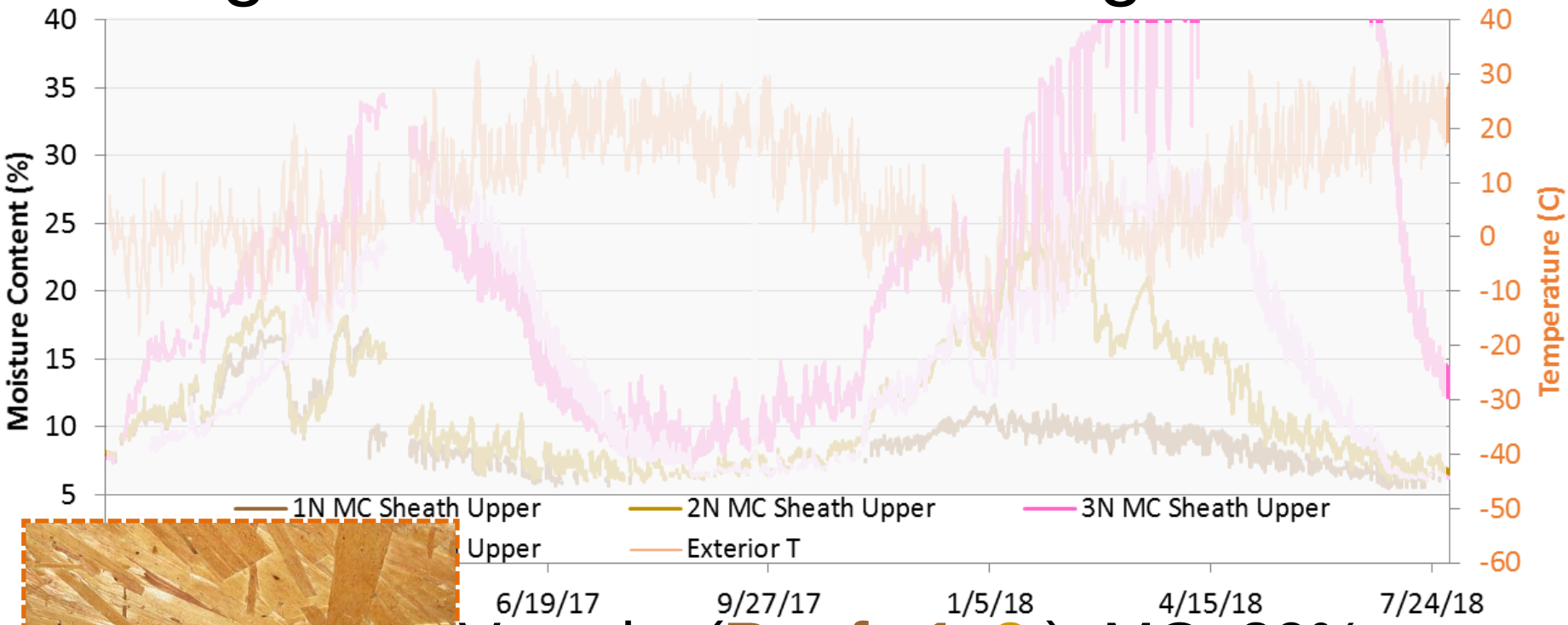
# Fiberglass Roofs: Ridge Wafers




- **Roof 3** indicates 25 perms not enough
- **Roofs 1, 2** & **4** (DV) differences not clear
  - **Roof 4** (sDV) restricted, **Roofs 1** VB vs SVR?
- All dry down in summer, **Roof 3** delayed

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

# Fiberglass Roofs: N Sheathing MCs




V works (**Roofs 1, 2** ), MC<20%

ot nearly as safe at 50% RH

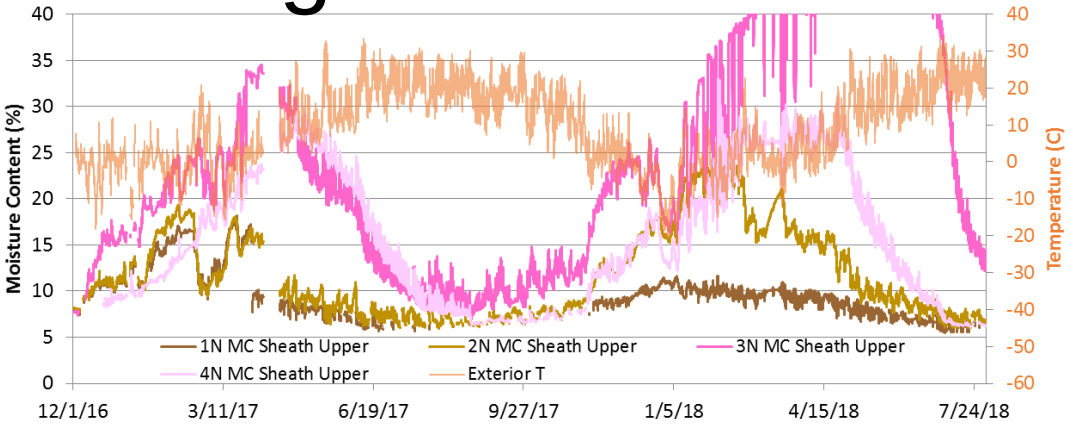
V) very wet, very long time

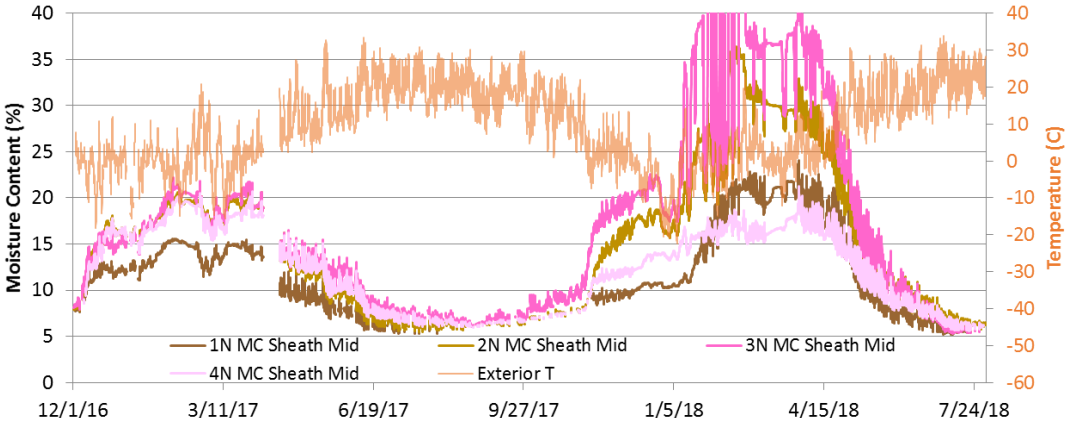
s–some over 20% MC

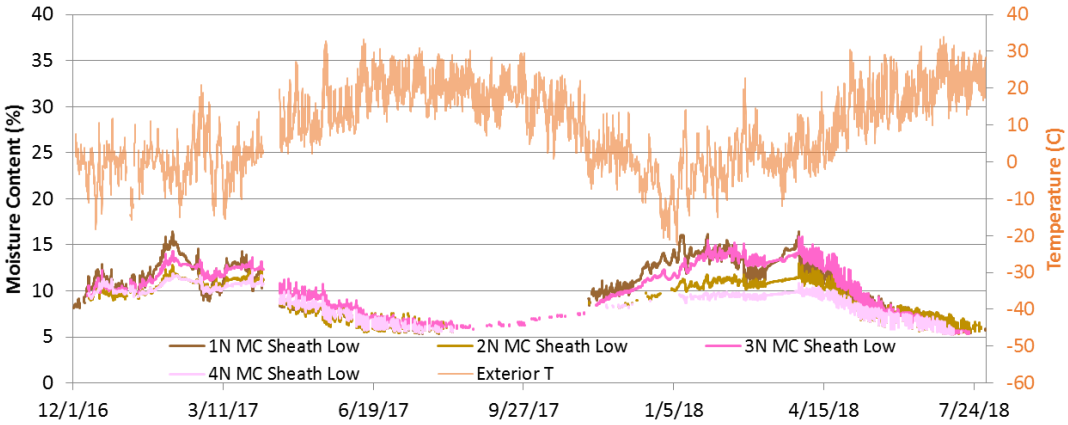
| Roof | Short Name |
|---|---|
| 1 | FG-VB-DV |
| 2 | FG-SVR-DV |
| 3 | FG-SVR-tDV |
| 4 | FG-SVR-sDV |

- **Roofs 1** vs. **Roof 2**–SVR opening up??

# Fiberglass Roofs: N Sheathing MCs




- North sheathing MCs
- High-Mid-Low
- Gradient of MCs (highest near ridge, lowest near eaves)
- Much higher MCs in Winter 2
- Many over 20% at mid-height sheathing
- “Low” location still safe (below 15%)

# Conclusions: Fiberglass

- All roofs show mold indices under 3.0: would pass ASHRAE 160… BUT
- **Roof 3** (tDV) moisture accumulation: 25 perms is not sufficient for DV
- Sheathing MCs above 20% when 50% RH inside: no longer an easy call
- **Roof 1** (fixed VB) inward drive—extended 100% RHs on north side; might not capture worst case (ridge)
- No consistent signal **Roof 4** (small, SVR) vs. **Roof 1-2** (larger, VB & SVR)
- Disassembly of ridge to look at sheathing conditions

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

# Results: Cellulose Roofs

# Cellulose Roofs: Color Codes

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

| Roof # | Insulation | Interior VB | |
|---|---|---|---|
| 1 | Fiberglass | Fixed perm (OC 1 perm) | |
| 2 | Fiberglass | Variable perm (MemBrain) | |
| 3 | Fiberglass | **Variable perm (MemBrain)** | **2”/±25 perm** |
| 4 | Fiberglass | Variable perm (MemBrain) | **2”/±300 perm** |
| 5 | Dense pack cellulose | **Variable perm (DuPont Variable)** | **2”/±25 perm** |
| 6 | Dense pack cellulose | Variable perm (DuPont Variable) | **2”/±300 perm** |
| 7 | Dense pack cellulose | Variable perm (DuPont Variable) | 6”/300 perm (Yes) |
| 8 | ccSPF + cellulose “flash and blow” | None | No |

- DV = Diffusion Vent
- nDV = no Diffusion Vent
- sDV = "small" Diffusion Vent (±300 perm, 2" wide)
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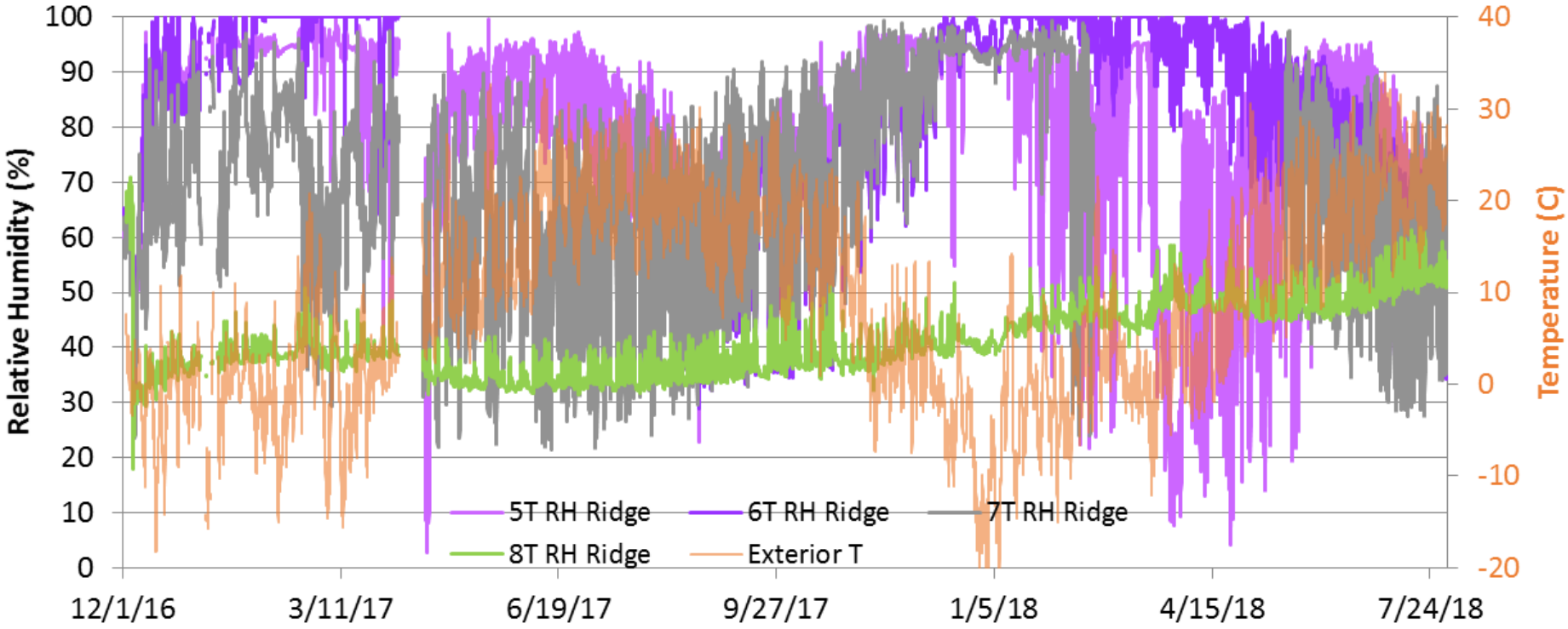
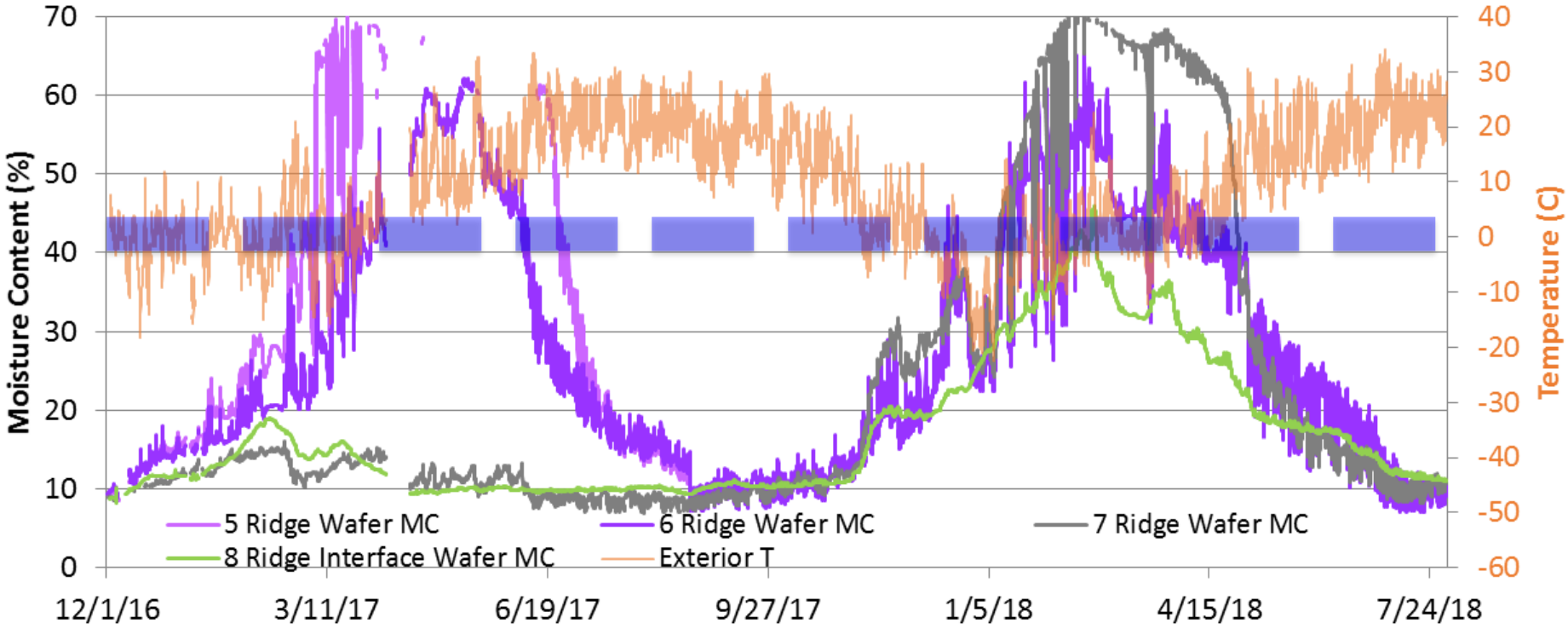
# Cellulose Roofs: Ridge RH




- Difficult to differentiate
- RH sensor failures: **Roof 6** (2017), **Roof 5** (unrealistic data 2018), **Roof 7** (2018)

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

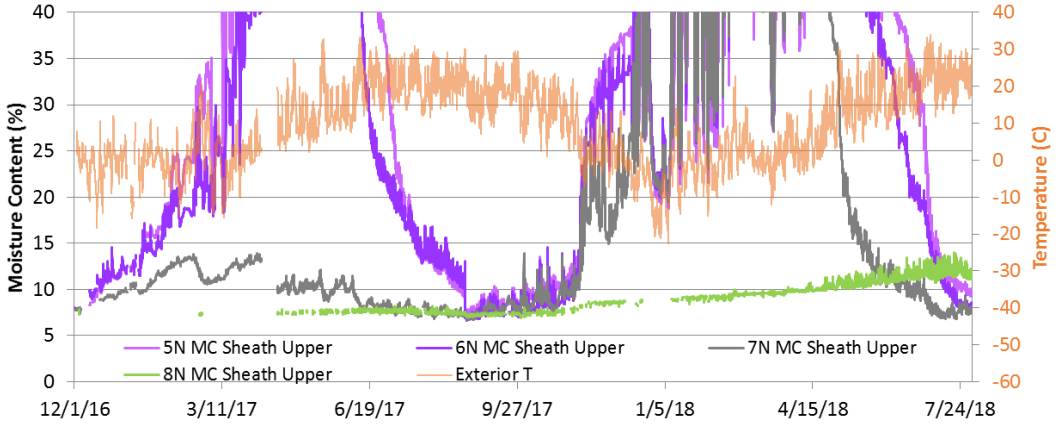
# Cellulose Roofs: Ridge Wafer

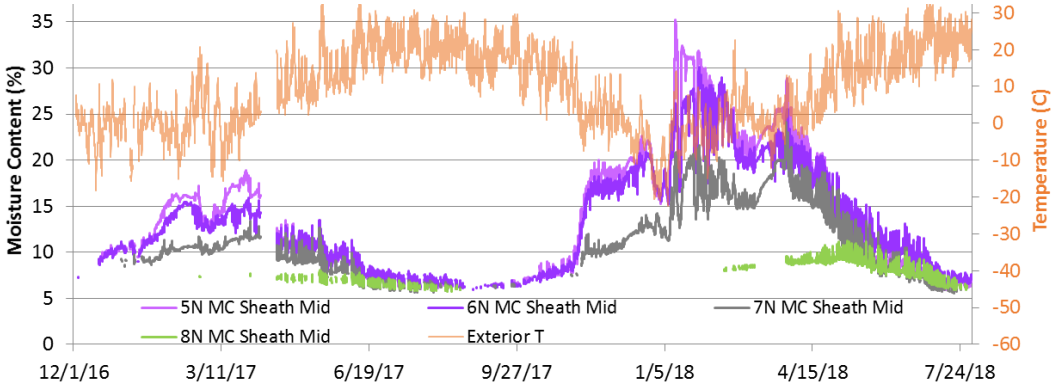


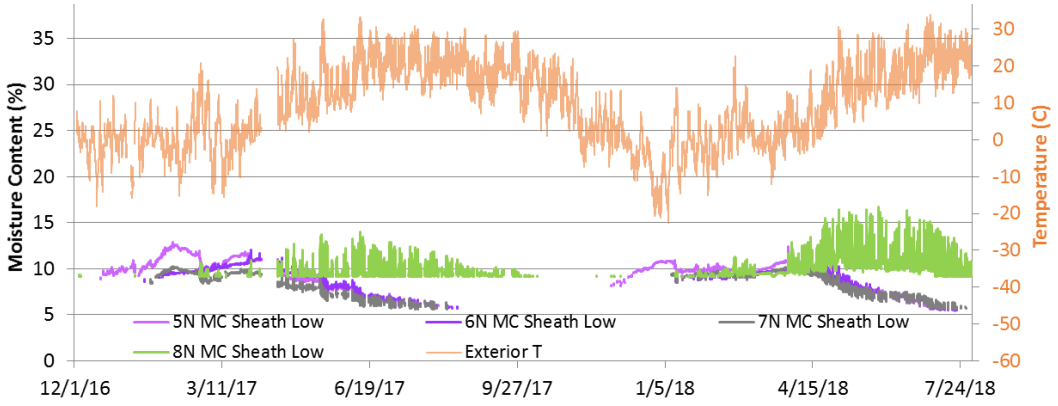

- Unrealistic MCs: condensation, borate migration
- **Roof 5** no data Winter 2 (unspliceable)
- **Roof 6** drier than **Roof 7**?
- **Roof 7** dries down faster (larger DV)

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

# Cellulose Roofs: N Sheathing MCs




- North sheathing MCs
- High-Mid-Low
- Upper: condensation & borate migration
- 50% RH much more challenging-many over 20% MC (“Mid”)
- “Low” MCs safe
- **Roof 8** (hybrid) MCs below 15%-safe

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

# Conclusions: Cellulose

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

- **Roof 8** (hybrid) safe through Winter 2
- **Roof 5-Roof 6-Roof 7**:
  - High RHs at sheathing (90-95% common)—not necessarily a problem, but paying attention
  - Wafers & MCs high but inconclusive (borate spreading)
  - Sheathing MCs high (uncertainty-borate migration)
  - **Roof 7** consistently fastest to dry (largest DV)
- Inward drive sensors non-issue in cellulose roofs, even after 50% RH winter (storage)
- All roofs show mold indices under 3.0: would pass ASHRAE 160… BUT

# Ridge Disassembly

# Summer 2 Ridge Disassembly Work

- Fiberglass: staining, rundown, some mold spotting


# Summer 2 Ridge Disassembly Work

- Cellulose: worst mold, settling (greater at north)


# Conclusions and Further Work

# Conclusions

- Interior at 50% RH creates much more challenging conditions: many pushing edge of risk
- Mold Index #s remain below 3.0
- BUT we grew mold in several roofs
- Many MCs over 20% to 30%, sustained high RH
- “Tight” diffusion vent (~25 perms vs. ~300 perms) did not work acceptably
- “Small” diffusion vent: smaller → less drying
- 50% RH pushes limits of “flash and blow” ratios—safe storage saves cellulose roof

# Conclusions

- At 50% RH interior, these are assemblies we “might get away with” without failure
- Consider requirements for interior conditions?
  - Control interior RH to maximum %?
  - Difficult to implement or enforce
  - 50% RH interior increasingly likely (tighter, multifamily)
- Takeaways from the research:
  - Diffusion vent good; bigger is better
  - Variable perm inward drying: every chance we can get
  - Hybrid roof is indisputably safest

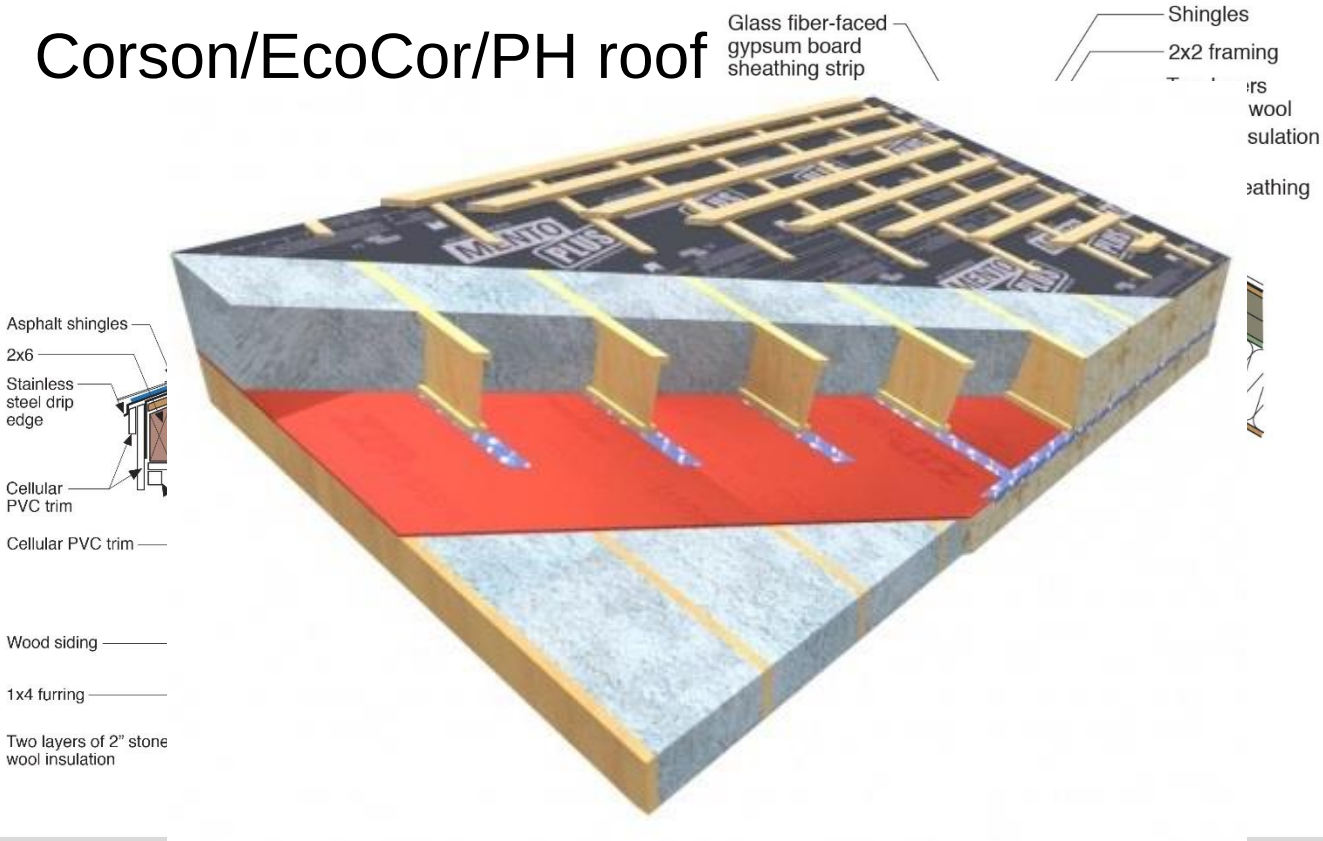
# Further Work

- Winter 3 Operation (Proposed)
  - Start at 50% RH, no air leakage
  - Introduce air leakage in later winter (possible on/off)
- "Tight" diffusion vent (**Roof 3** & **Roof 5**): replacement?
  - Full-size 300 perm diffusion vent (like others)
  - Different variable-perm interior air barrier/vapor retarder

# Recommendations

# 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

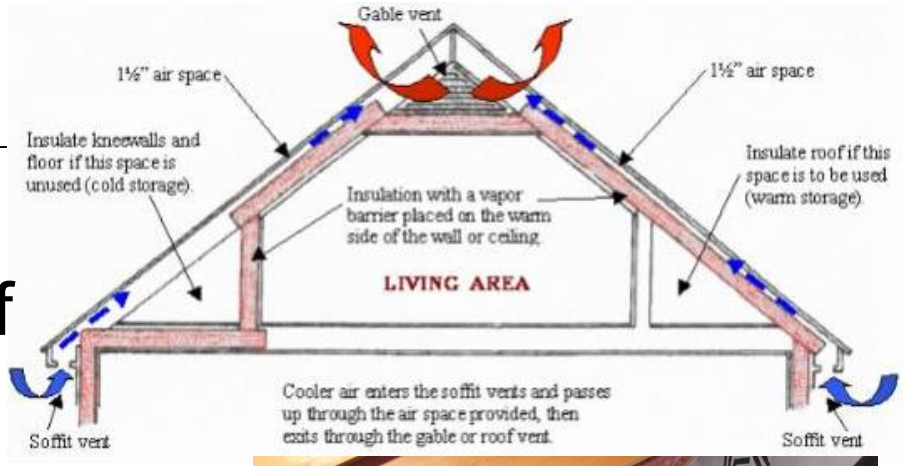


# Recommendations

- Fibrous-only insulation (no exterior insulation) roof assemblies are “off-label” (against code)
- Diffusion vent + variable-perm vapor retarder best
- 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?

# 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



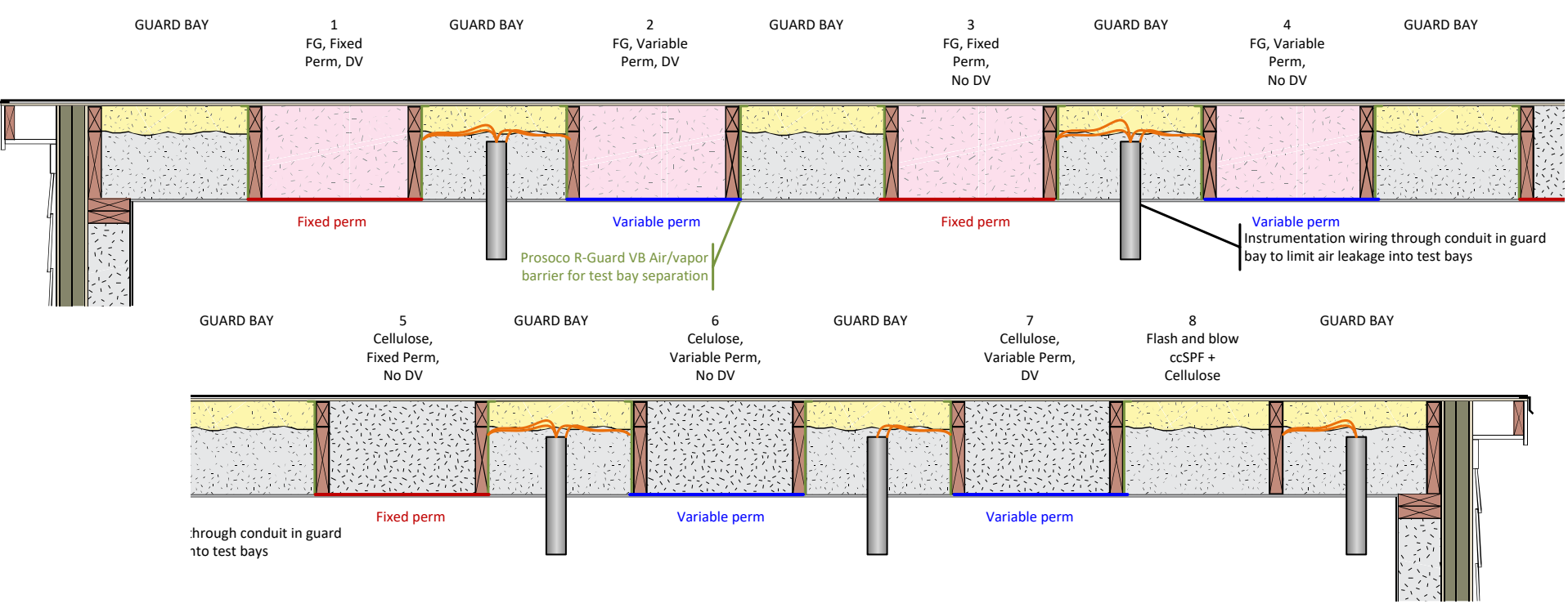


# Questions?

Kohta Ueno
kohta (at sign) buildingscience dot com

This presentation will be posted at: https://buildingscience.com/past-events

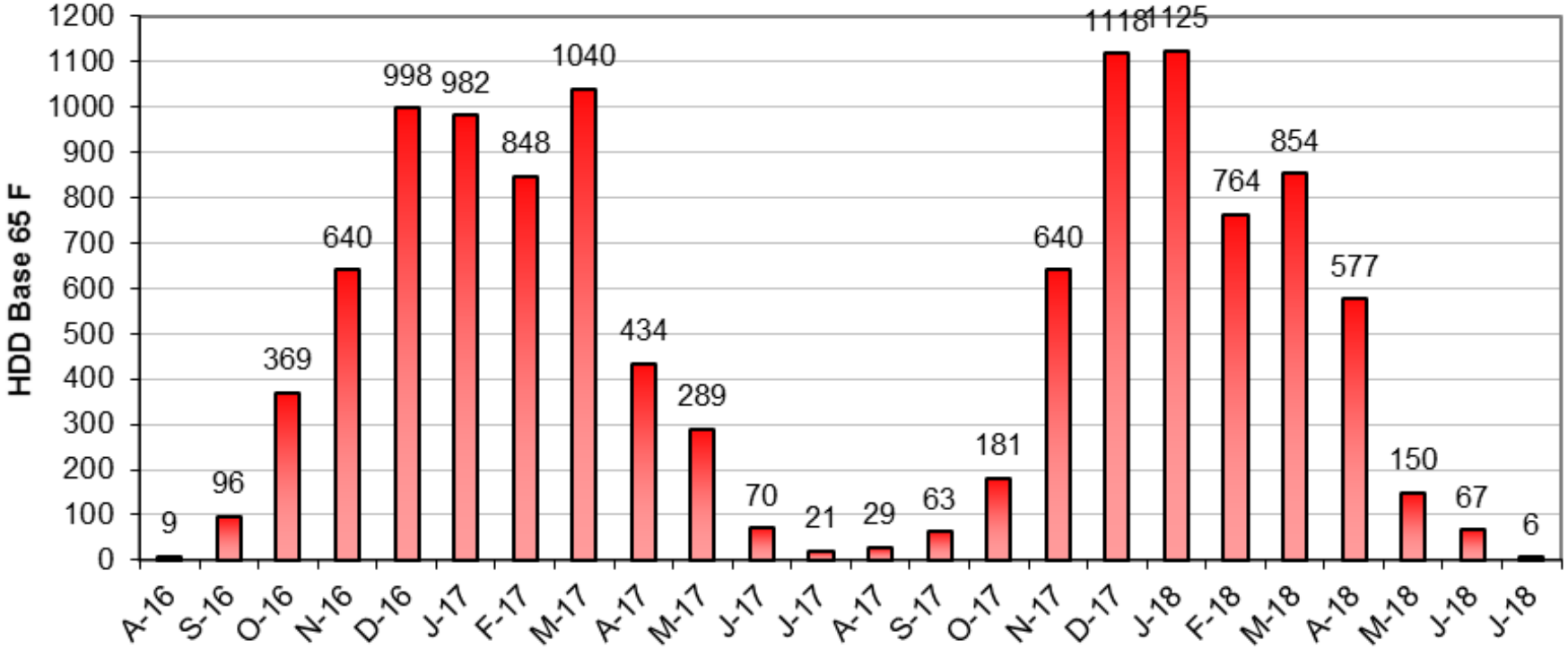

# Experimental Approach: Roof Section




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

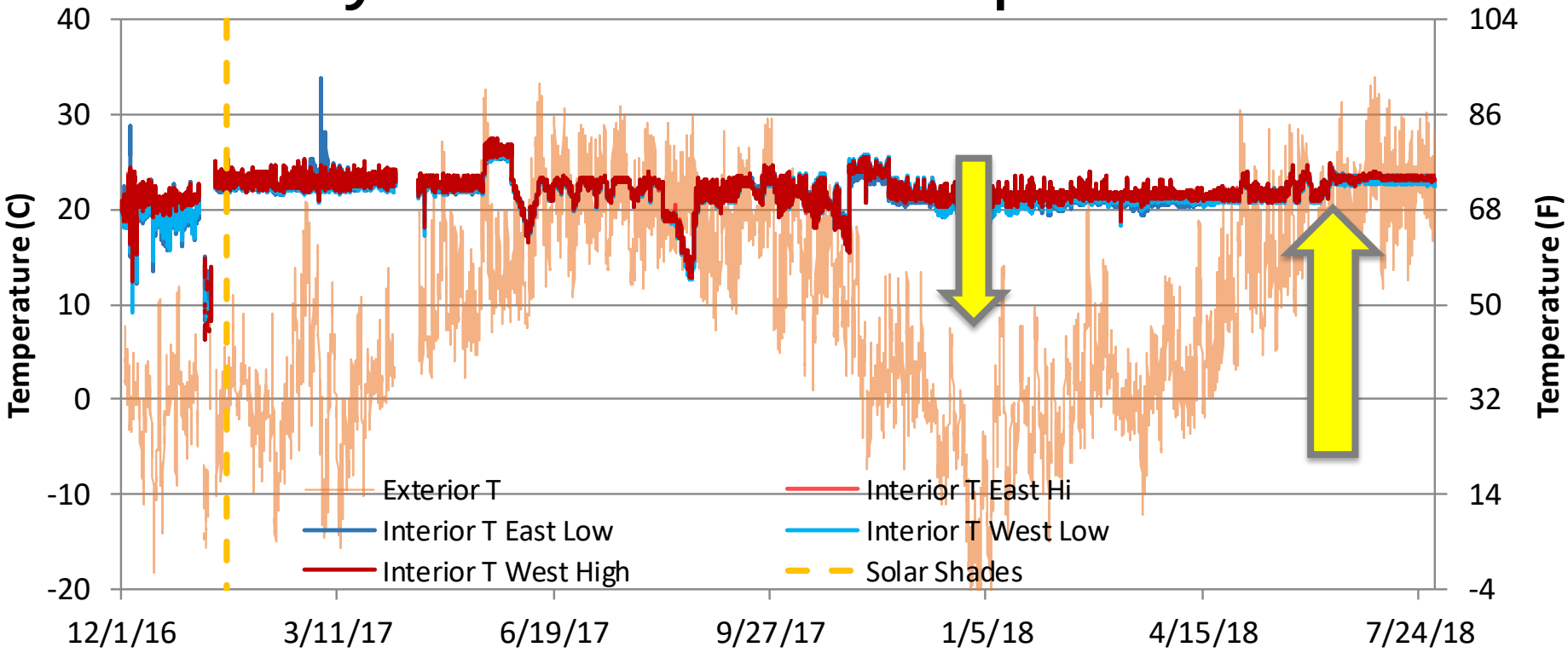
# Results: Boundary Conditions

# Boundary Conditions: Exterior Climate



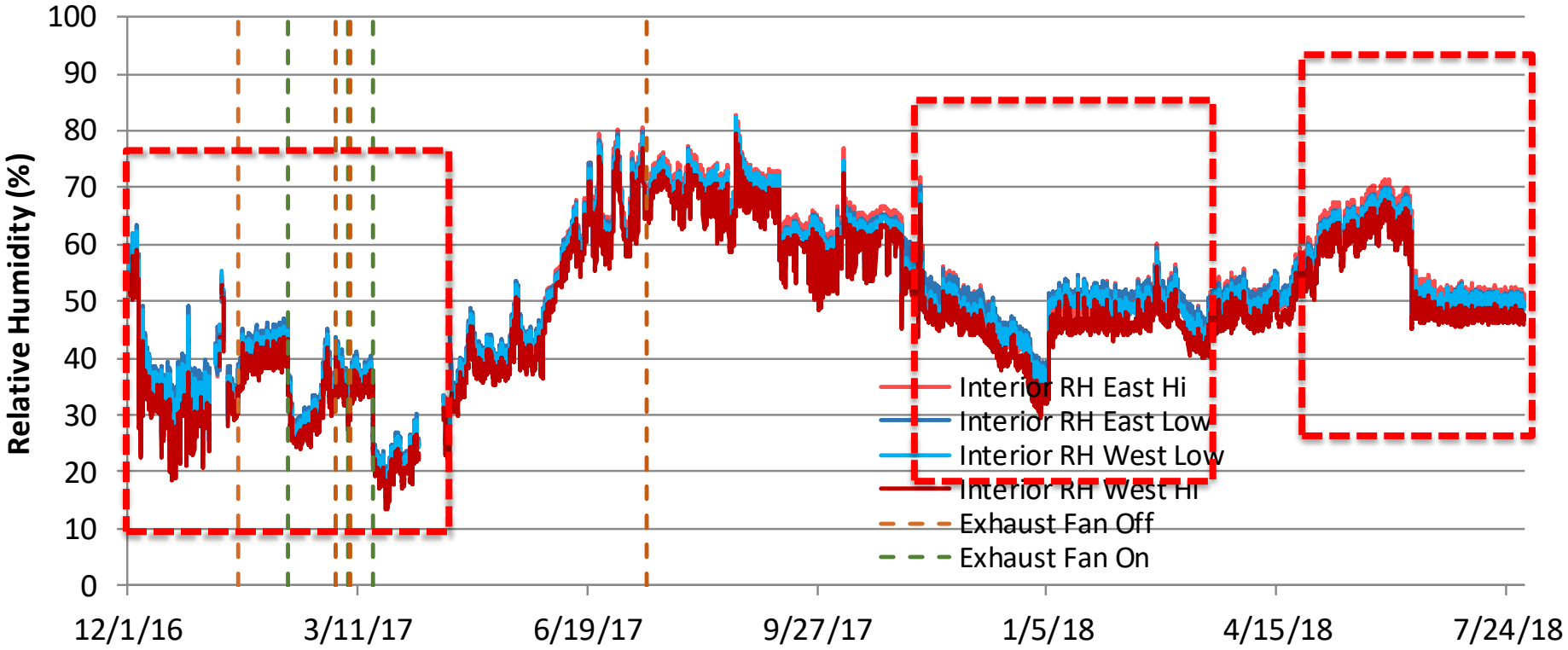

- KLWM (Lawrence MA) airport HDD data
- Winter 2016-2017: 5796 HDD (89% of normal)
- Winter 2017-2018: 5574 HDD (85% of normal)
- KBOS weather 94% & 96% of normal

# Boundary Conditions: Temperature



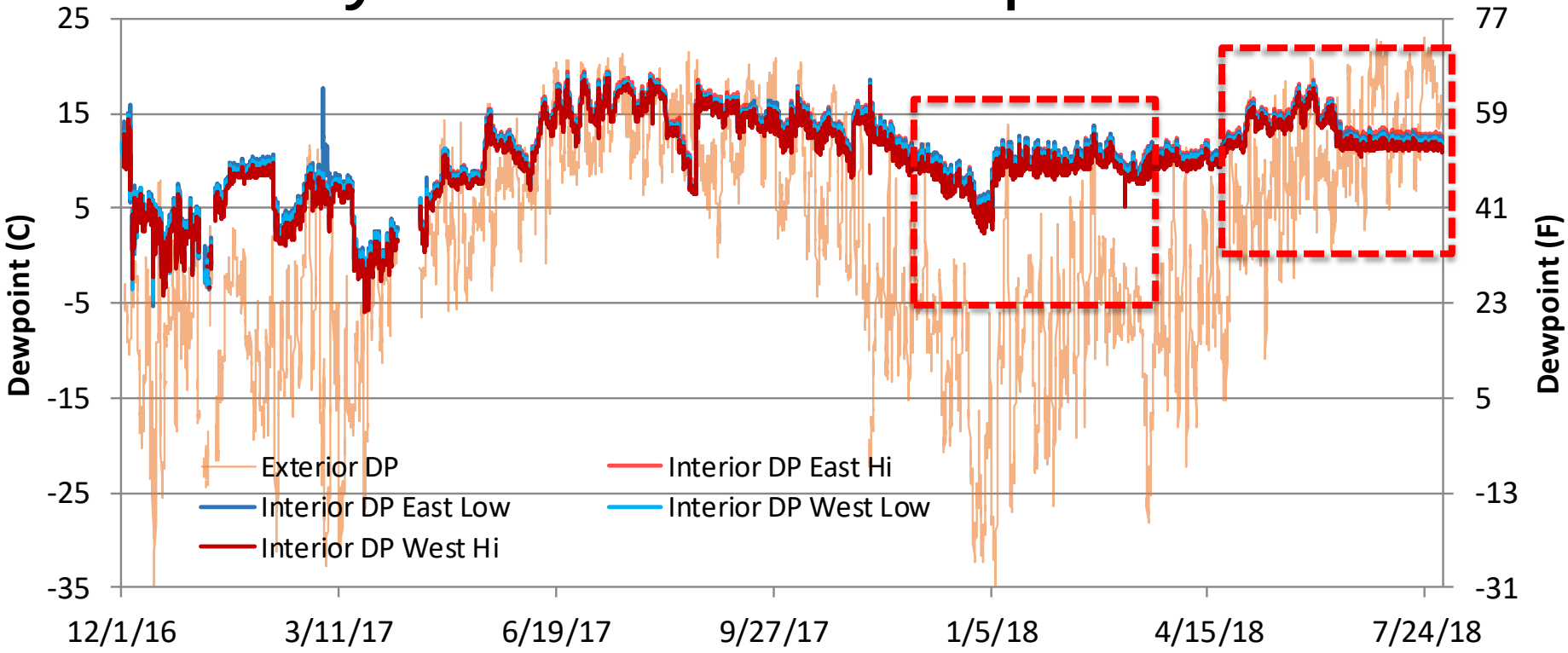

- Data collected December 2016-July 2018
- Winter 2017-2018 similar HDD, more extreme cold
- Interior temperature held near-constant

# Boundary Conditions: Relative Humidity




- Winter 1 RHs varied 25% to 45% (exhaust fan)
- Winter 2 RH 50% after early January
- Spring/Summer 2018 added dehumidifier (50% RH)

# Boundary Conditions: Dewpoint

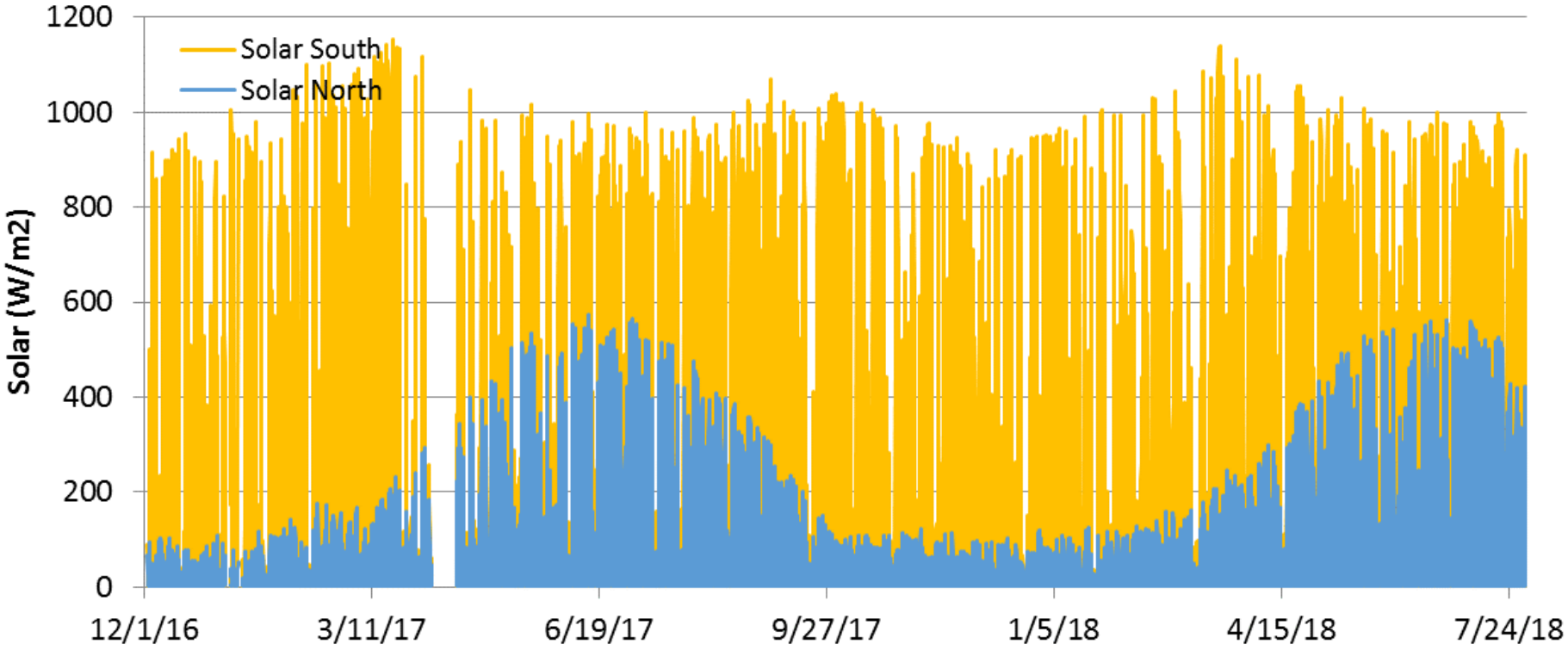



- Humidification operation
- Dehumidification operation

# Humidification

- Humidification confirmed via direct measurement and experience

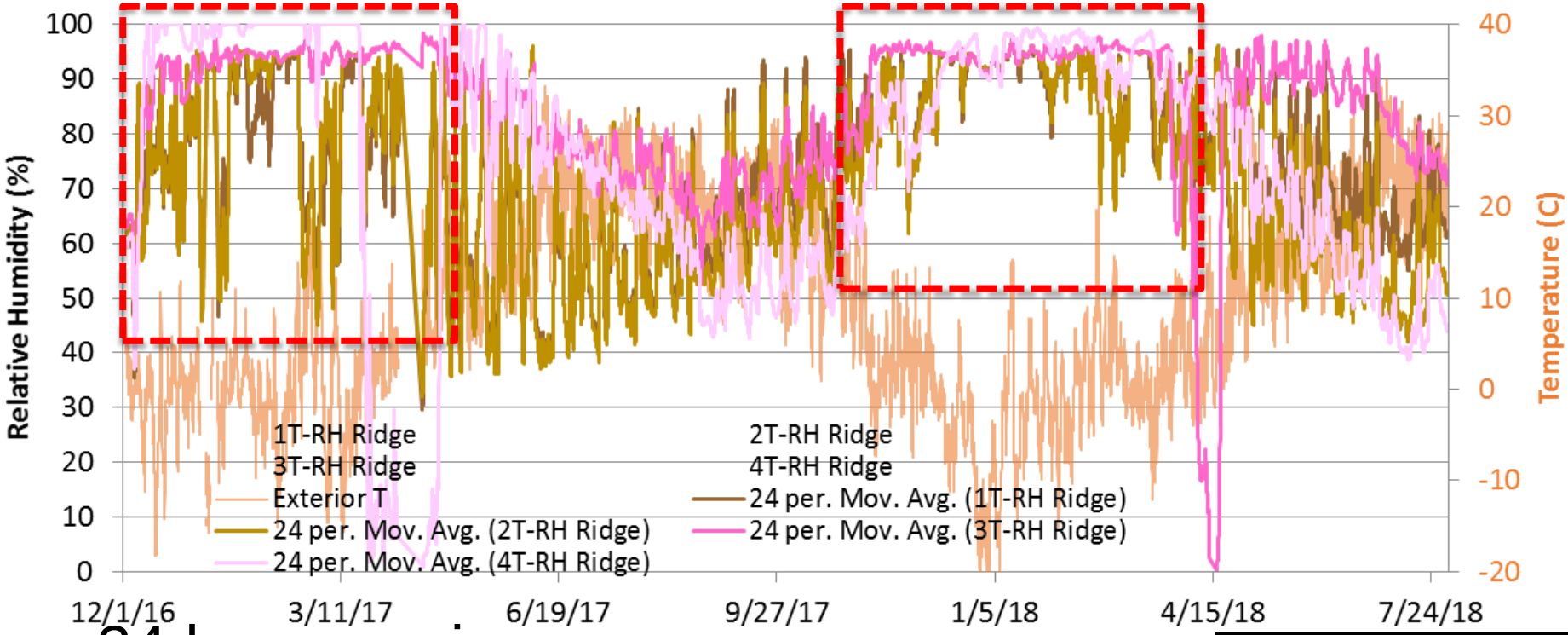
# Boundary Conditions: Solar




- Solar data primary collected if future modeling work, correlation with events
- North solar on 8:12 roof in MA

# Results: Fiberglass Roofs

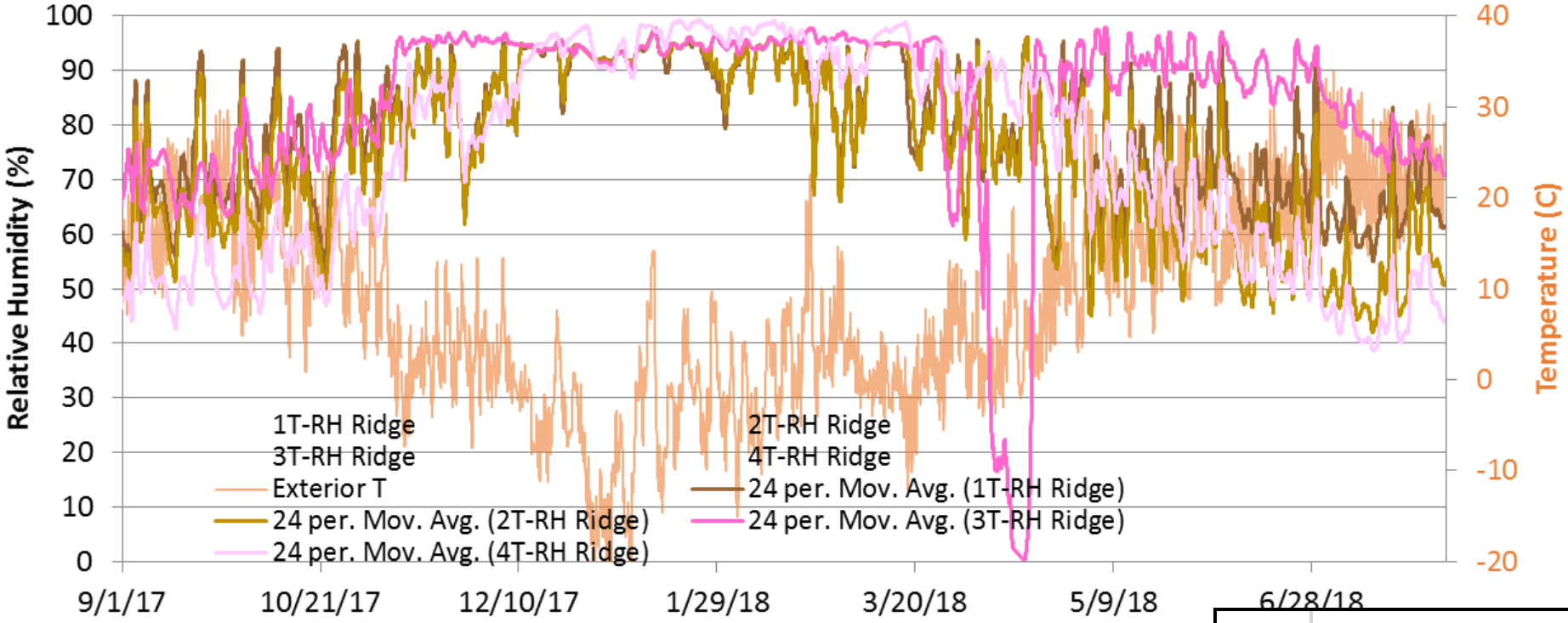
# Fiberglass Roofs: Ridge RH




- 24 hour moving average
- **Roof 3** (tDV) & **Roof 4** (sDV) wettest
- **Roof 3** (tDV) stays wet into spring
- **Roofs 1 & 2** higher RHs than Winter 1

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

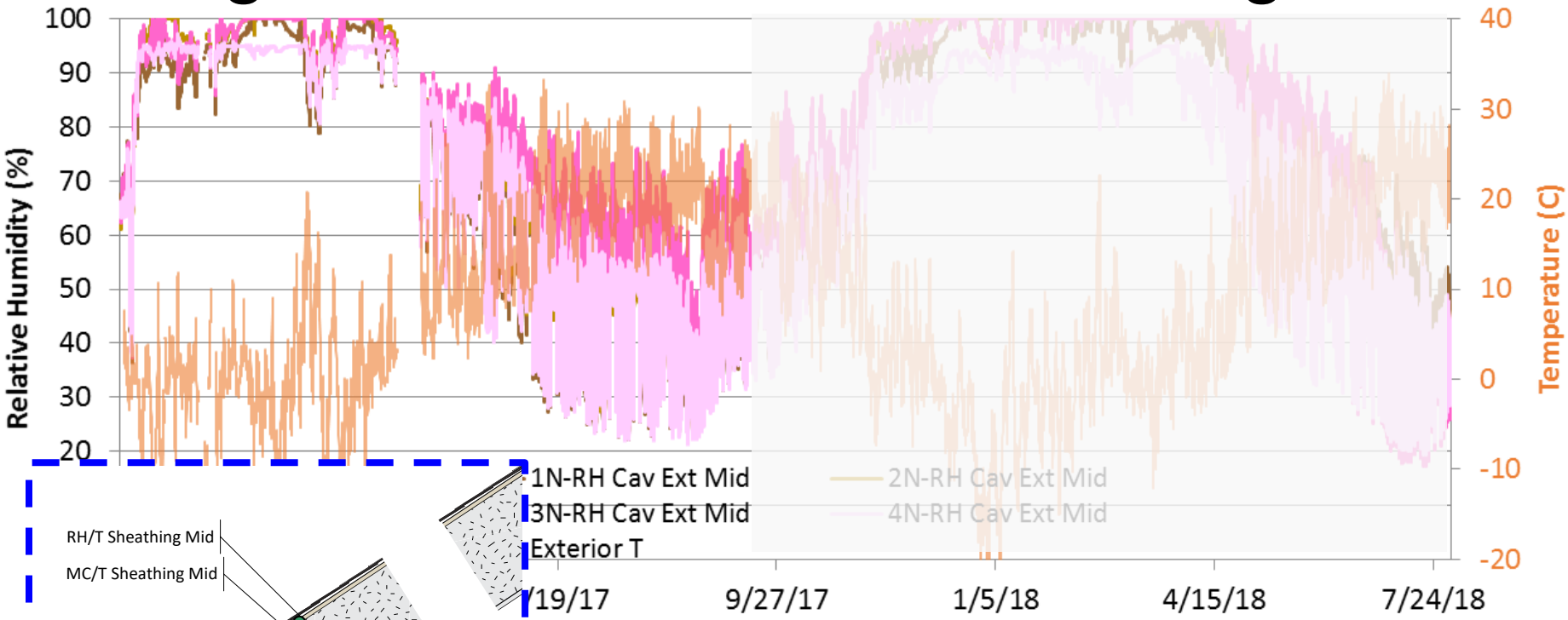
# Fiberglass Roofs: Ridge RH

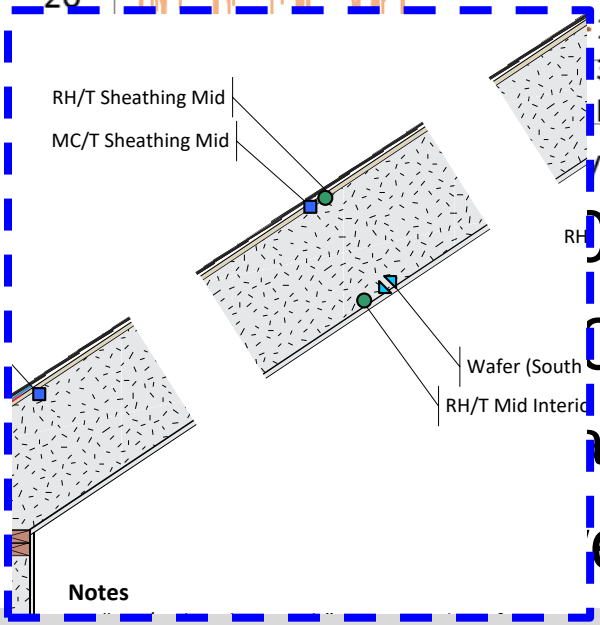



- Zoom in on Winter 2
- **Roof 3** (tDV) RH sensor failure, wet
- **Roof 1** (VB) stays wetter in summer
  - Inward drying season-constricted?

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

# Fiberglass Roofs: North Sheathing RH




0% Winter 1

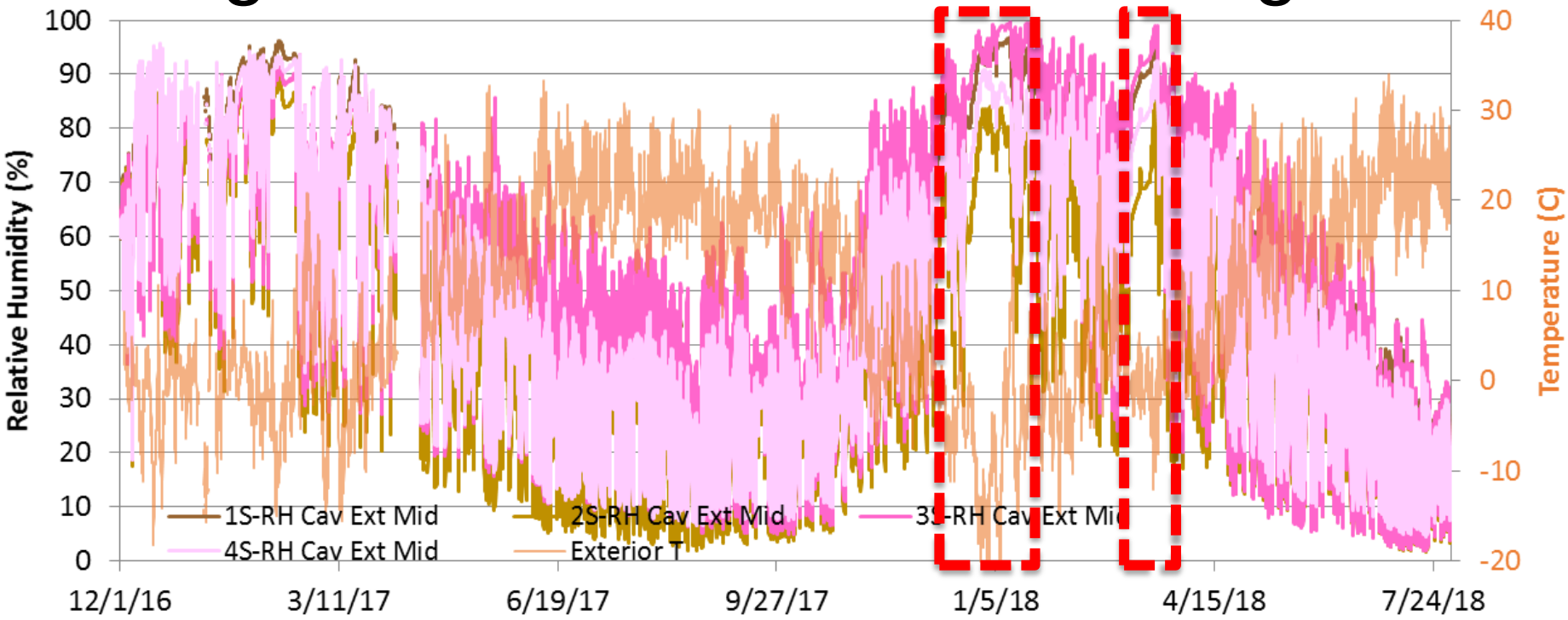
0% all winter long

ctually drier? Sensor difference

ettest (not just local drying)

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

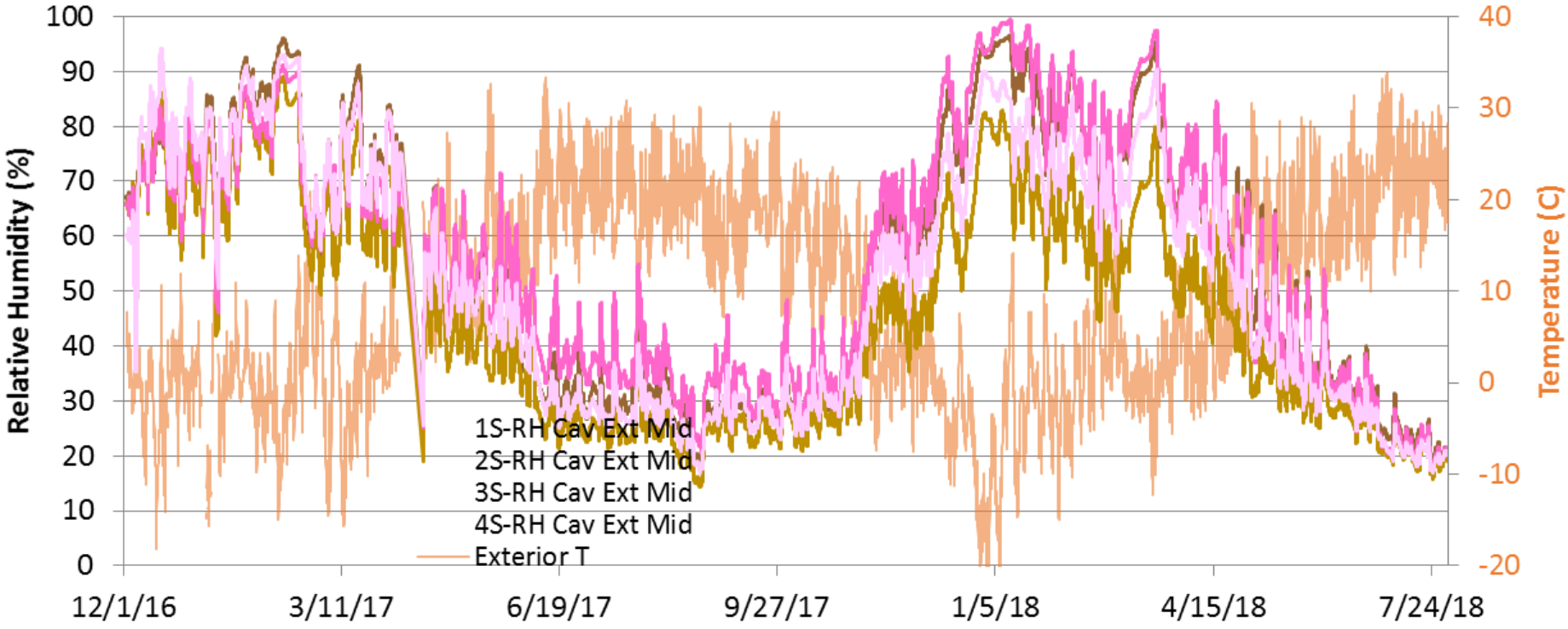
# Fiberglass Roofs: South Sheathing RH




- S roofs drier than N roofs (solar warming)
- Diurnal variations/swings (solar gain)
  - Stable periods = snow cover
- Can't differentiate roofs (swings)

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

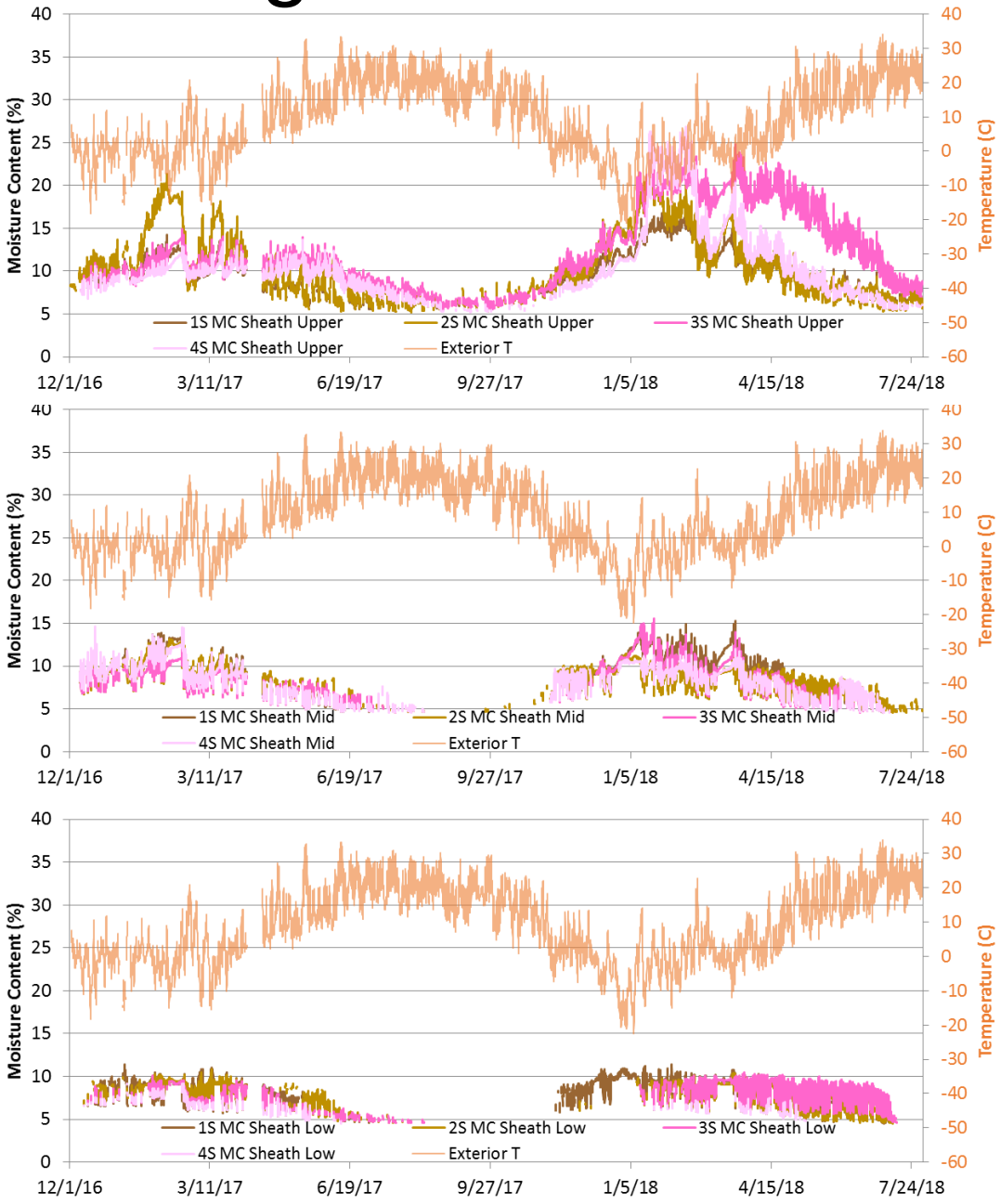
# Fiberglass Roofs: South Sheathing RH




- 24 hour moving average RH data
- **Roof 3** (tDV) appears wettest
- **Roof 2** (SVR/DV) appears driest

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

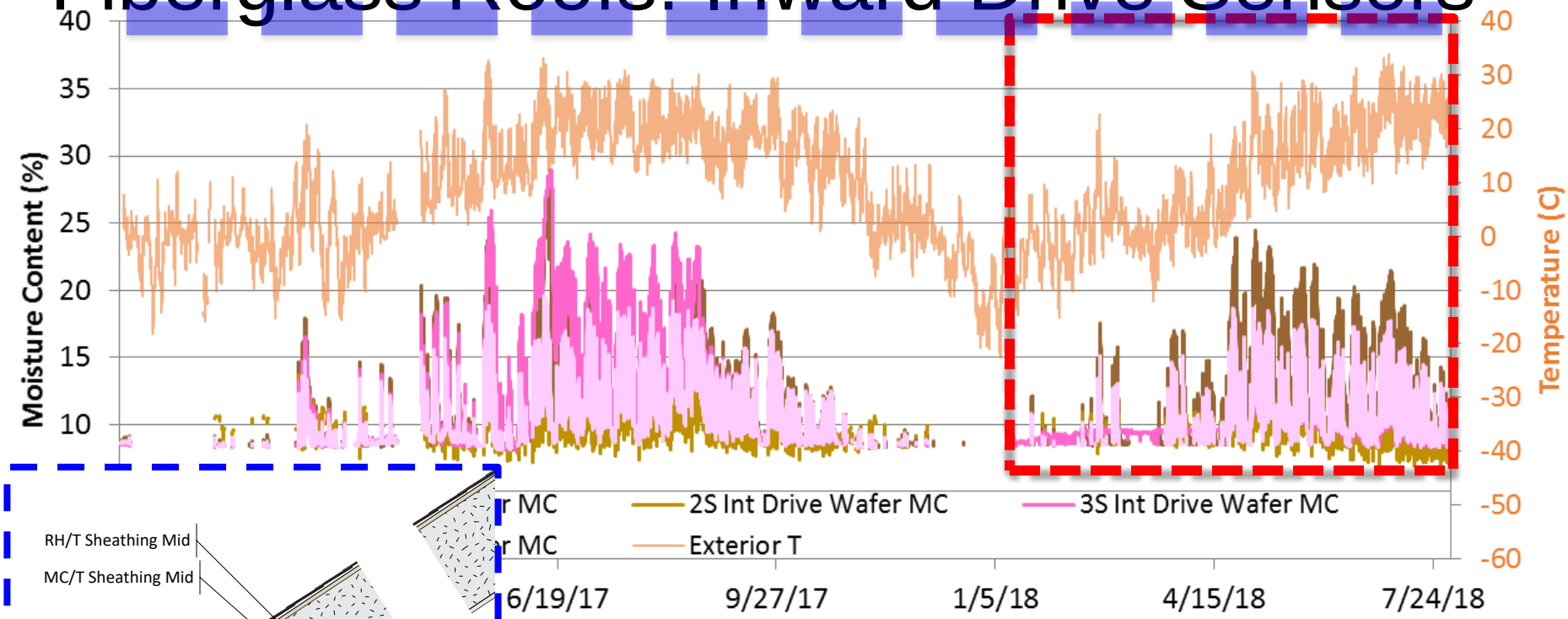
# Fiberglass Roofs: S Sheathing MCs

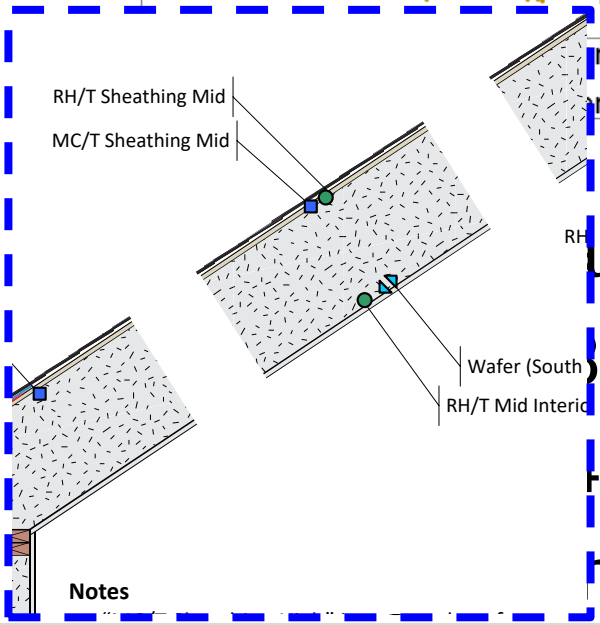



- South sheathing MCs all drier than corresponding north
- Upper location rises over 15% MC
- Others all below 15%
- **Roof 3** (tDV) wettest

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

# Fiberglass Roofs: Inward Drive Sensors




fer sensors

: **Roofs 1** worst (fixed VB)

5% MC condensation level

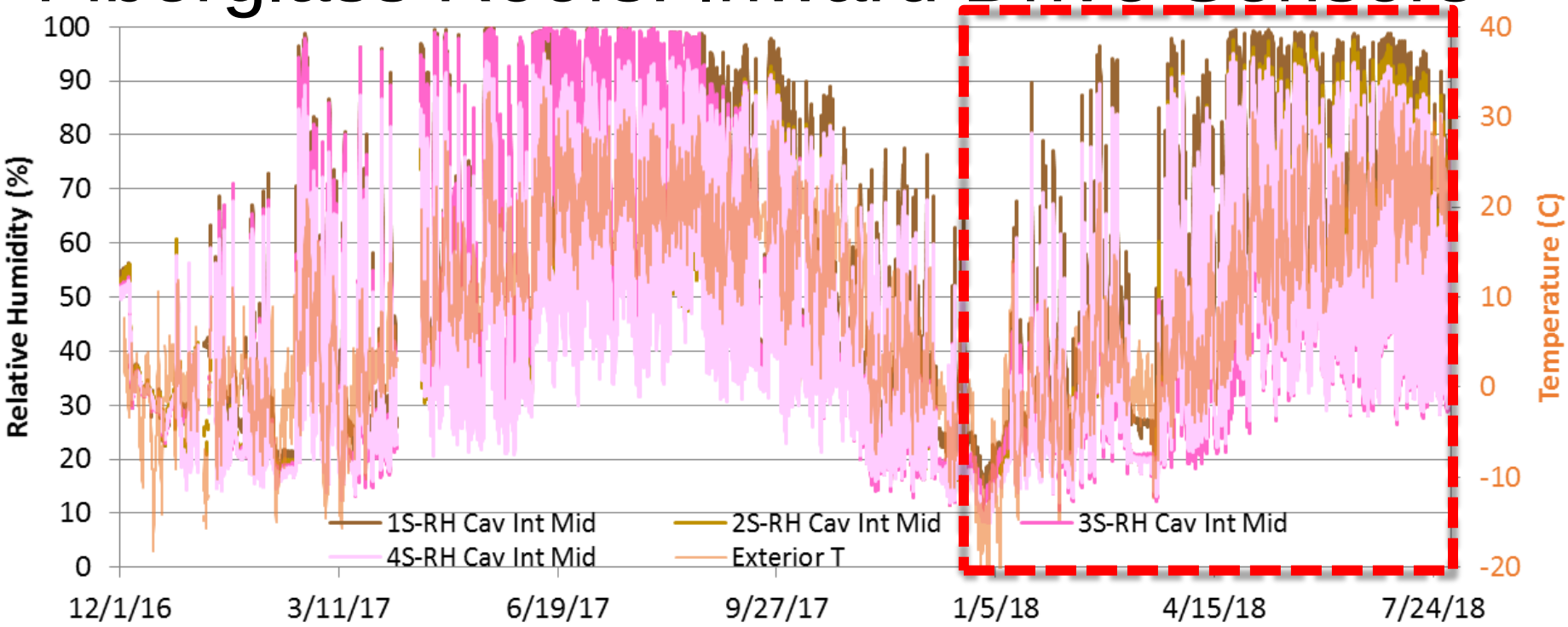
ot worst-case for inward drive!

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

# Summertime Inward Drive


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

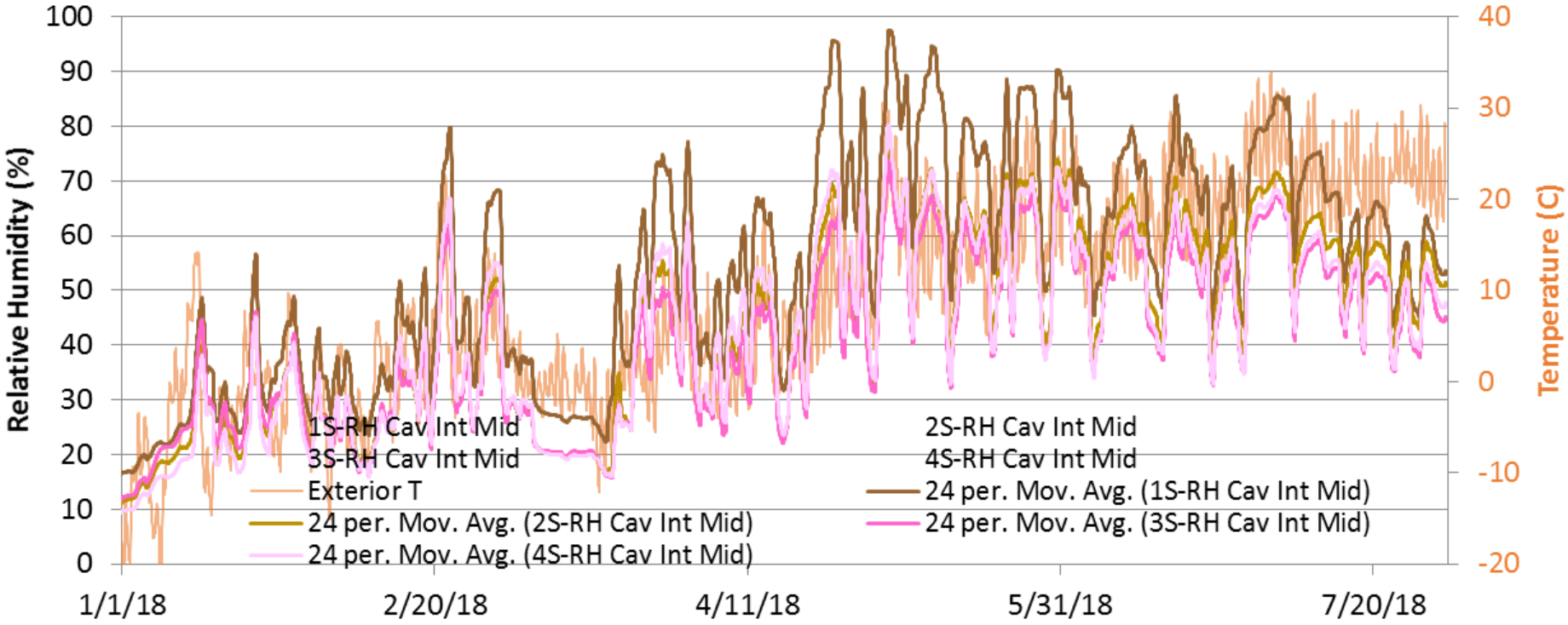
# Fiberglass Roofs: Inward Drive Sensors




- Difficult to differentiate
- **Roofs 1** (fixed VB) appears to be worst performer (moisture accumulation)

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

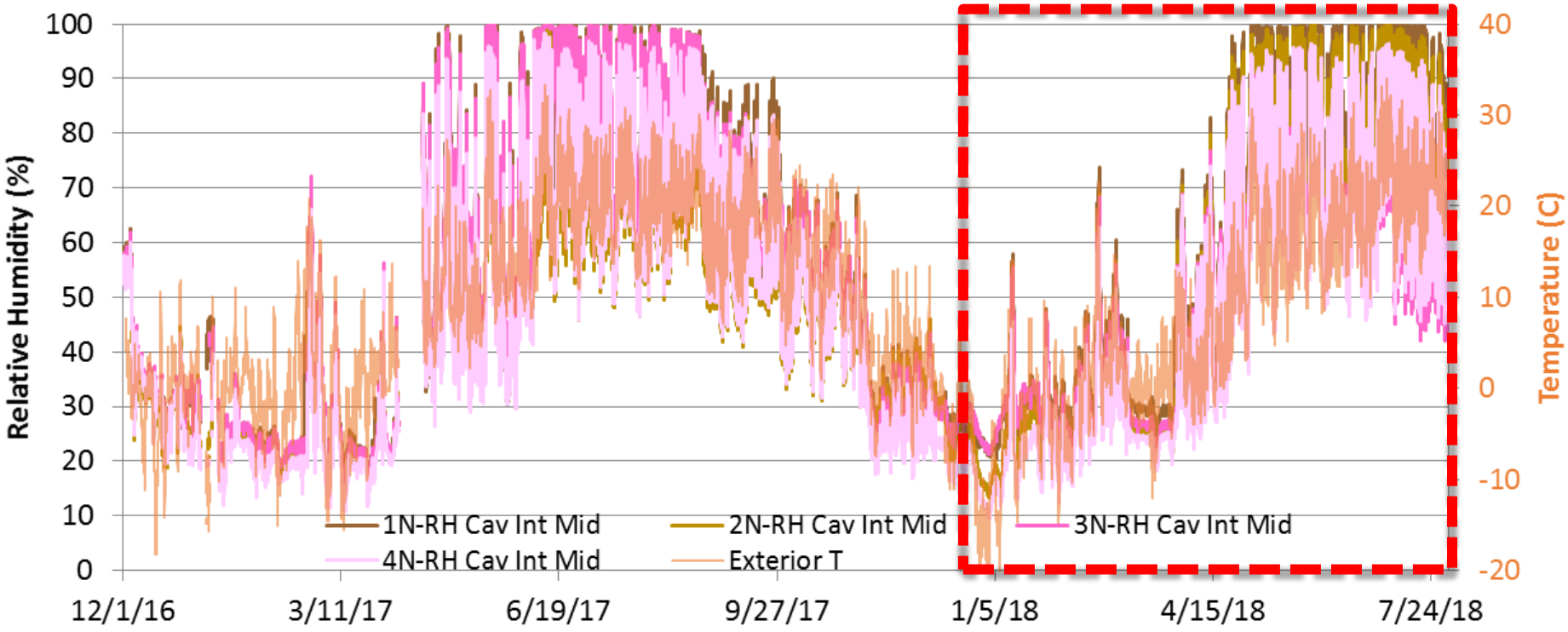
# Fiberglass Roofs: Inward Drive Sensors




- 24 hour moving averages, 2018
- **Roof 1** (fixed VB) is outlier, greater summertime accumulation/higher RHs
- Peaks over 90% RH, brief periods

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

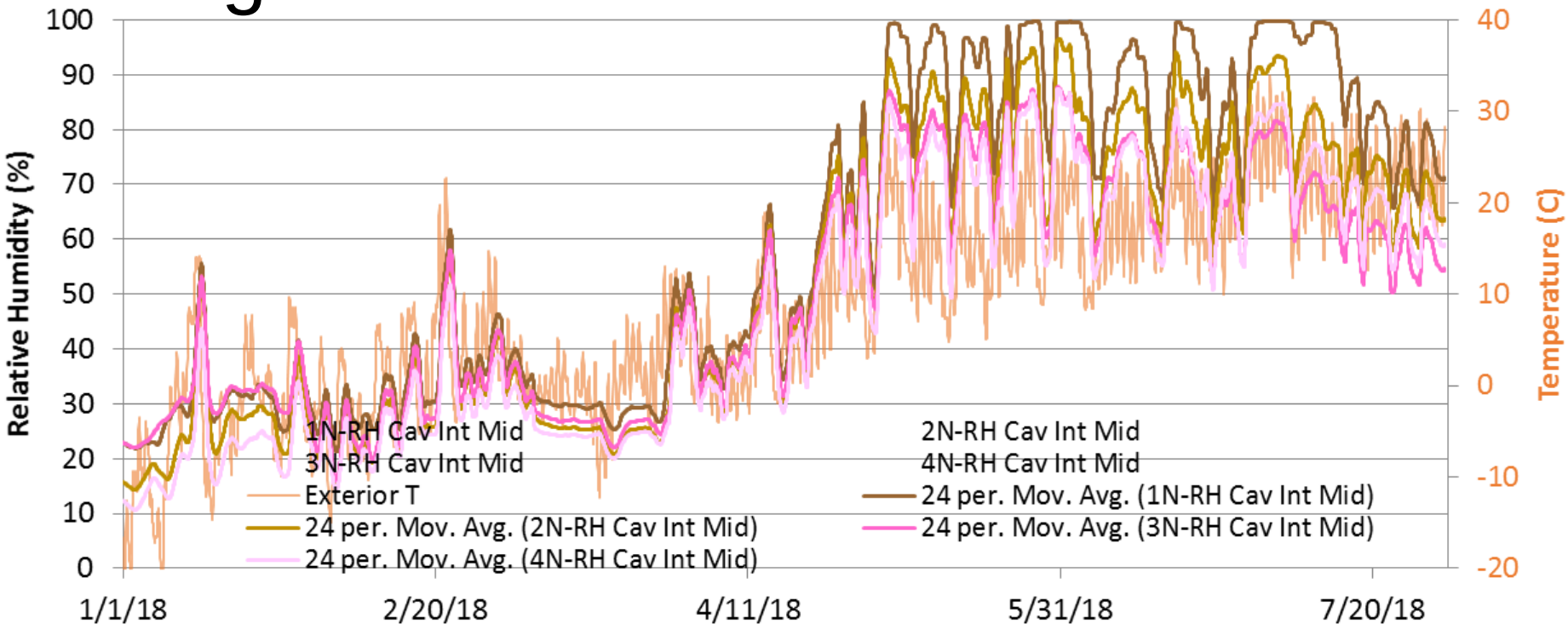
# Fiberglass Roofs: Inward Drive Sensors




- North side RH sensors
- Difficult to differentiate

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

# Fiberglass Roofs: Inward Drive Sensors




- North side RH sensors, 24 hour average, 2018
- **Roof 1** (fixed VB) at extended 100% RH
- North worse inward drive than south side-more stored moisture?

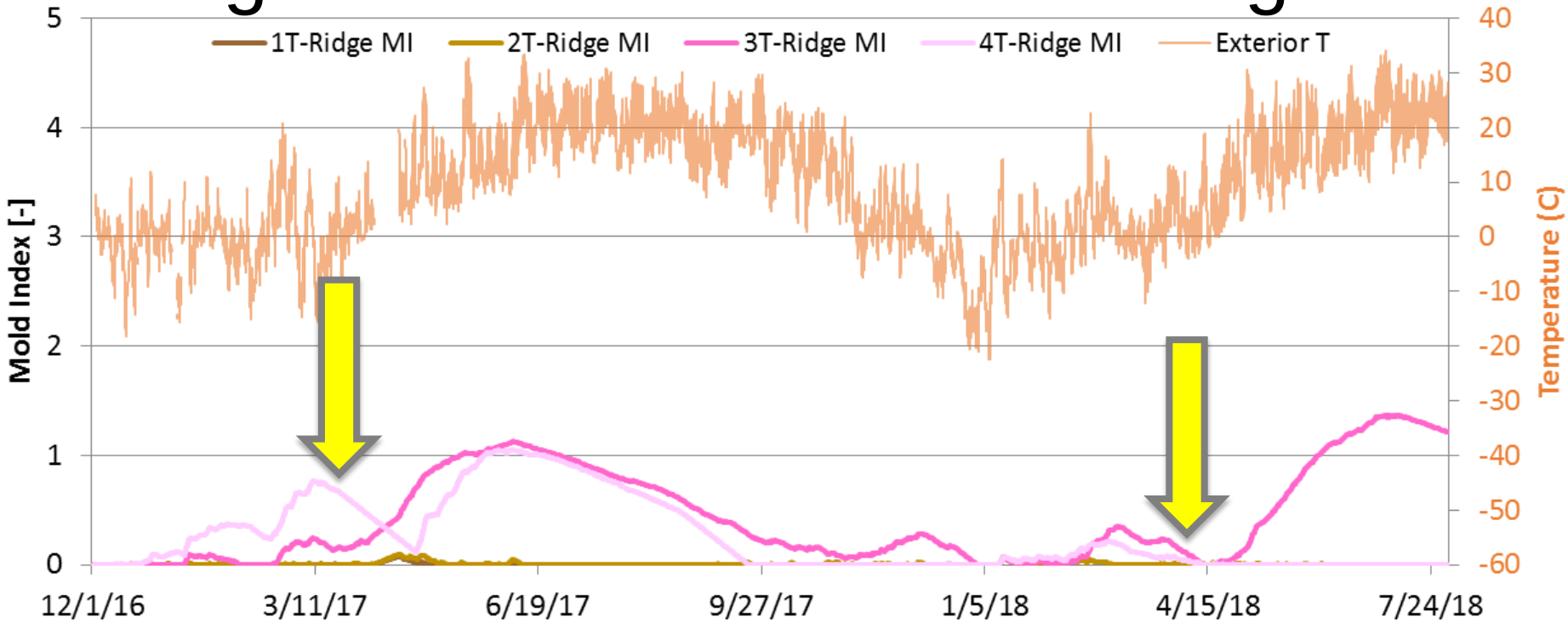
| Roof | Short Name |
|---|---|
| 1 | FG-VB-DV |
| 2 | FG-SVR-DV |
| 3 | FG-SVR-tDV |
| 4 | FG-SVR-sDV |

# 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
- Indebted to Sam Glass/Forest Products Laboratory

| 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% |

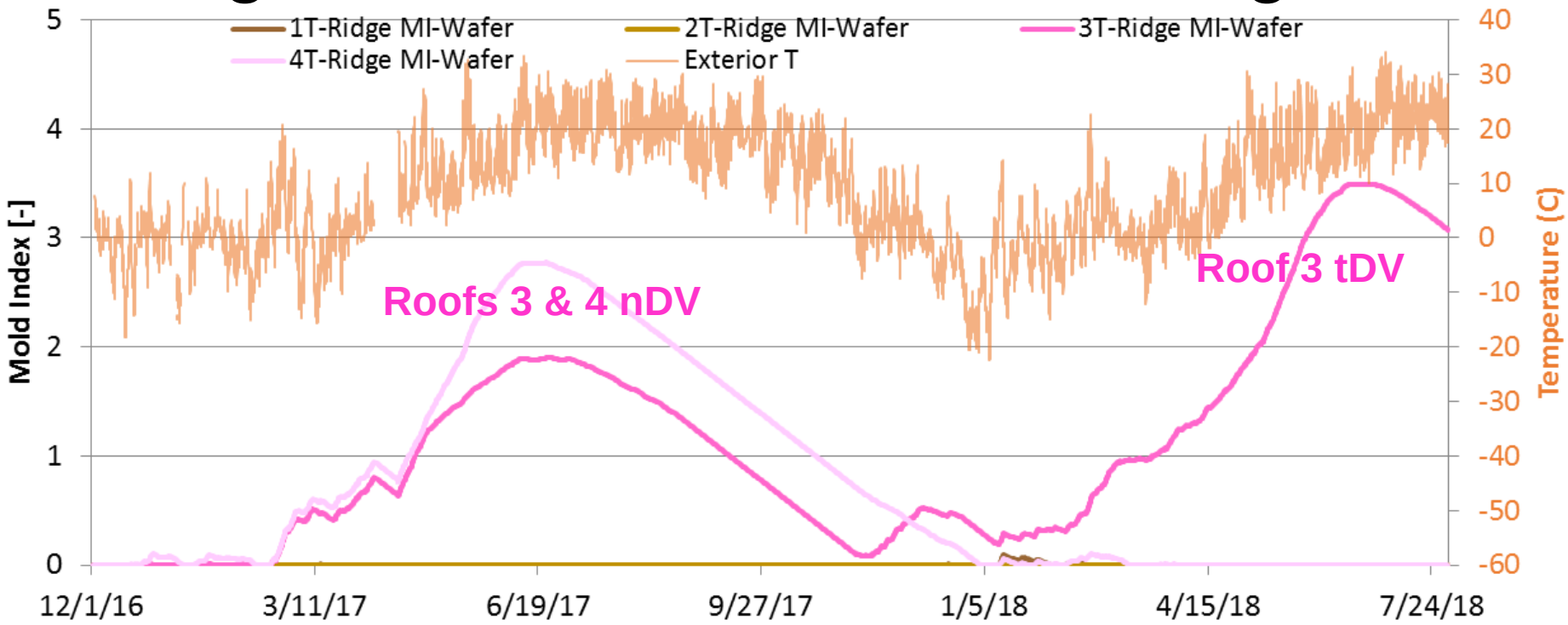
# Fiberglass Roofs: Mold Index-Ridge RH




- All roofs 95-100% most of winter
- Roof 4 RH sensor failed mid March 2017
- **Roof 3** RH sensor intermittent April 2018
- Mold index remains below 2

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

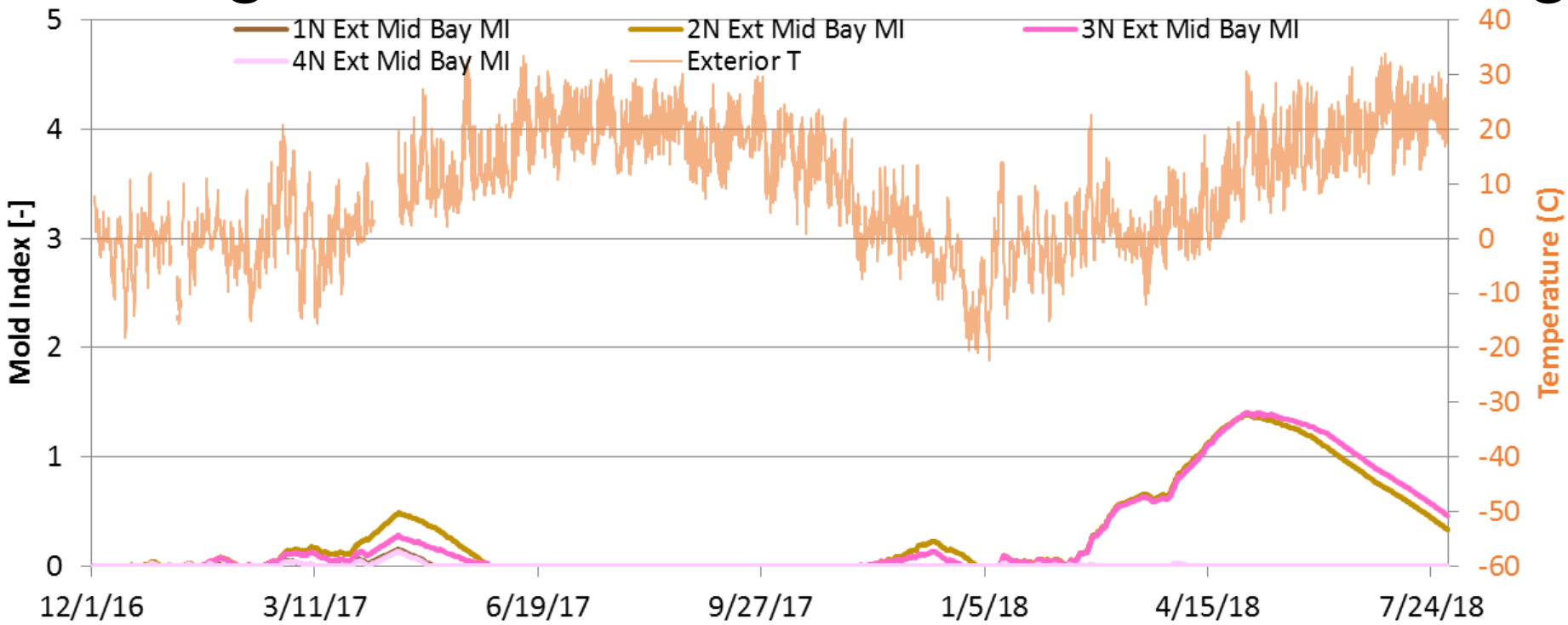
# Fiberglass Roofs: Mold Index-Ridge Wafer




- Calculated RH from ridge wafer MC: higher MI #s
- Winter 1: **Roof 3** & **Roof 4** high MCs (no DV)
- Winter 2: **Roof 3** "tight" 25 perm DV
- Mold index over 3 in Winter 2 (wafer)

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

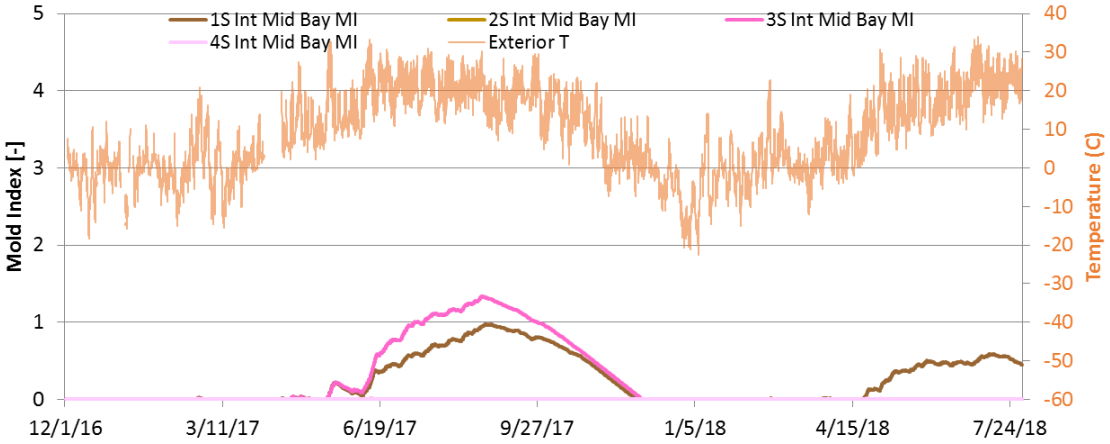
# Fiberglass Roofs: Mold Index-N Sheathing

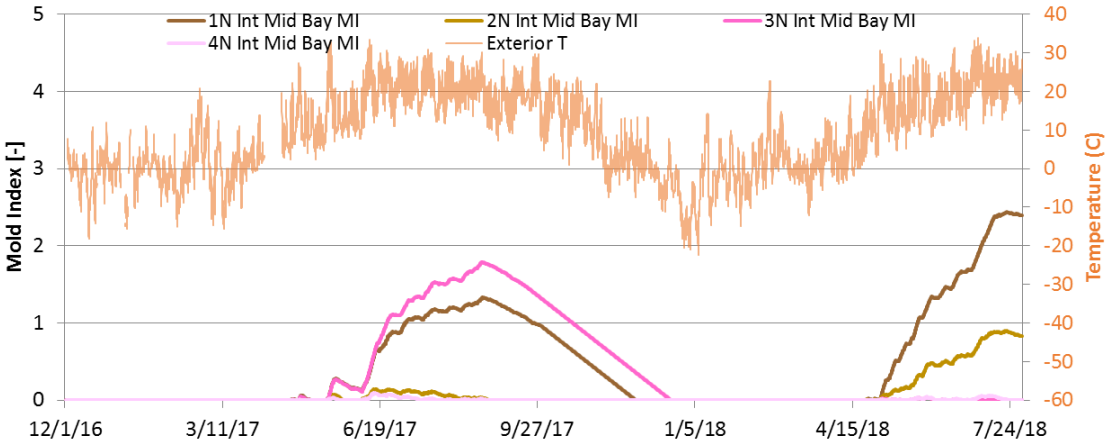



- Higher sheathing MCs Winter 2 (50% RH)
- Roof 4 RH sensor was drier than 1/2/3→low MI
  - Ascribed to sensor/installation anomaly
- Mold index remains below 2

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

# Fiberglass Roofs: Mold Index-Inward Drive



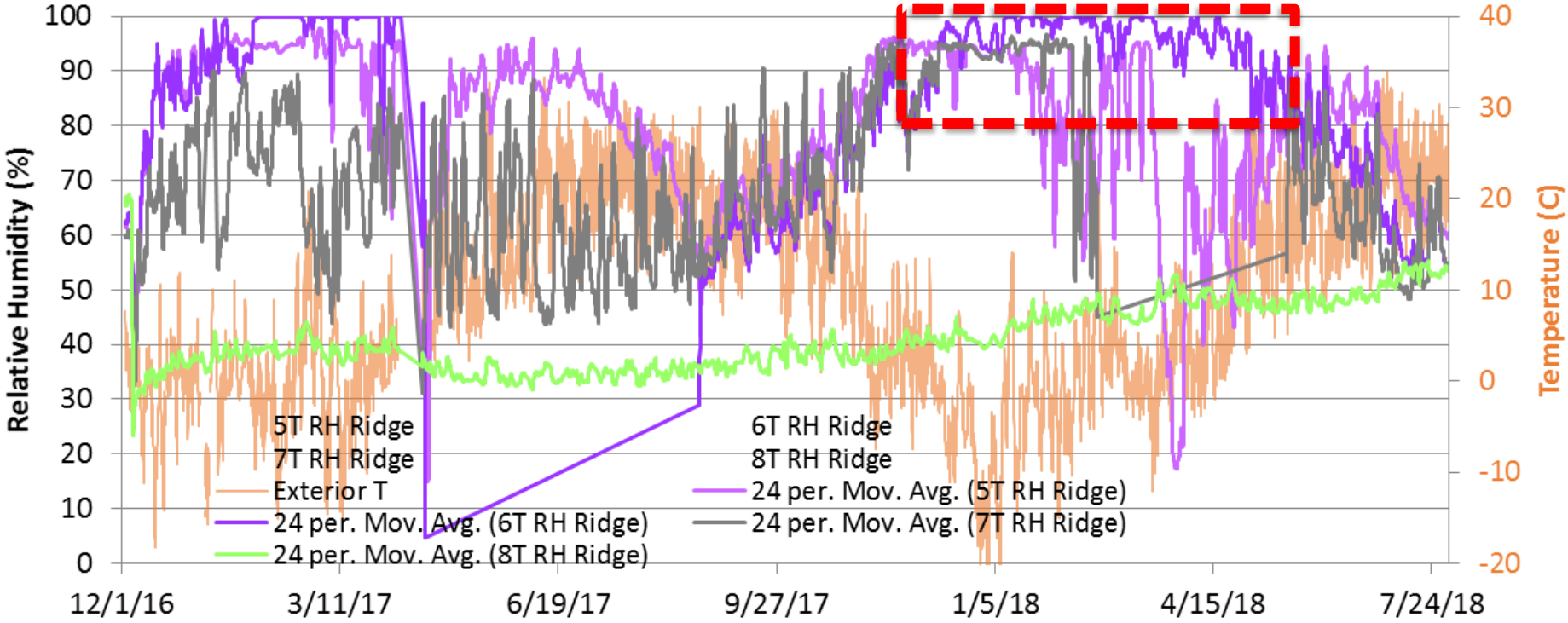




- **Roof 1** (fixed VB) only fixed perm in Winter 2
- Highest MI
- MI stays below 3-barely
- North shows higher peaks than south
  - Stored moisture?

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

# Results: Cellulose Roofs

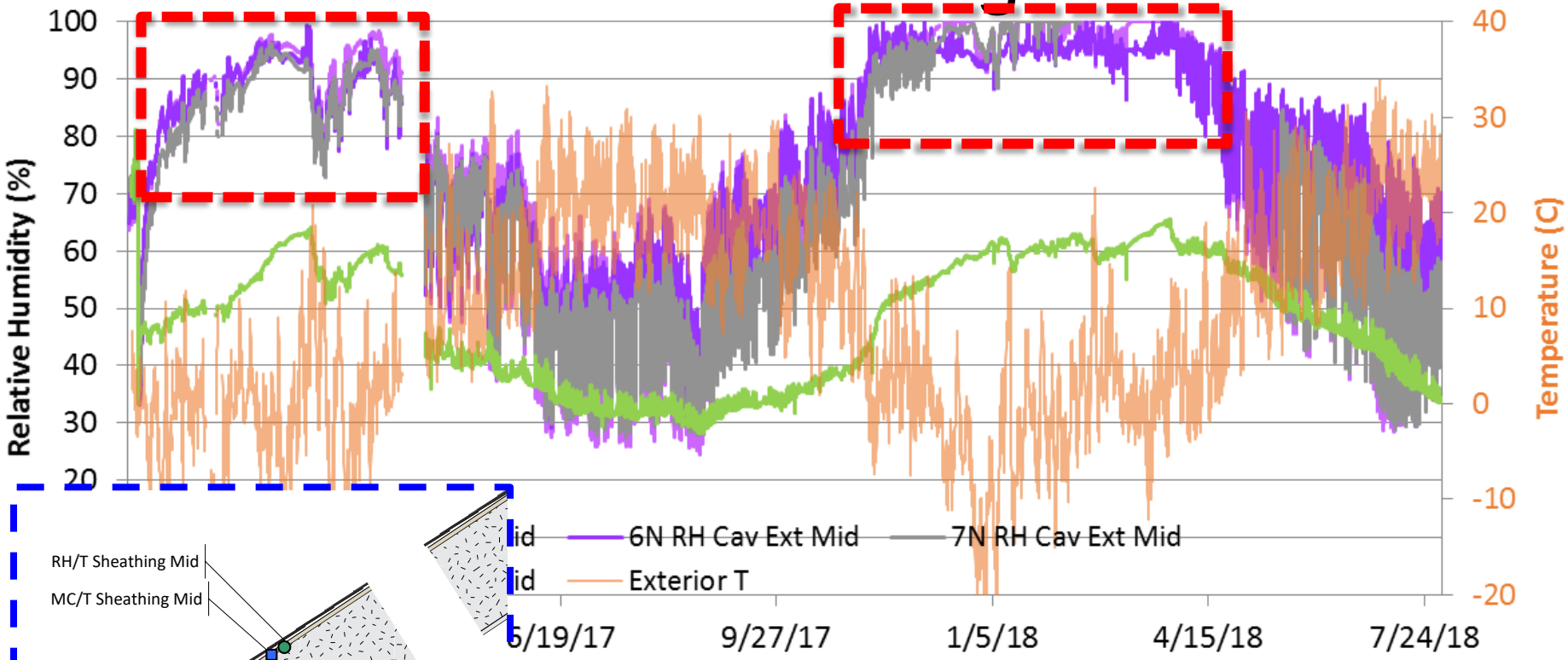
# Cellulose Roofs: Ridge RH 24 hr. Avg.

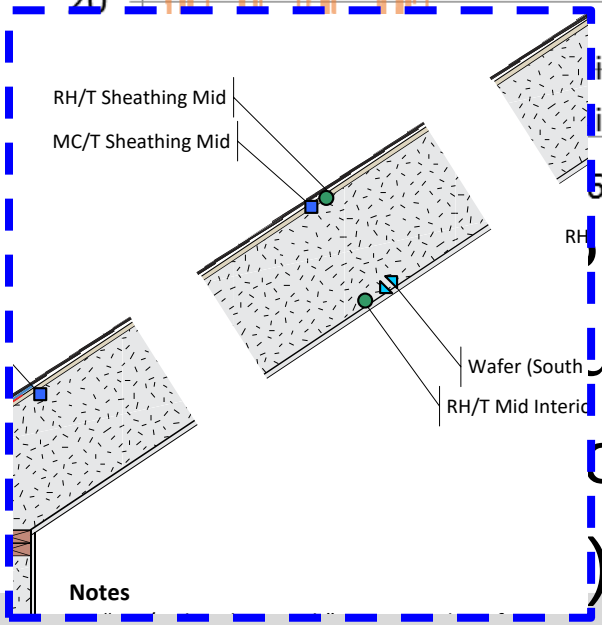



- **Roof 8** (hybrid) no issues @ 50% RH
- **Roof 5**, **Roof 6,** **Roof 7** all 95-100% RH thru Winter 2 (before sensor failure)
- **Roof 7** dries fastest? (biggest DV)

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

# Cellulose Roofs: Sheathing RH North




-100% RH most of Winter 2

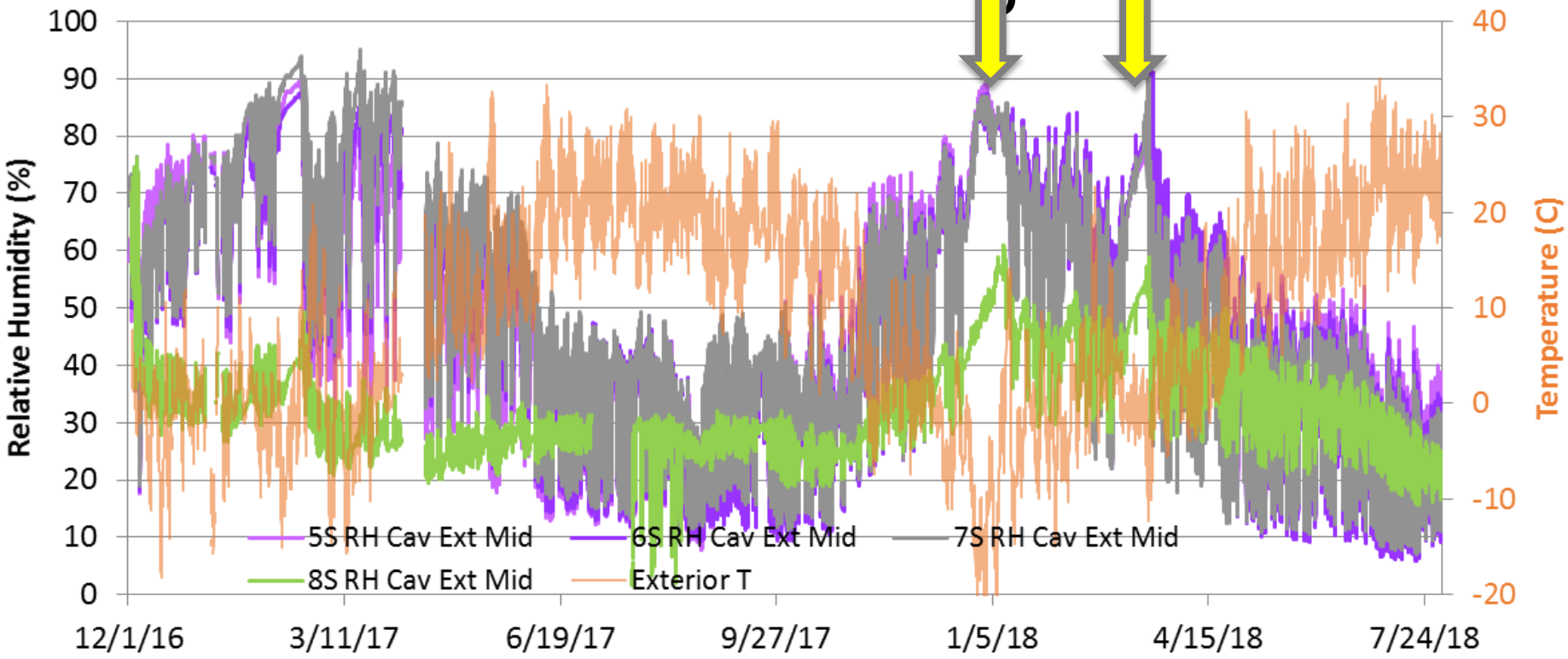
ustained RHs than Winter 1

own faster (larger DV)

) non-risky RH levels

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

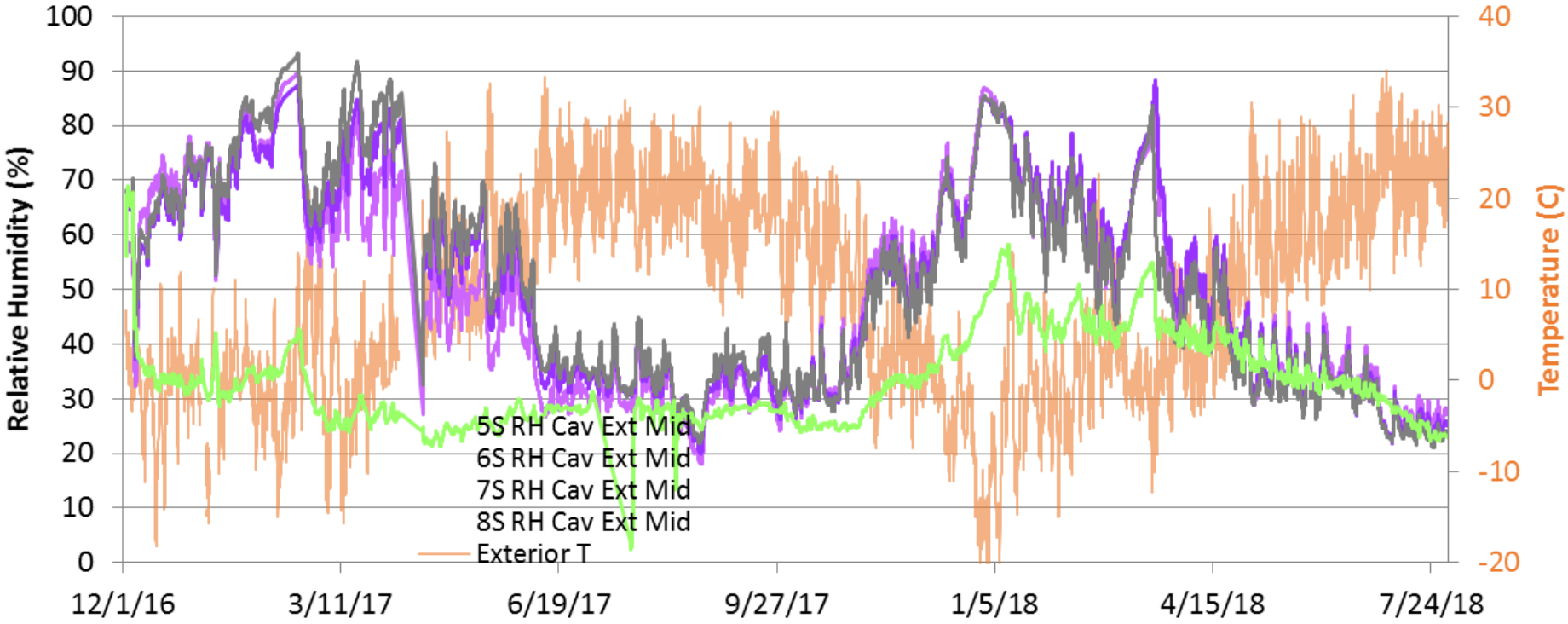
# Cellulose Roofs: Sheathing RH South




- Drier conditions south vs. north
- Diurnal variations (solar gain, snow)
- Winter 2 wetter than Winter 1
- Brief excursions over 90% RH

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

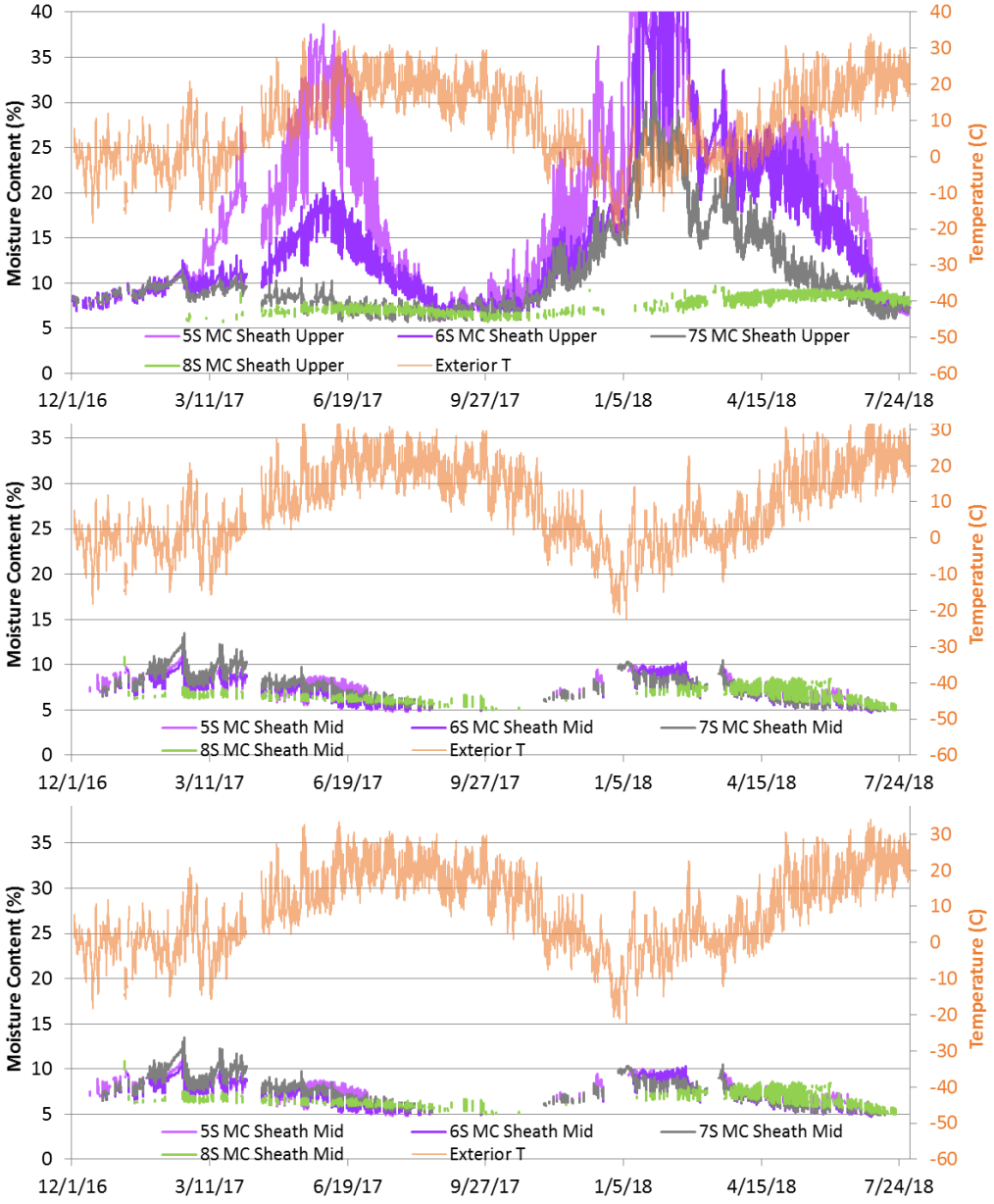
# Cellulose Roofs: Sheathing RH South




- 24 hour moving average
- Little differentiation Roofs 5-6-7
- **Roof 8** (hybrid) driest

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

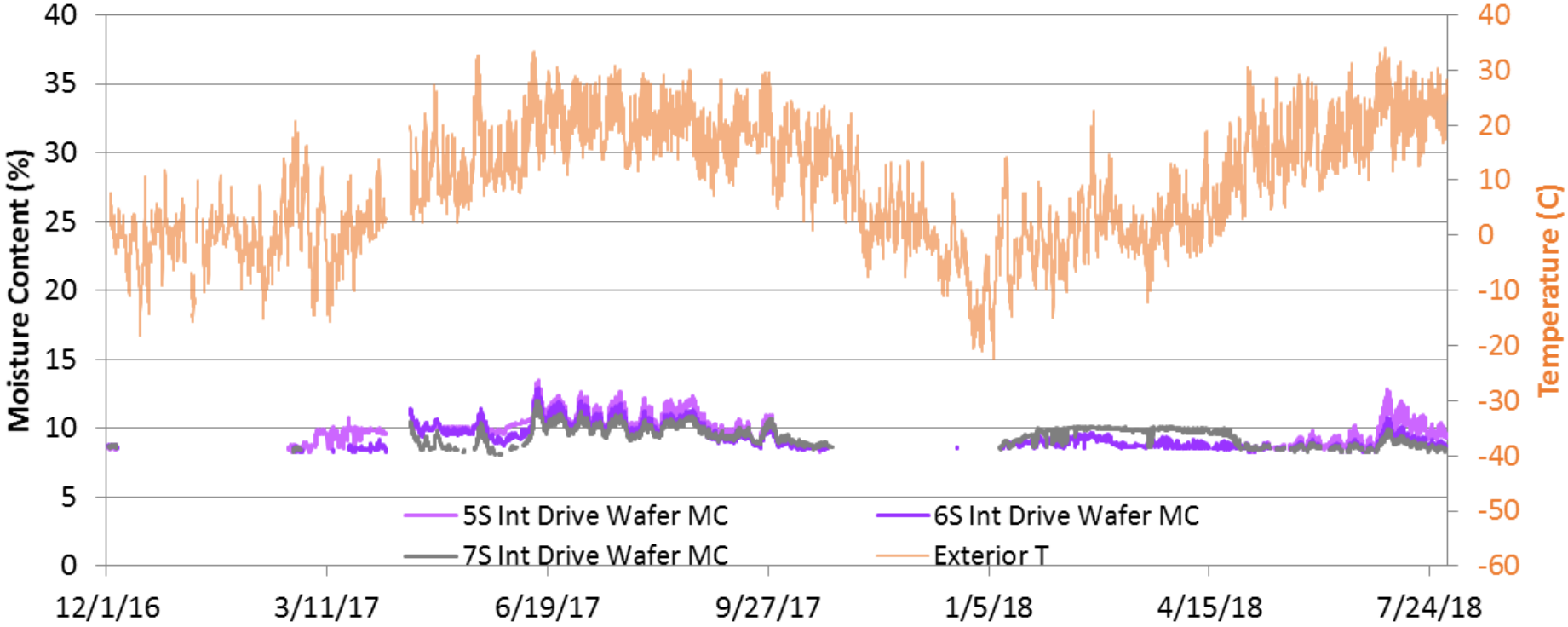
# Cellulose Roofs: S Sheathing MCs




- South sheathing MCs
- South consistently drier than north
- Upper MCs distorted by borate migration
- Winter 2 more challenging than Winter 1 (even **Roof 7**): real risks or borate migration?

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

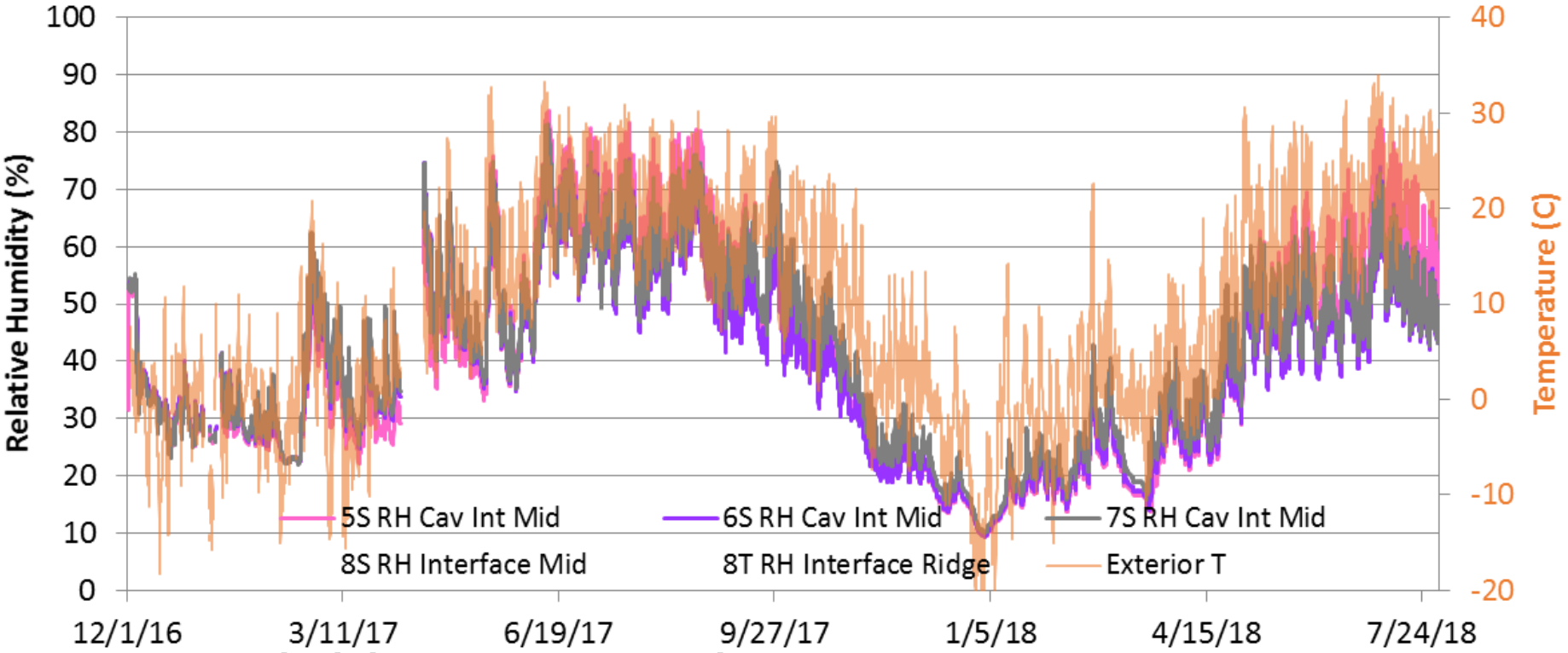
# Cellulose Roofs: Inward Drives




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

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

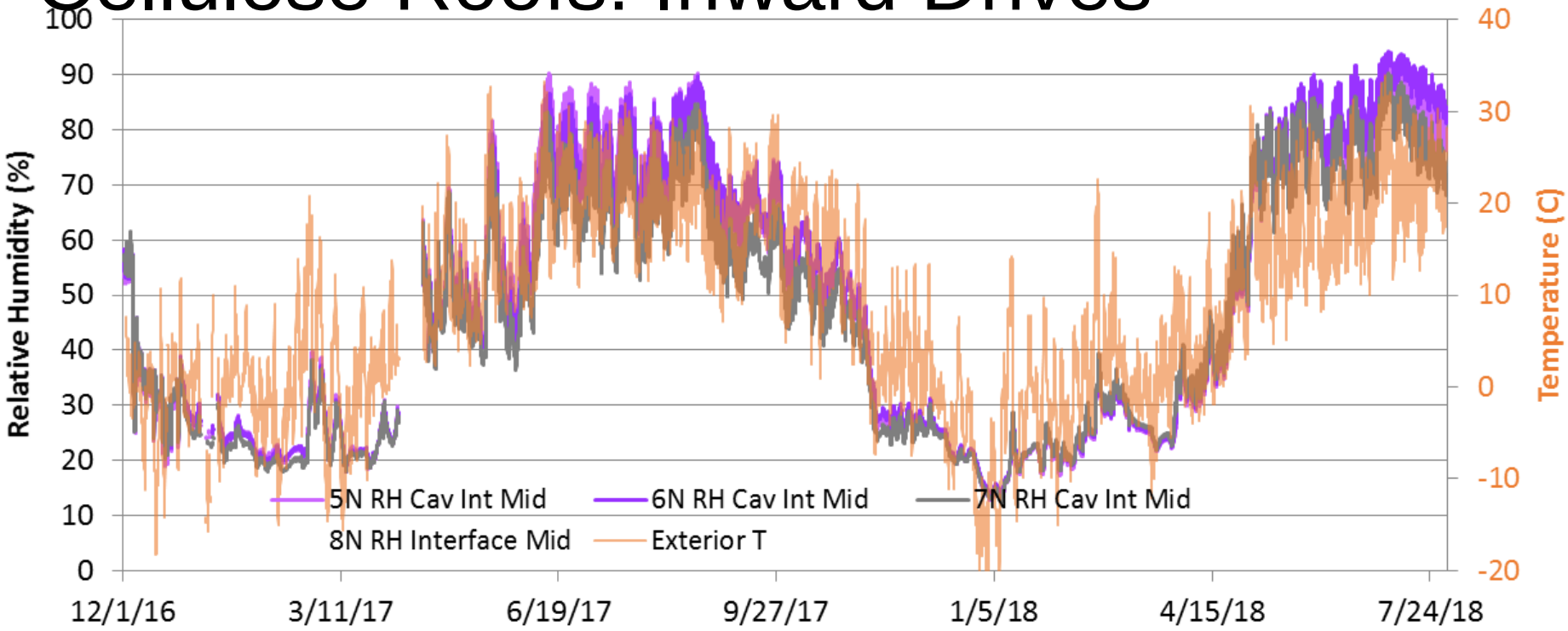
# Cellulose Roofs: Inward Drives




- Inward drive RH, south
- Peaks barely over 80% RH
- Roofs 5-6-7 all SVR interior

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

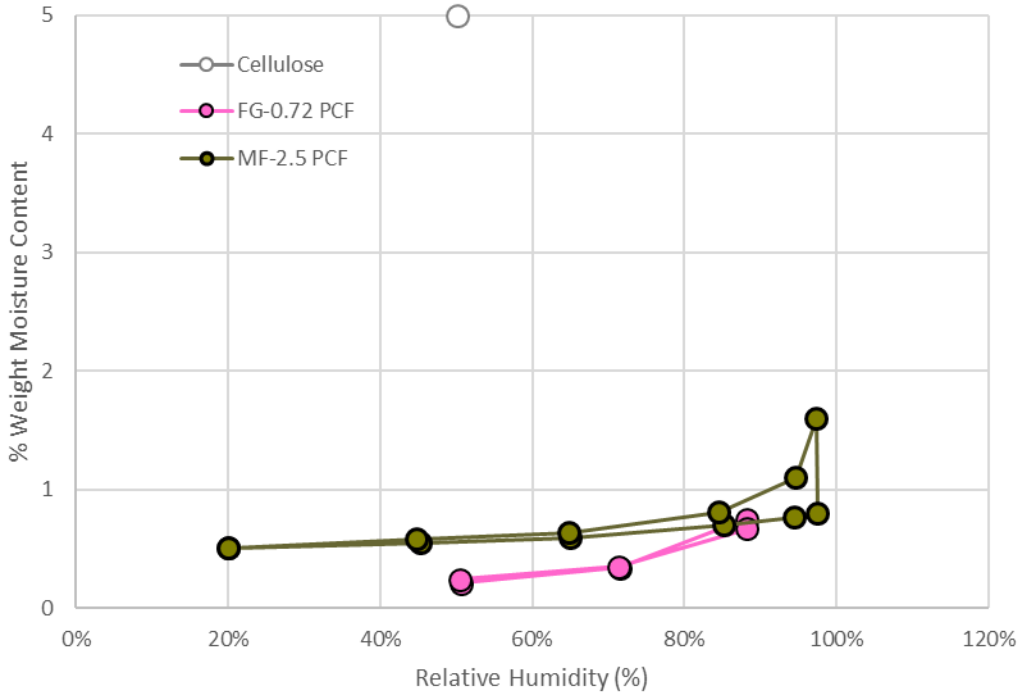
# Cellulose Roofs: Inward Drives




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

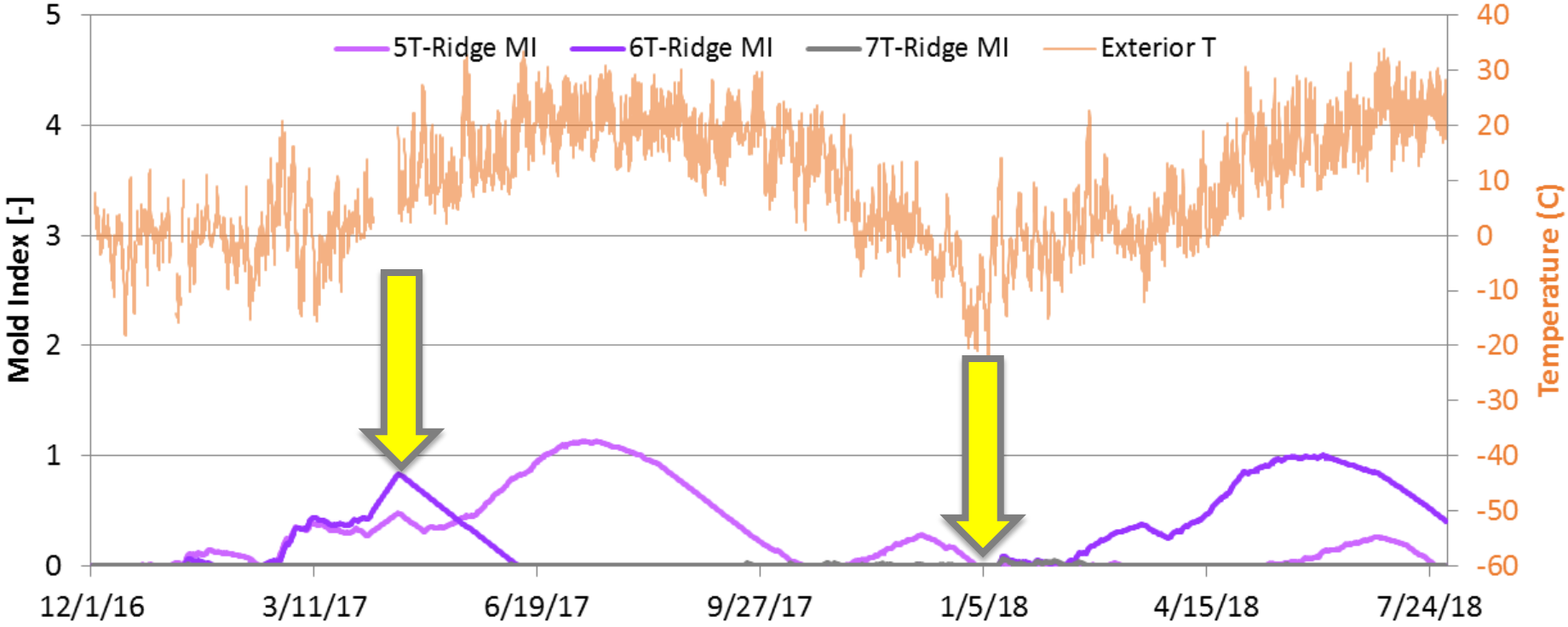
| Roof | Short Name |
|---|---|
| 5 | Cell-SVR-tDV |
| 6 | Cell-SVR-sDV |
| 7 | Cell-SVR-DV |
| 8 | ccSPF-Cell |

# Cellulose vs. Fiberglass Moisture Storage




- ASHRAE Fundamentals data (Kumaran, Burch)
- Moisture buffering/storage ability of cellulose
- Raw data, shown by weight, not volume (2.5x diff)

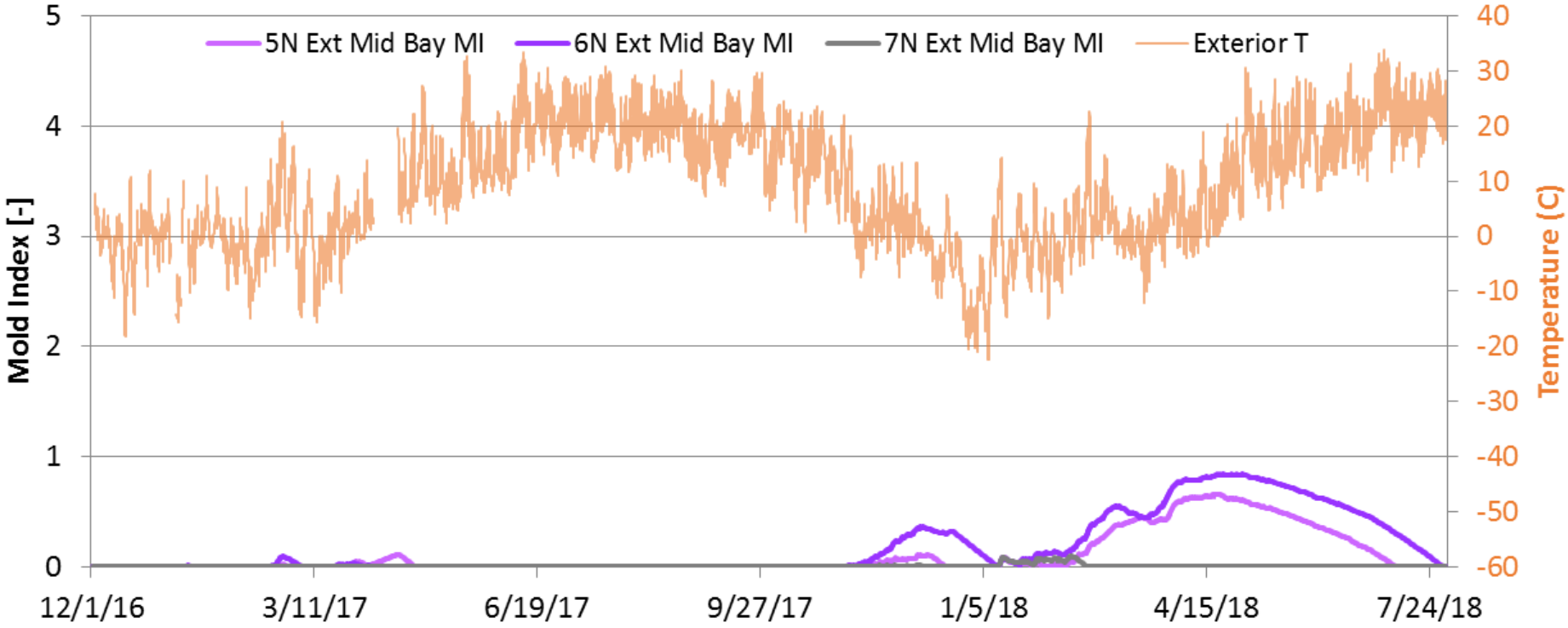
# Cellulose Roofs: Mold Index Ridge




- **Roof 5-Roof 6** RH 90-100% most of winter
- **Roof 6** RH sensor failed mid 4/2017
- **Roof 5** bad data 1/2018
- All mold index values below 2

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

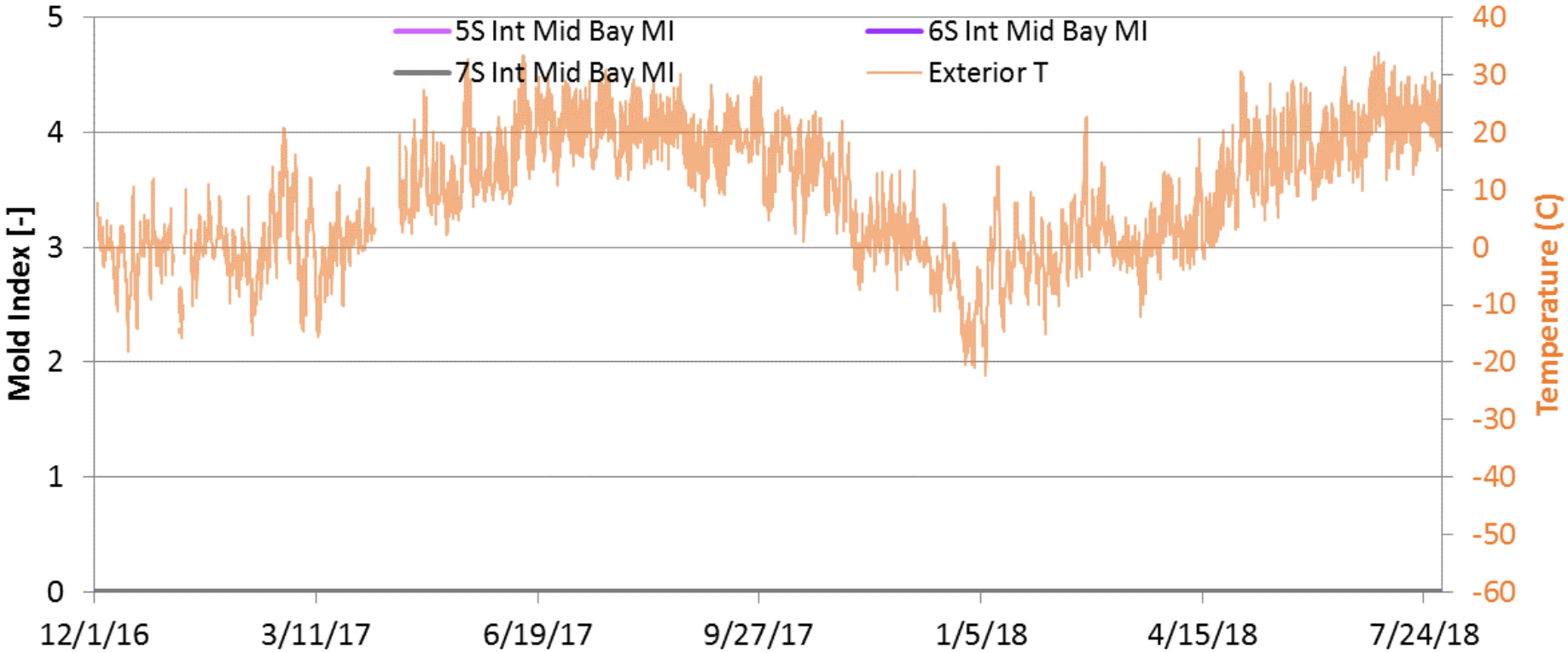
# Cellulose Roofs: Mold Index North Sheath.




- RH peaks 90-100% much of winter
- Winter 2 worse than Winter 1
- Mold indices all below 1
- South even drier-lower risk (MI=0 typ.)

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

# Cellulose Roofs: Mold Index Inward Drive

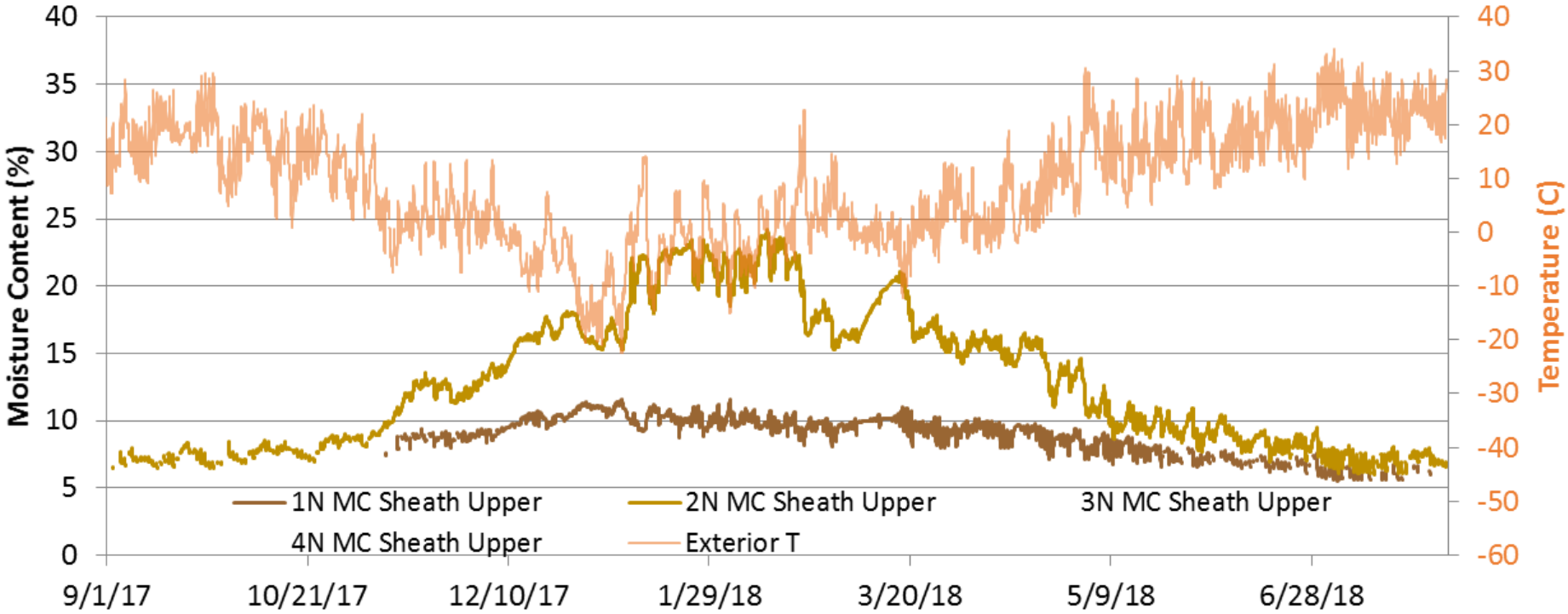



- RH south side inward drive
- Not mis-plotted: max mold index 0.004

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

# Conclusions and Further Work

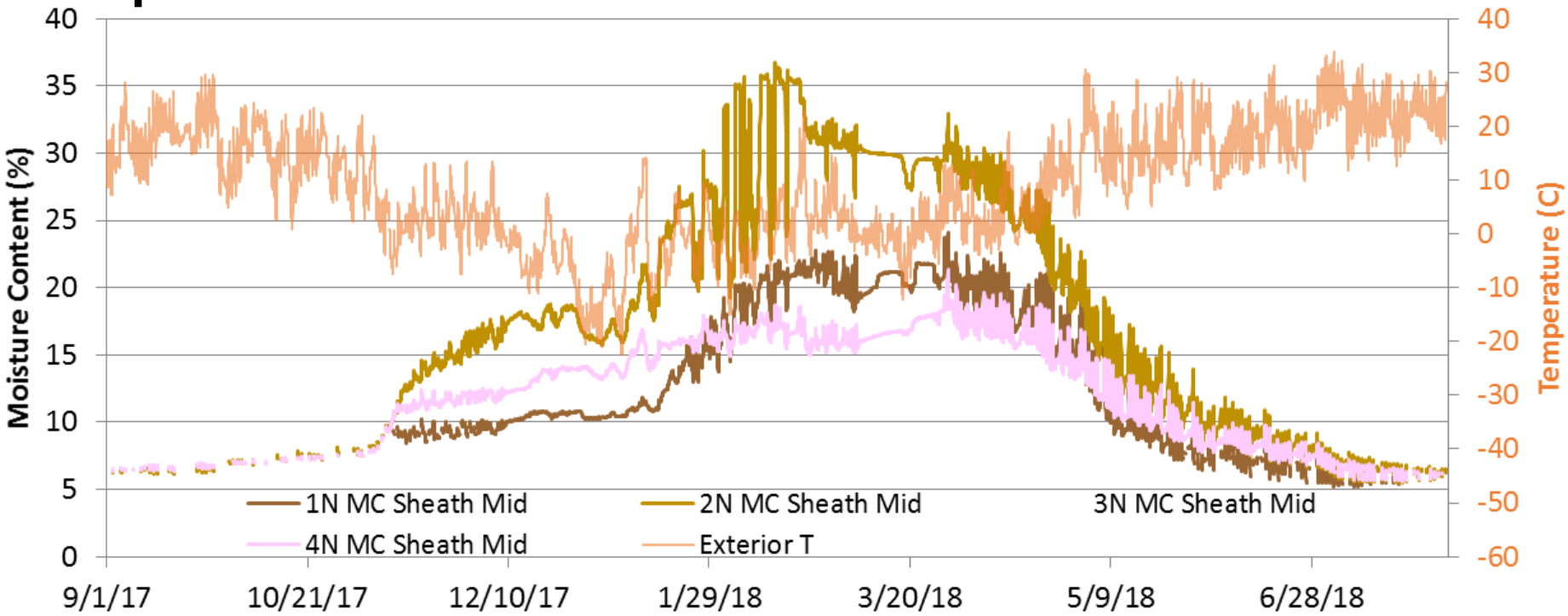
# Vapor Retarder Alternative




- FG North upper sheathing MC data
- **Roof 3** "tight" **Roof 4** "small"
- Why **Roofs 1** vs. **Roof 2**? VB vs. SVR
- SVR possibly opening up at 50% interior RH?

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

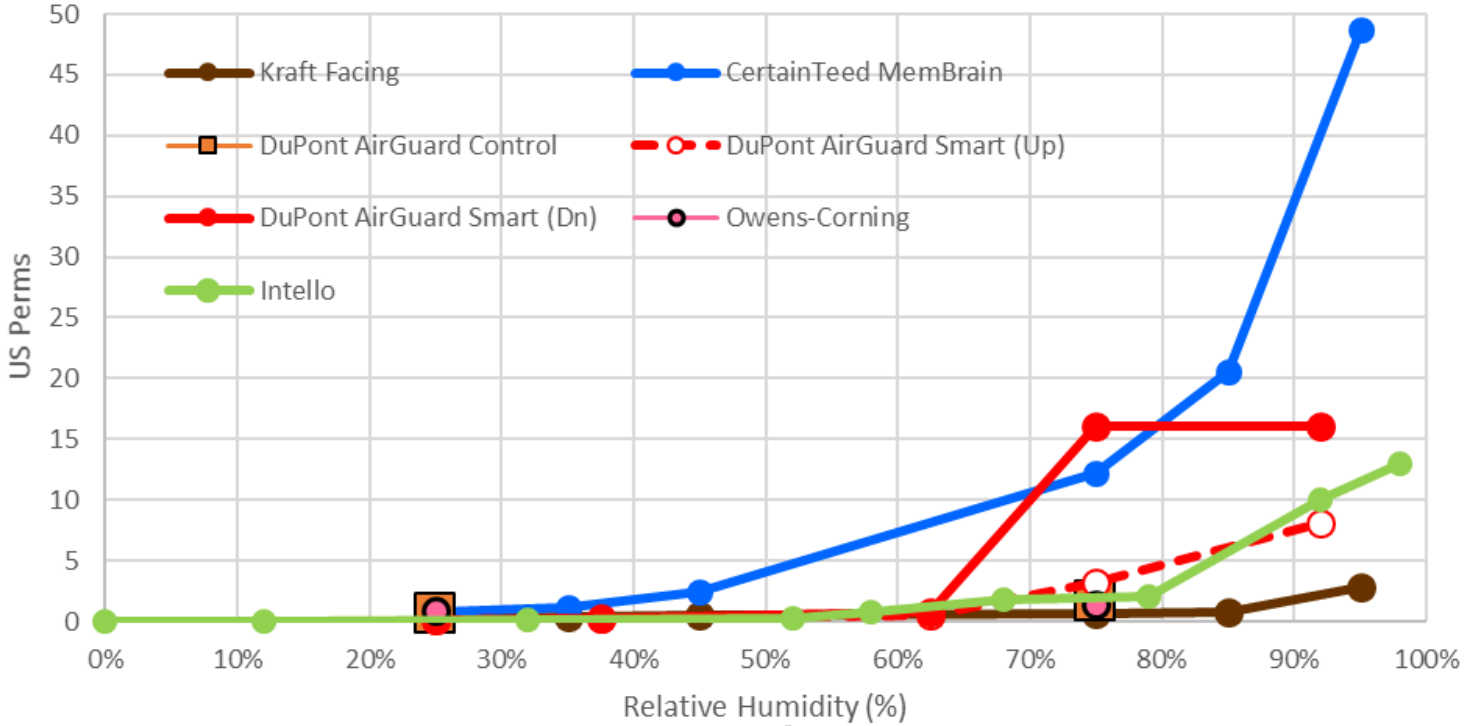
# Vapor Retarder Alternative




- FG North mid-height sheathing MC
- Consistent pattern **Roofs 1** vs. **Roof 2**

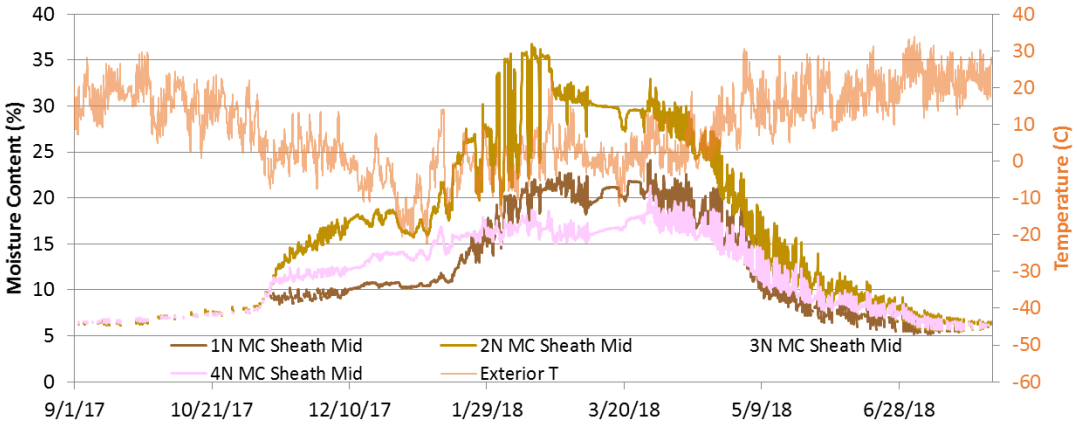
| Roof | Short Name |
|---|---|
| 1 | FG-VB-DV |
| 2 | FG-SVR-DV |
| 3 | FG-SVR-tDV |
| 4 | FG-SVR-sDV |

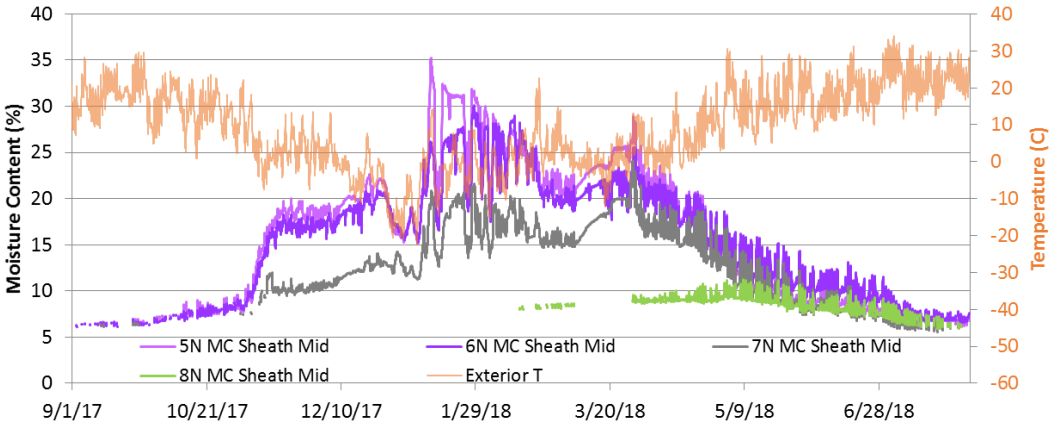
# Vapor Retarder Alternative




- Vapor permeance curves (SVRs-DuPont, MemBrain)
- Intello marketing: “stays closed at higher RHs”
- Similar mid-range behavior to DuPont SVR

# Vapor Retarder Alternative



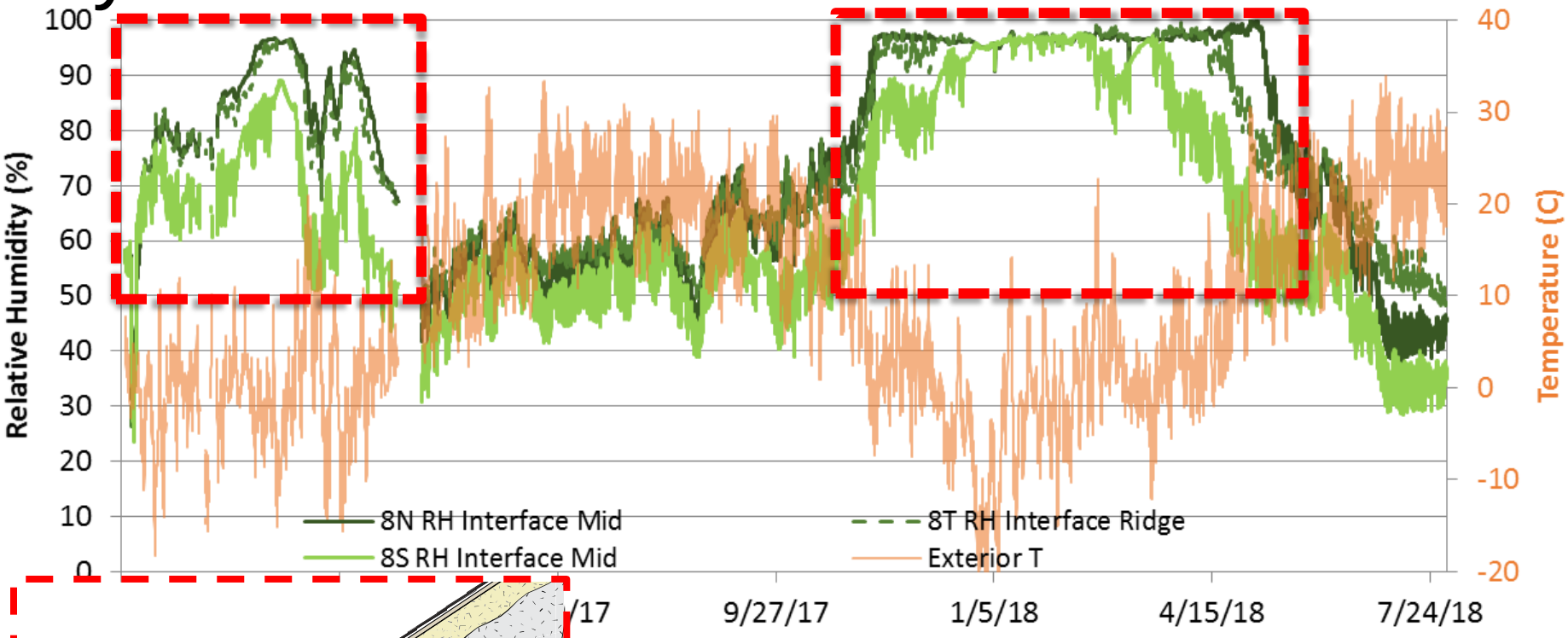

- Upper Graph FG:
  - Roofs 1, 2, 4
  - CertainTeed MemBrain, OC 1 perm
- Lower Graph Cell:
  - Roofs 5, 6, 7
  - DuPont SVR
- Both “Mid” height
- Not a clear signal

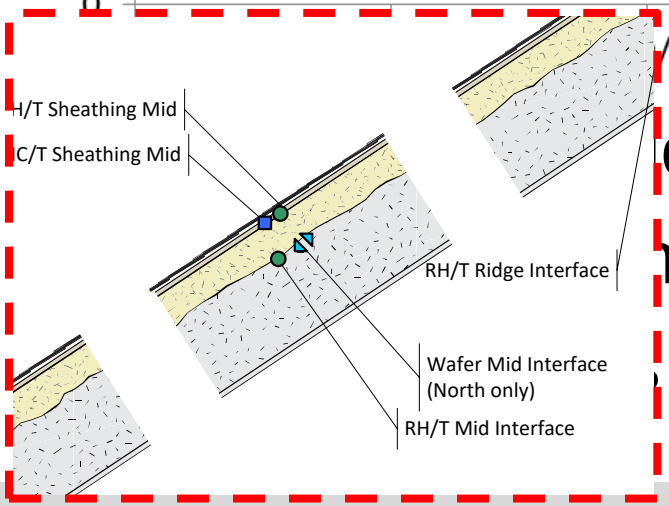
| Roof | Short Name |
|---|---|
| 1 | FG-VB-DV |
| 2 | FG-SVR-DV |
| 3 | FG-SVR-tDV |
| 4 | FG-SVR-sDV |

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

# Hybrid Roofs (ccSPF & cellulose)

# Hybrid Roof Interface: RH



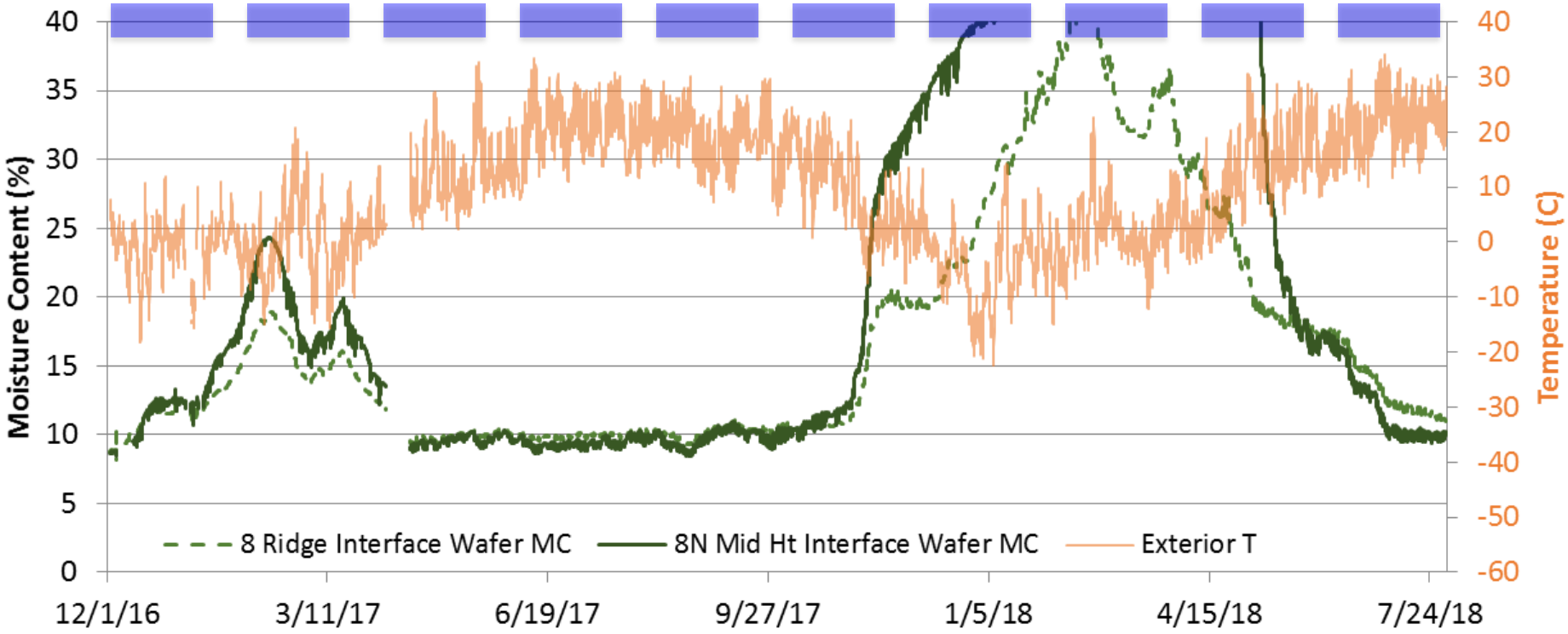




ons to 90-95% RH

nterior RH): 95-100% RH all winter

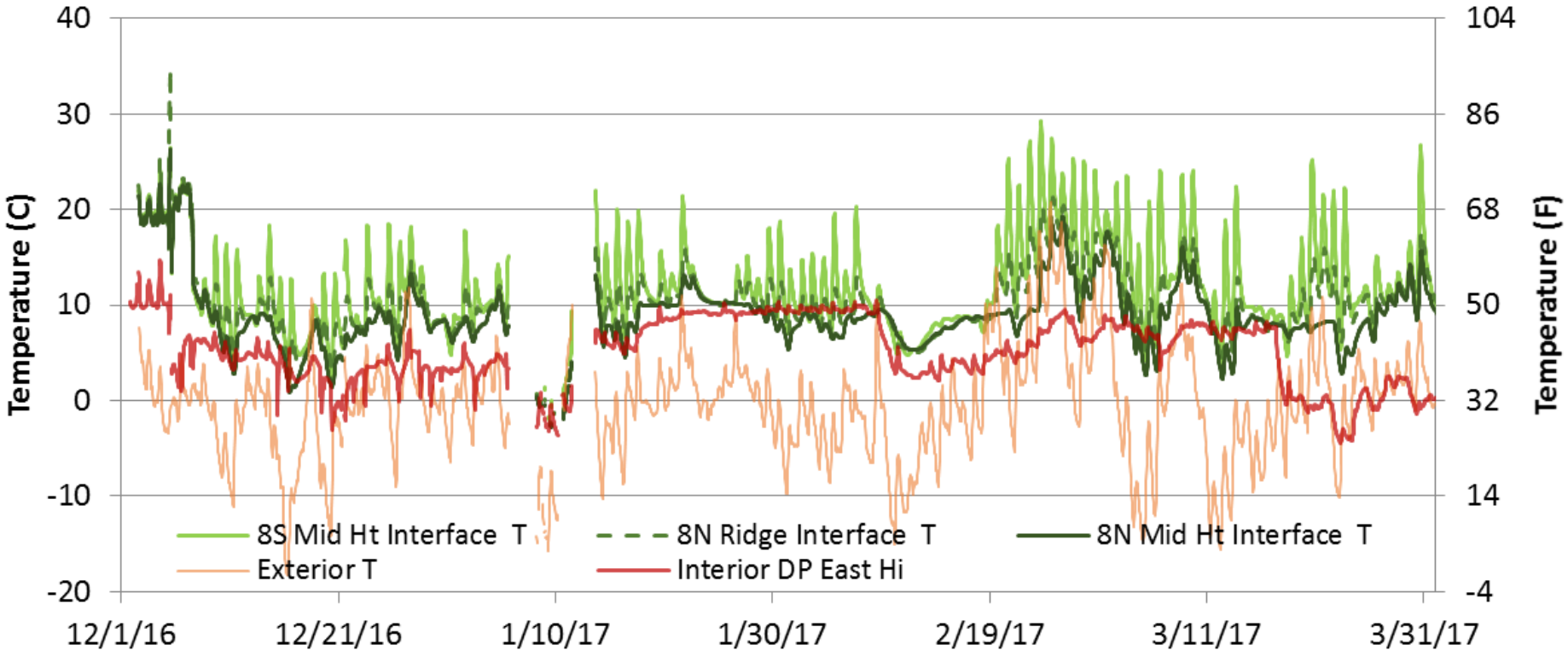
from interior (cellulose storage)

# Hybrid Roof Interface: Wafer



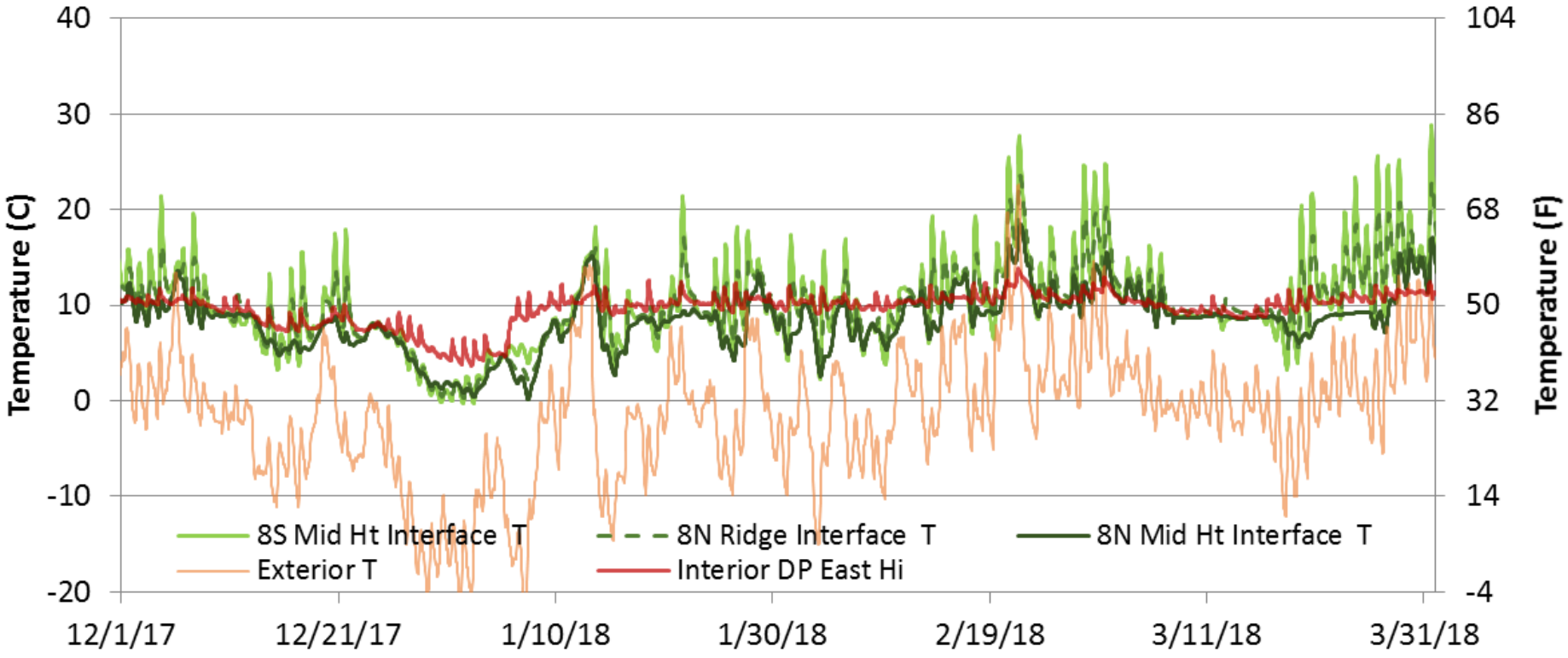

- Winter 2 interface possibly in condensation range
- But also possibly borate contamination

# Hybrid Roof Interface: Winter 1 DP




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

# Hybrid Roof Interface: Winter 2 DP




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

# Conclusions: Hybrid Roofs

- **Roof 8** (hybrid) consistently showed low RHs and low sheathing MCs vs. experimental roofs (1-7)
- At typical interior RH (30-40%), interface at safe conditions
- At elevated interior RH (50% flatline), accumulation at interface (interior DP > T) **BUT**
- This assembly had **no interior air barrier or vapor control** (no Class III VR/gypsum board/latex paint)
- Readily dried down in warmer weather

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