

Kohta Ueno and Joseph Lstiburek

# Unvented Roof Without Spray Foam:

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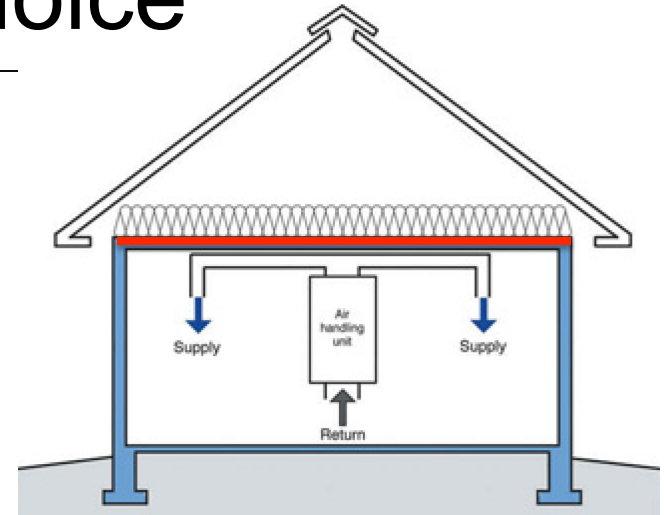
## The Latest Building America Research

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# 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)



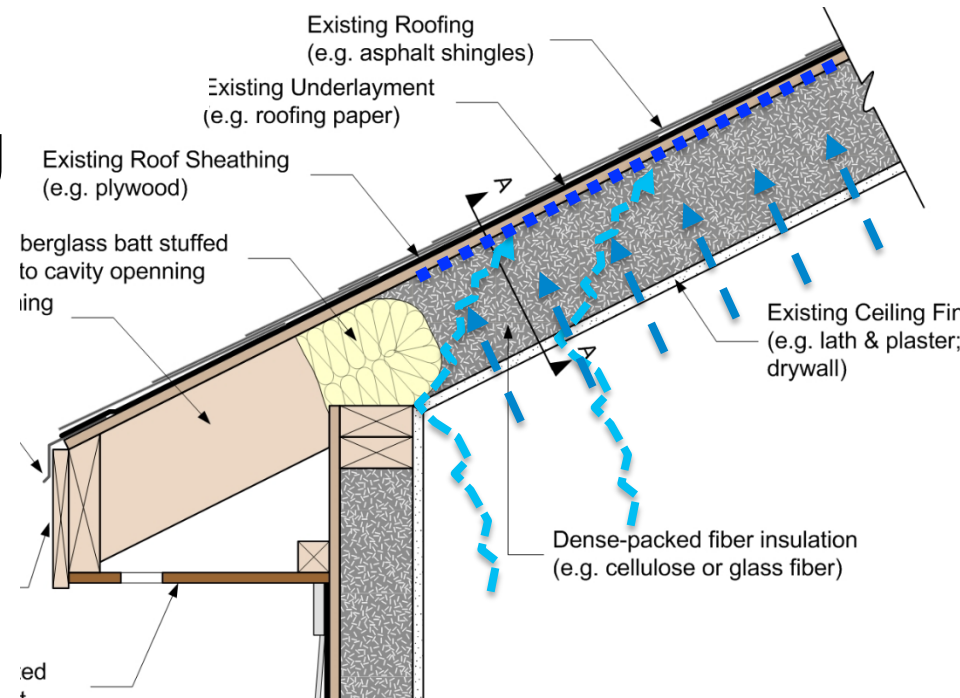
# Then Why Unvented Roofs?

- 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

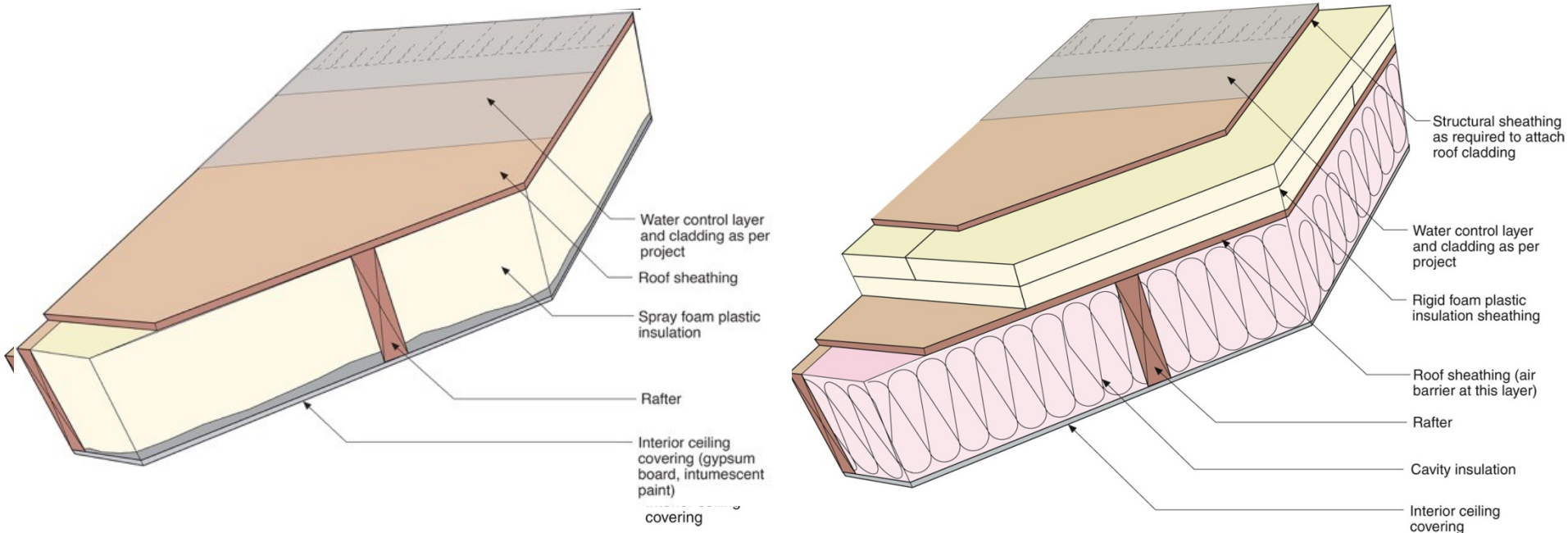


# Why Unvented + Fibrous Risky?

- 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)



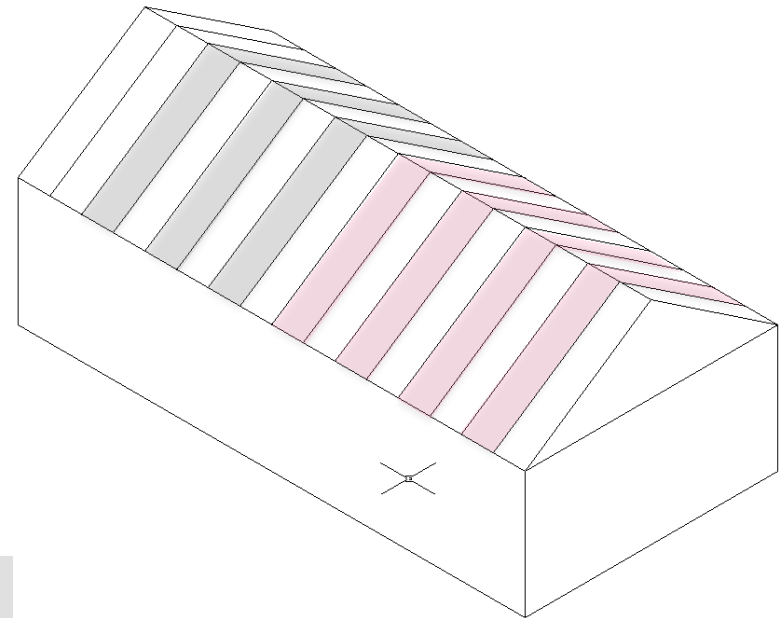
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# Research Project Background



# Test Hut Experimental Approach

- Climate Zone 5A test hut
- Eight north-south roof bays
- $\pm R-50$  (14- $\frac{3}{4}$ " 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 Construction



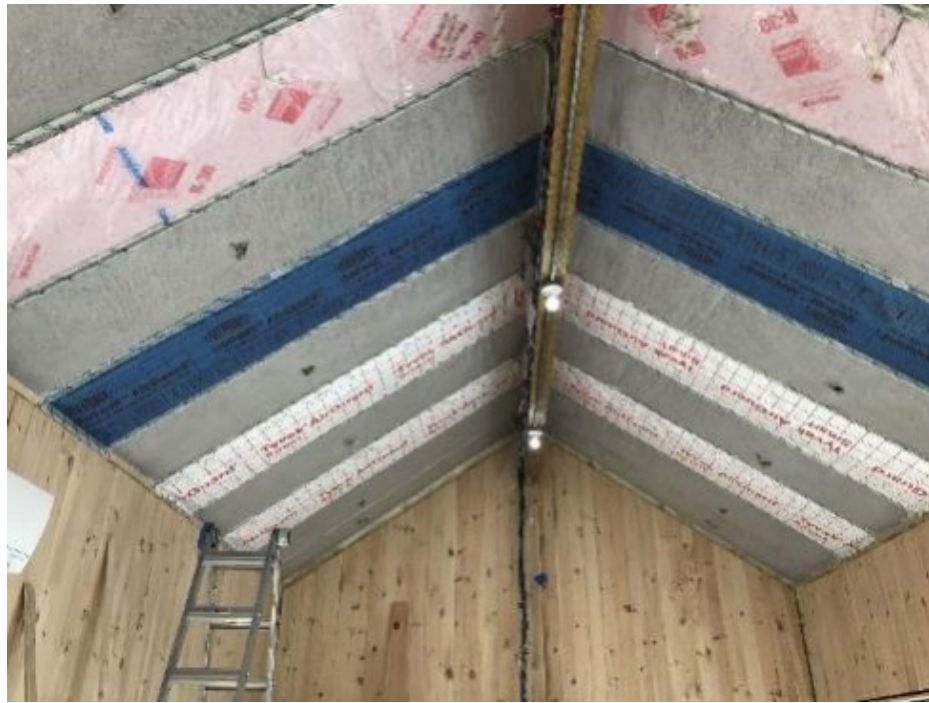
- Roof bays 24" o.c.
- Guard bays between experimental bays (“flash and blow” ccSPF + cellulose)
- Fluid-applied air and vapor barrier at guard bays

# 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

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- Instrumentation completion

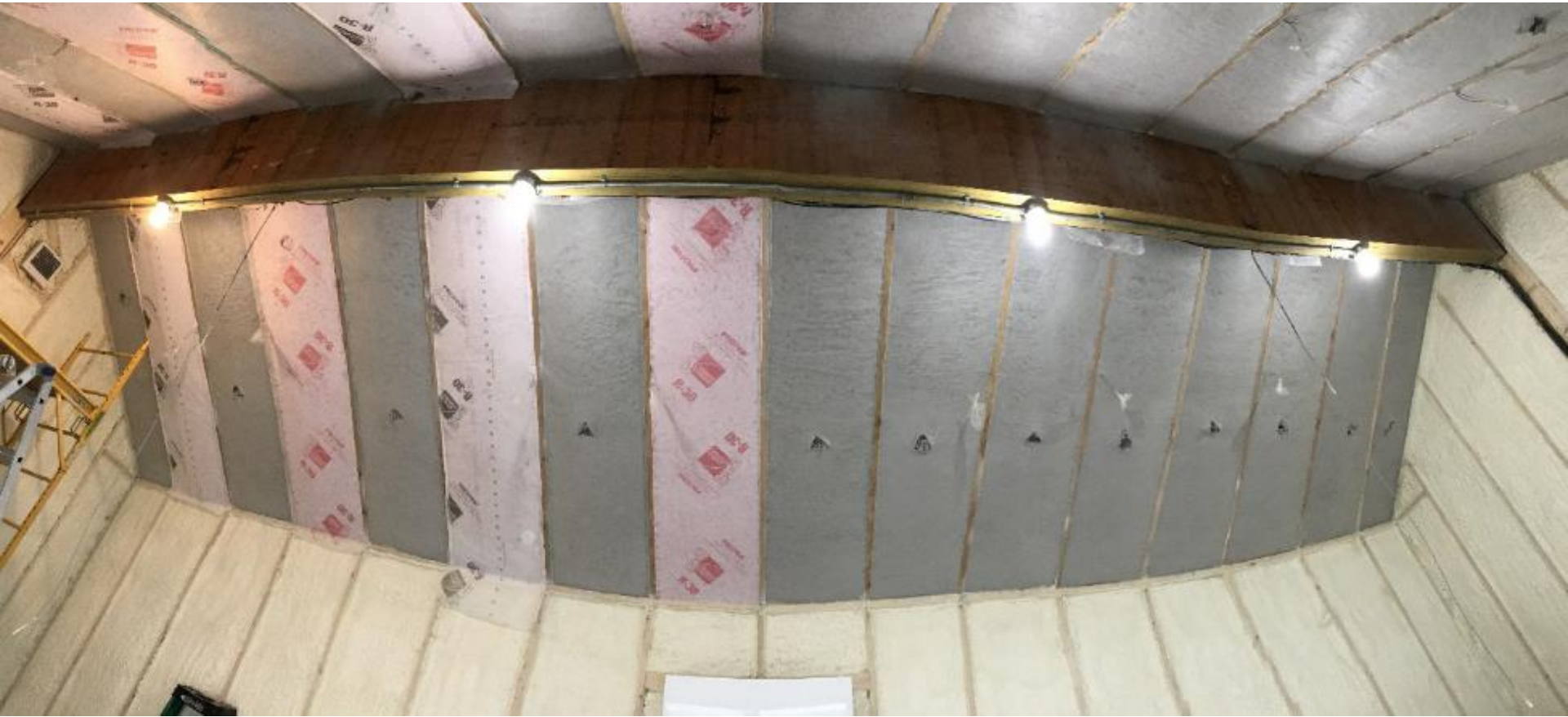
# Test Hut Construction



- ccSPF in guard bays and walls

# Test Hut Construction

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- Fibrous insulation installed

# Test Hut Construction

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- Interior air/vapor control installed



# Experimental Approach: Diffusion Vent



- $\pm 6$  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

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

# Warning on Presentation of Results

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- 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

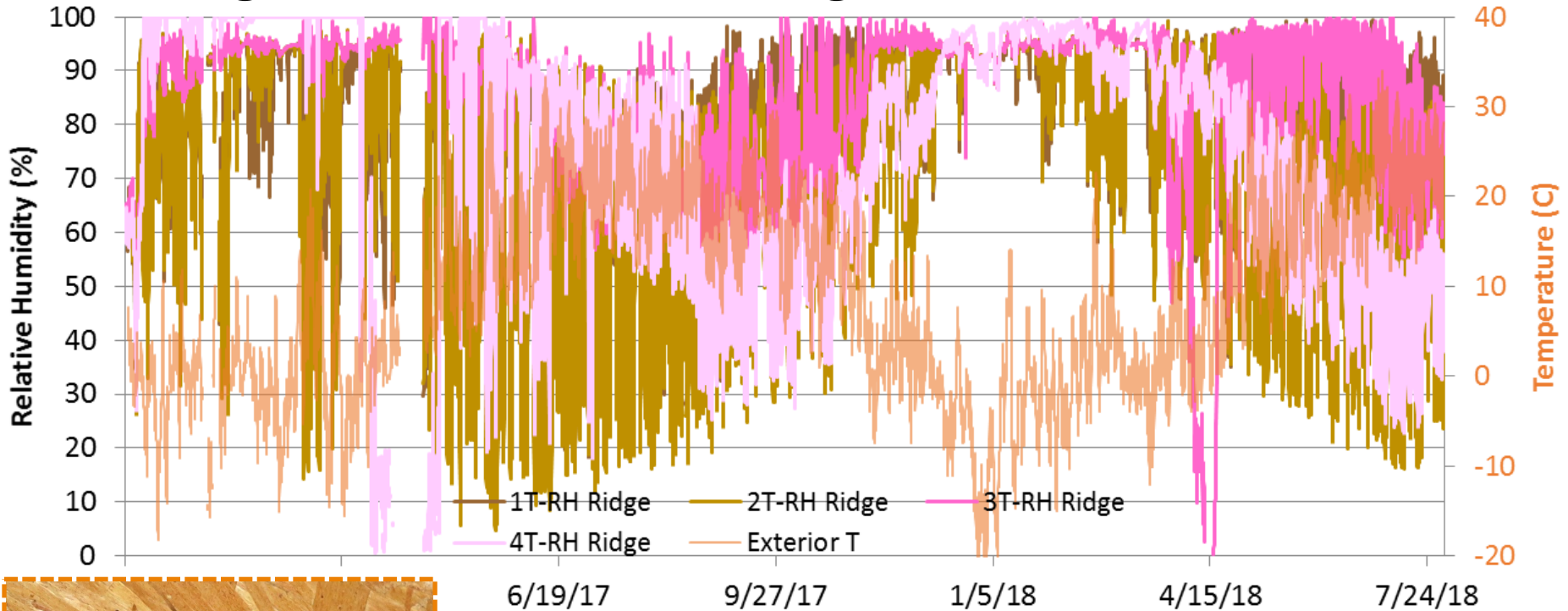
# Fiberglass Roofs: Color Codes

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 Variable)	2"±300 perm
7	Dense pack cellulose	Variable perm (DuPont Variable)	2"±300 perm
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



resolve-variations

) > 95% RH most of Winter

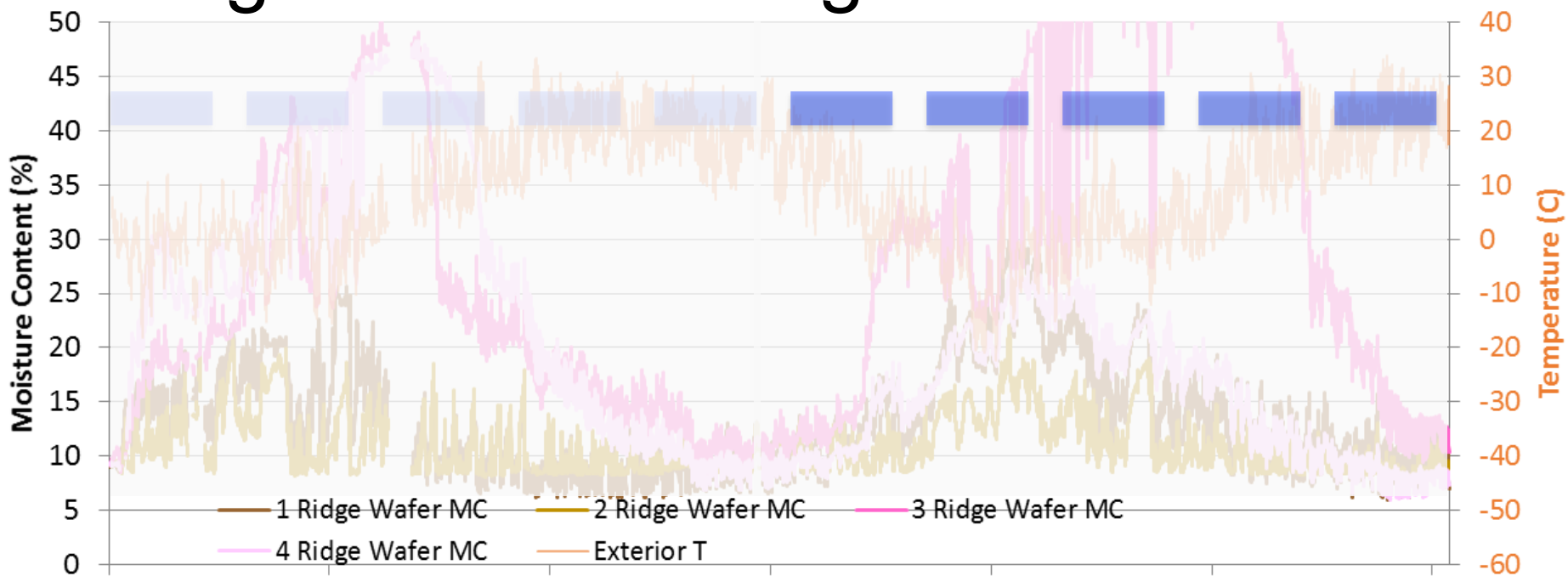
test into summer

) 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

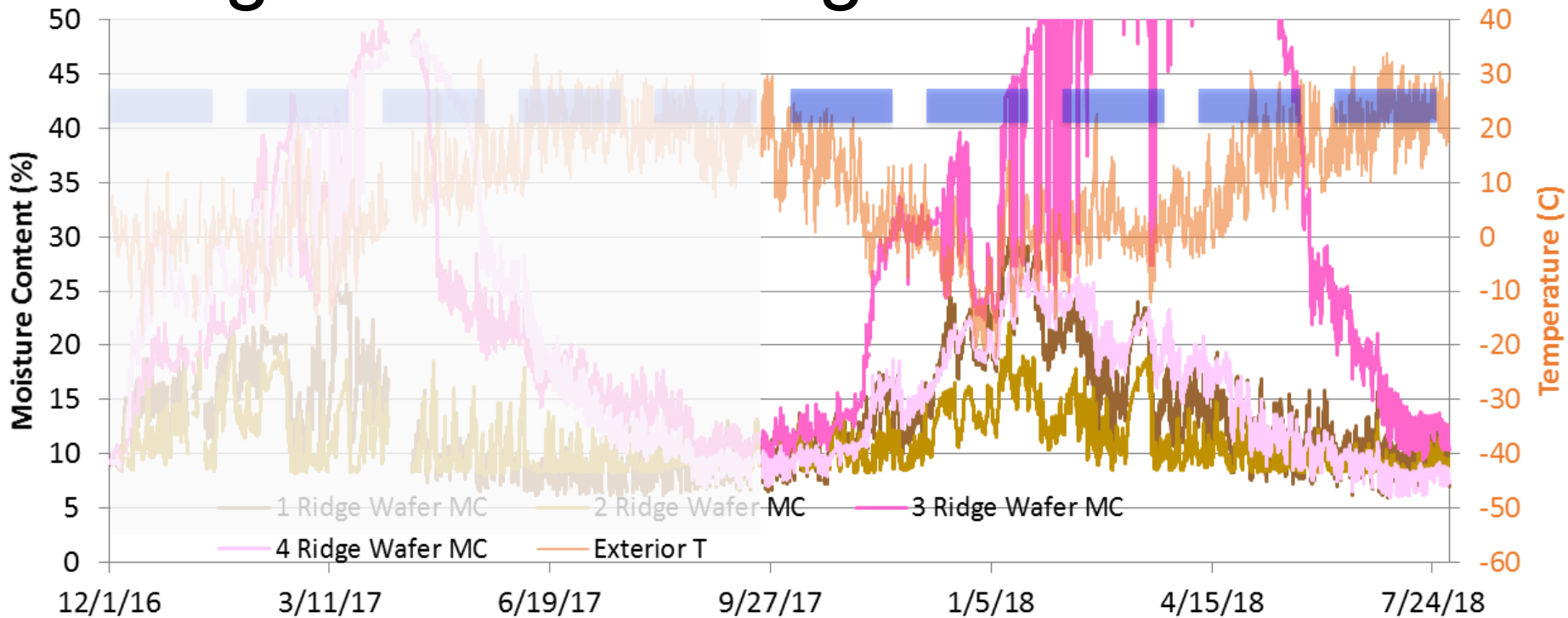


6/19/17    9/27/17    1/5/18    4/15/18    7/24/18

**Roof 3 & 4 (nDV) > 40% MC**  
 Ridge wafer calibrated ~40-45% MC  
 Unvented **Roofs 1 & 2** stay drier <25%  
**Roof 3** (tDV) soaking wet ridge  
**Roofs 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

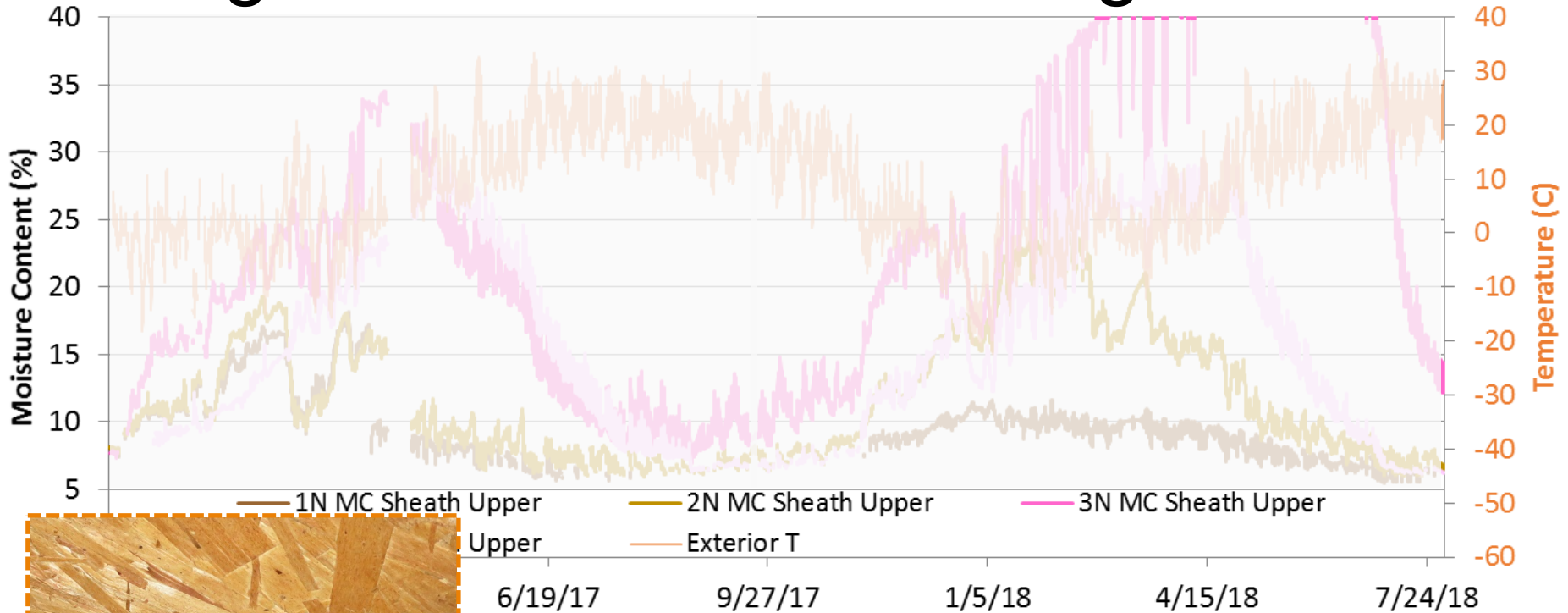
# Fiberglass Roofs: Ridge Wafers



- **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%

not nearly as safe at 50% RH

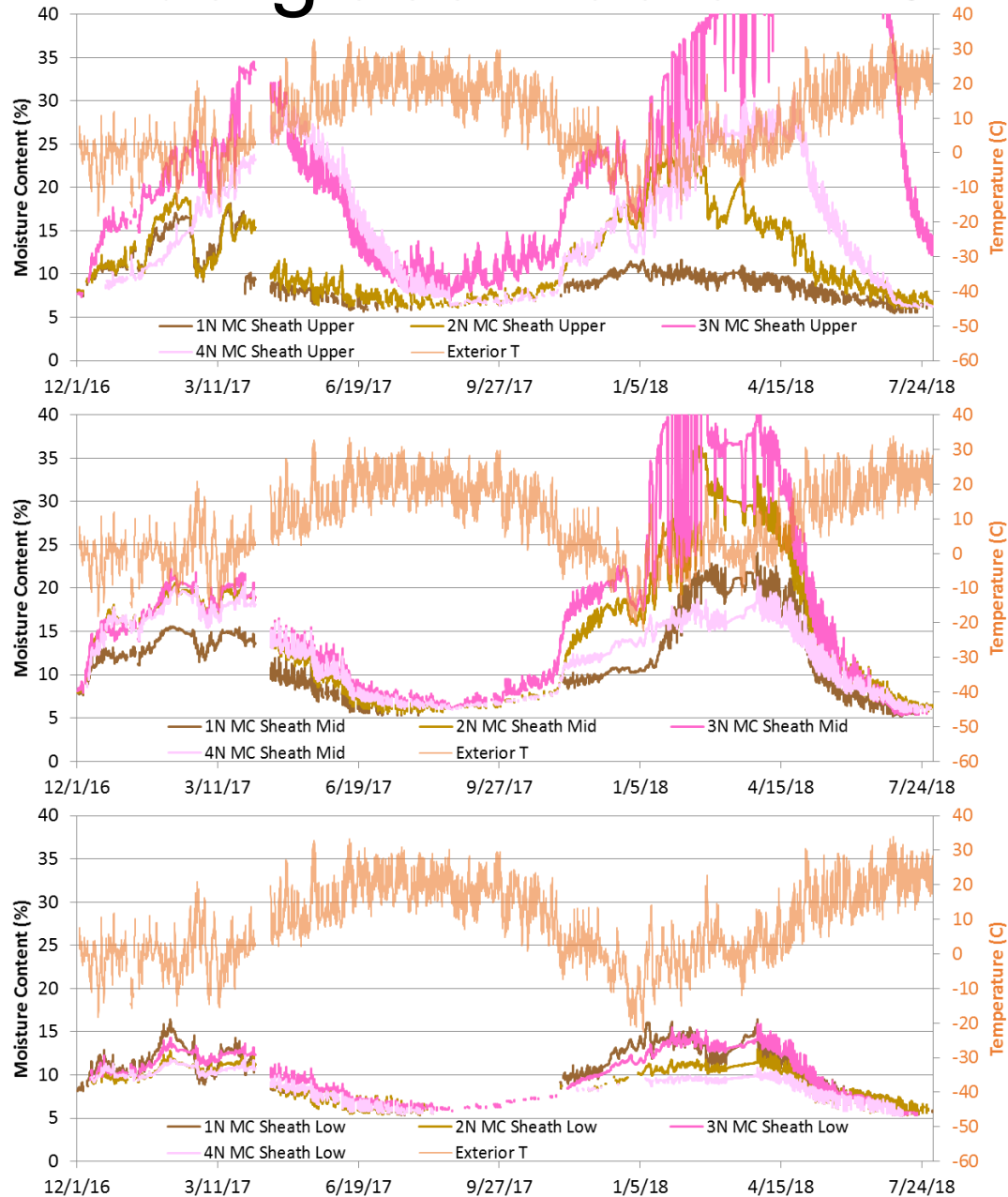
(V) very wet, very long time

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

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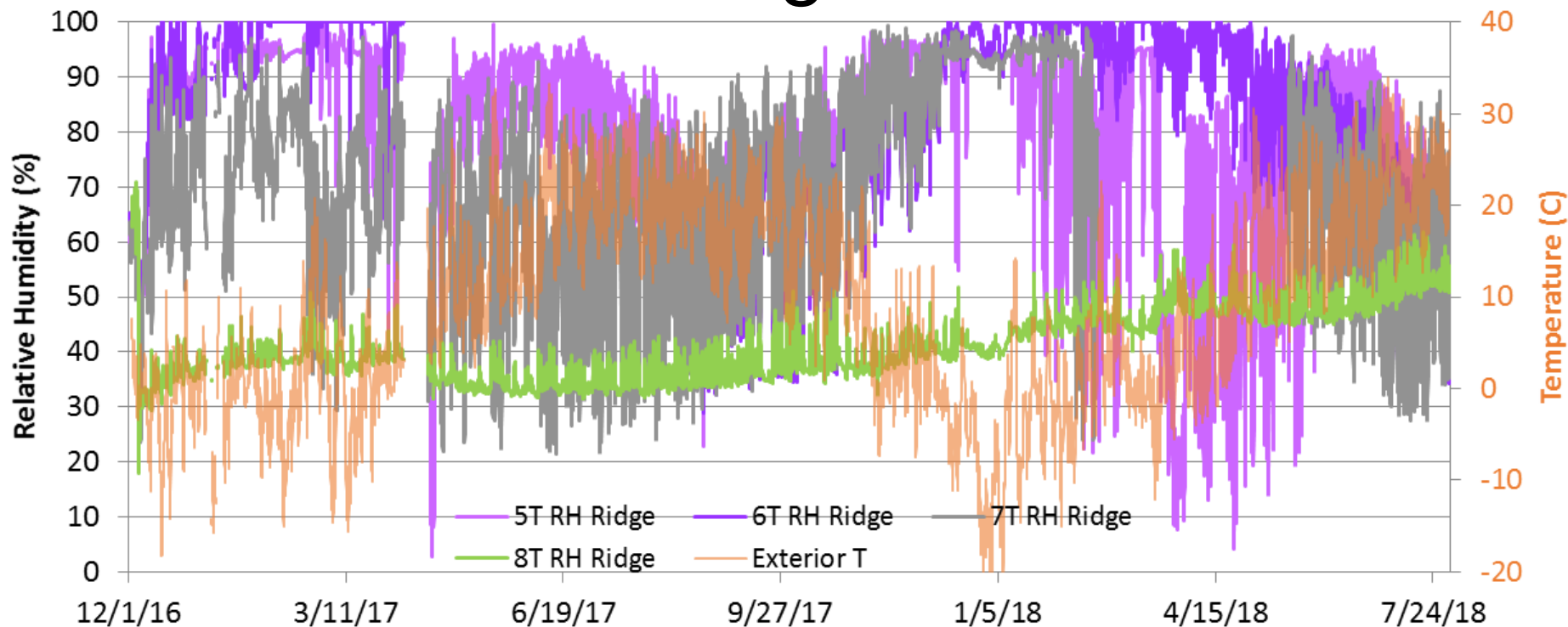
# Results: Cellulose Roofs

# Cellulose Roofs: Color Codes

Roof #	Insulation	Interior VB	Roof	Short Name
1	Fiberglass	Fixed perm (OC 1 perm)	5	Cell-SVR-tDV
2	Fiberglass	Variable perm (MemBrain)	6	Cell-SVR-sDV
3	Fiberglass	Variable perm (MemBrain)	7	Cell-SVR-DV
4	Fiberglass	Variable perm (MemBrain)	8	ccSPF-Cell
5	Dense pack cellulose	Variable perm (DuPont Variable)		
6	Dense pack cellulose	Variable perm (DuPont Variable)		
7	Dense pack cellulose	Variable perm (DuPont Variable)		
8	ccSPF + cellulose "flash and blow"	None		

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

# Cellulose Roofs: Ridge RH

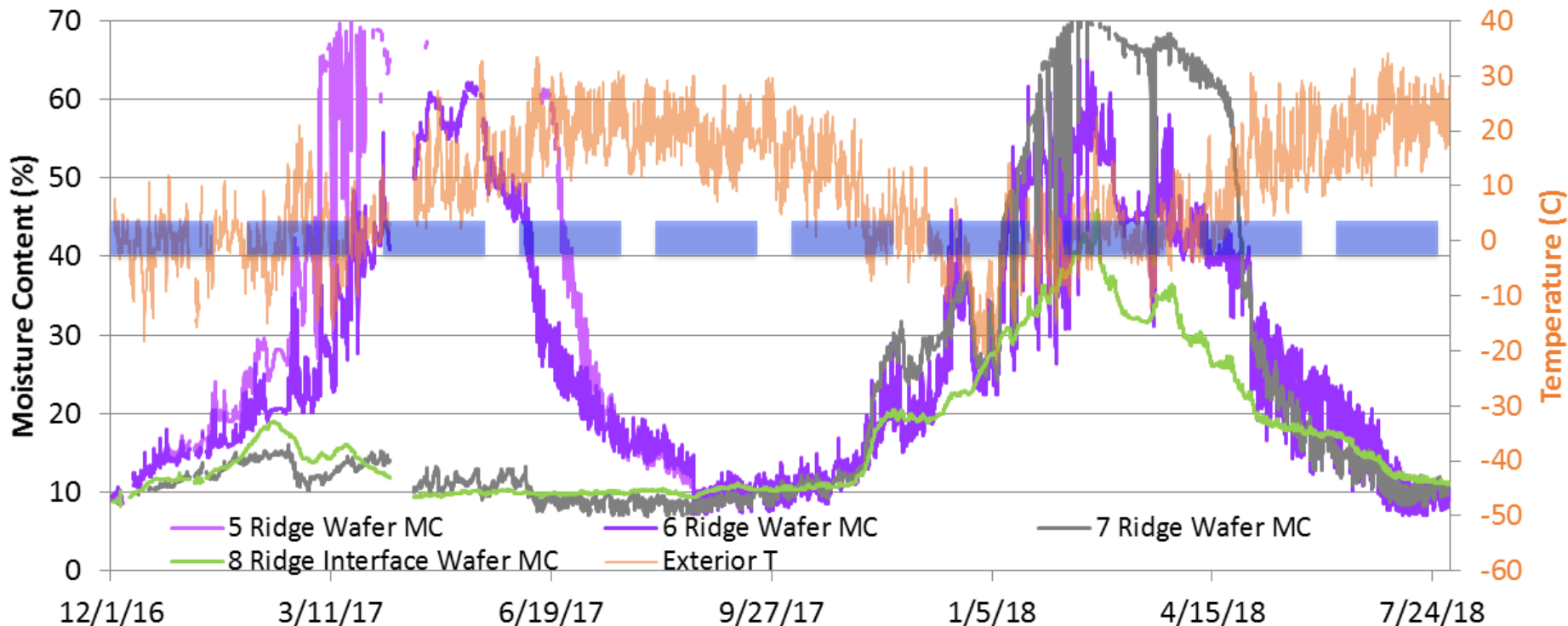


- Difficult to differentiate
- RH sensor failures: **Roof 6** (2017), **Roof 5** (unrealistic data 2018), **Roof 7** (2018)

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



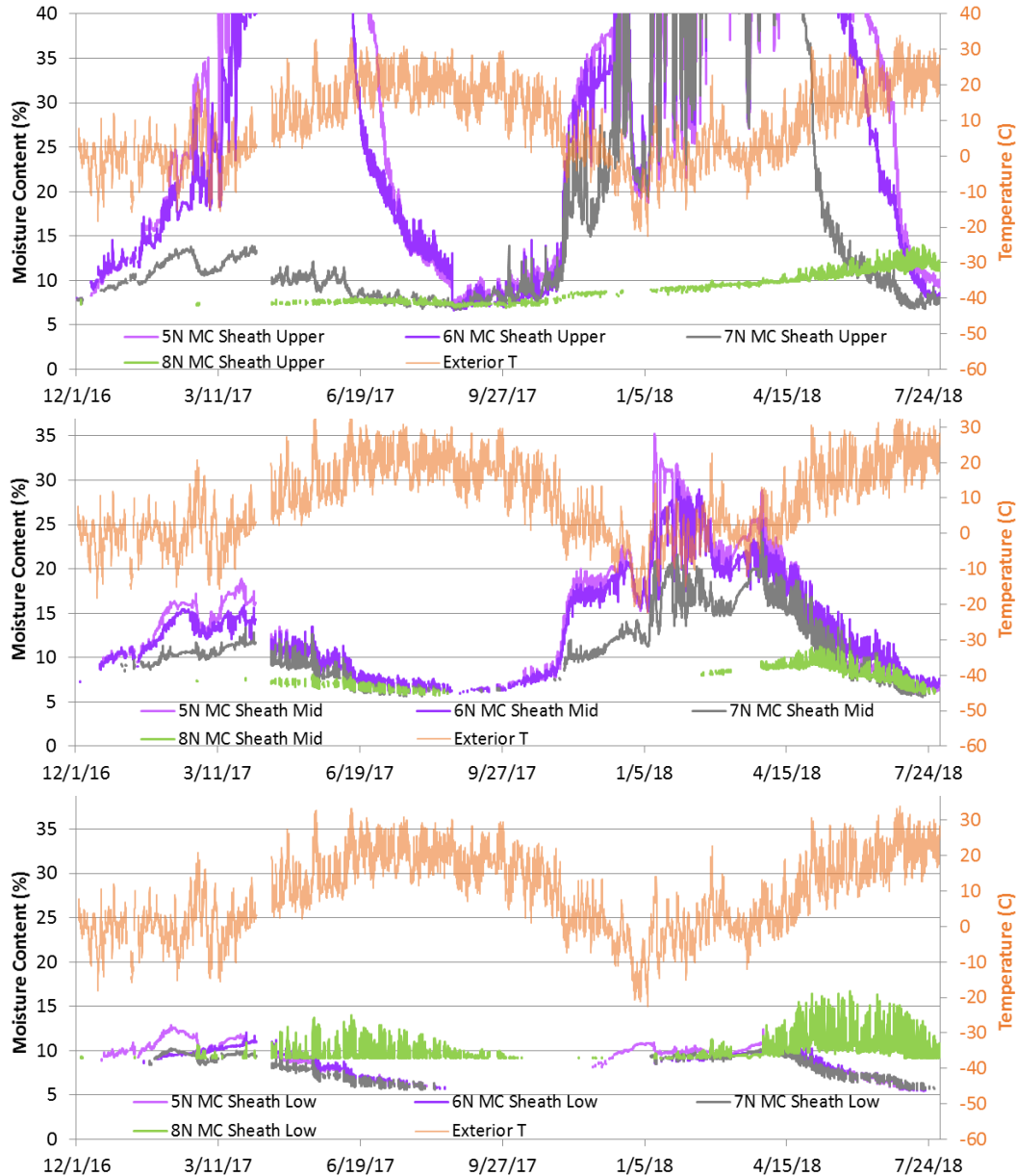
# Cellulose Roofs: Ridge Wafer



- 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

Building America

# 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

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# 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)



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# Conclusions and Further Work

# Conclusions

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- 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

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- 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

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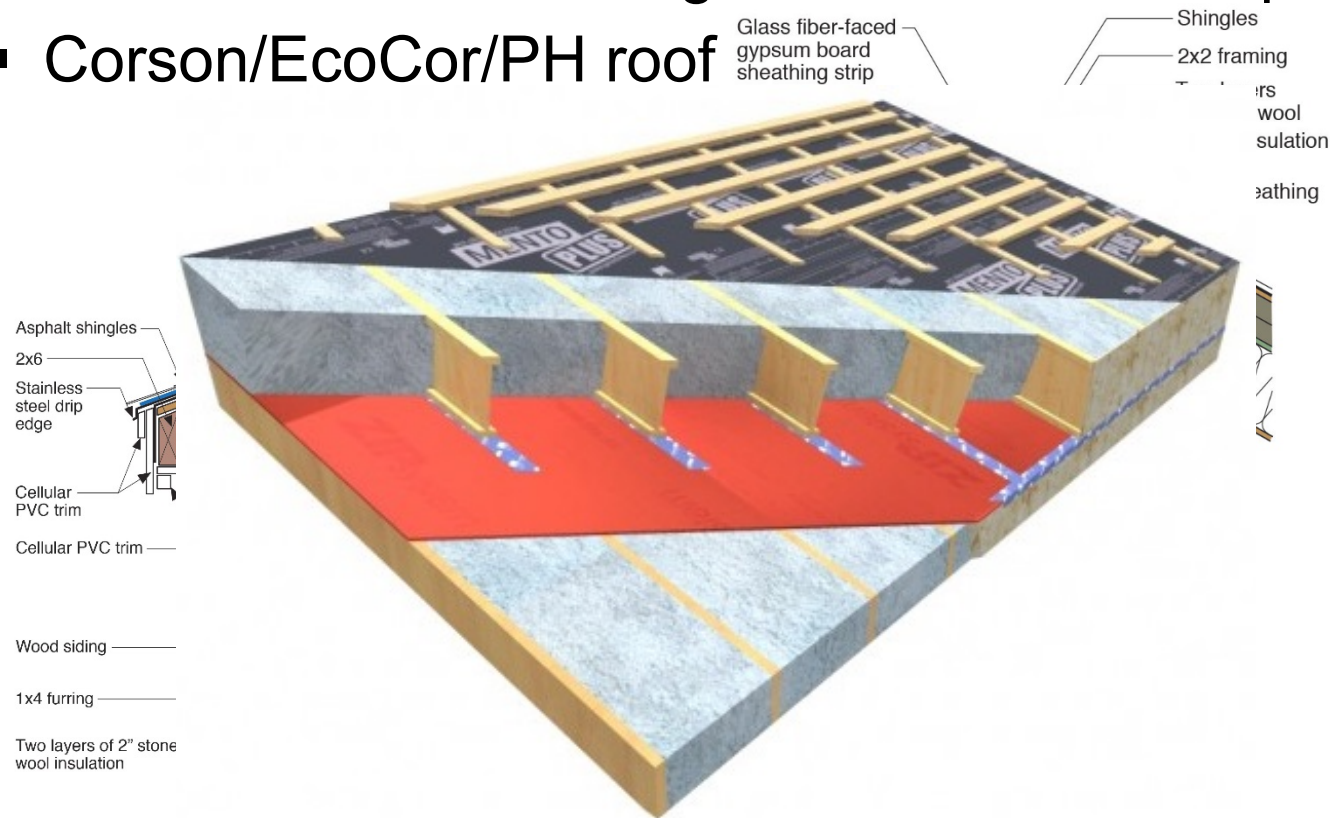
- Winter 3 Operation (Proposed)
  - Start at 50% RH, no air leakage
  - Introduce air leakage in later winter (possible on/off)
- “Tight” diffusion vent (**Roof 3** & **Roof 5**): replacement?
  - Full-size 300 perm diffusion vent (like others)
  - Different variable-perm interior air barrier/vapor retarder

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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



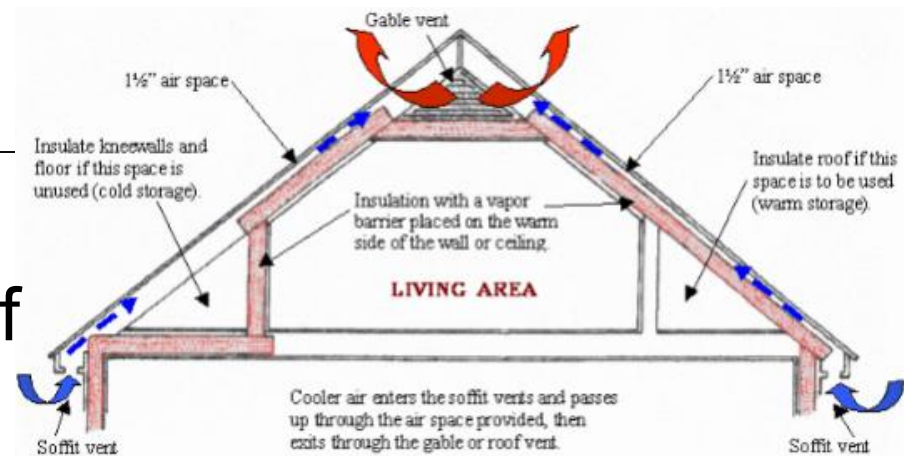
# Recommendations

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- 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 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



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# Questions?

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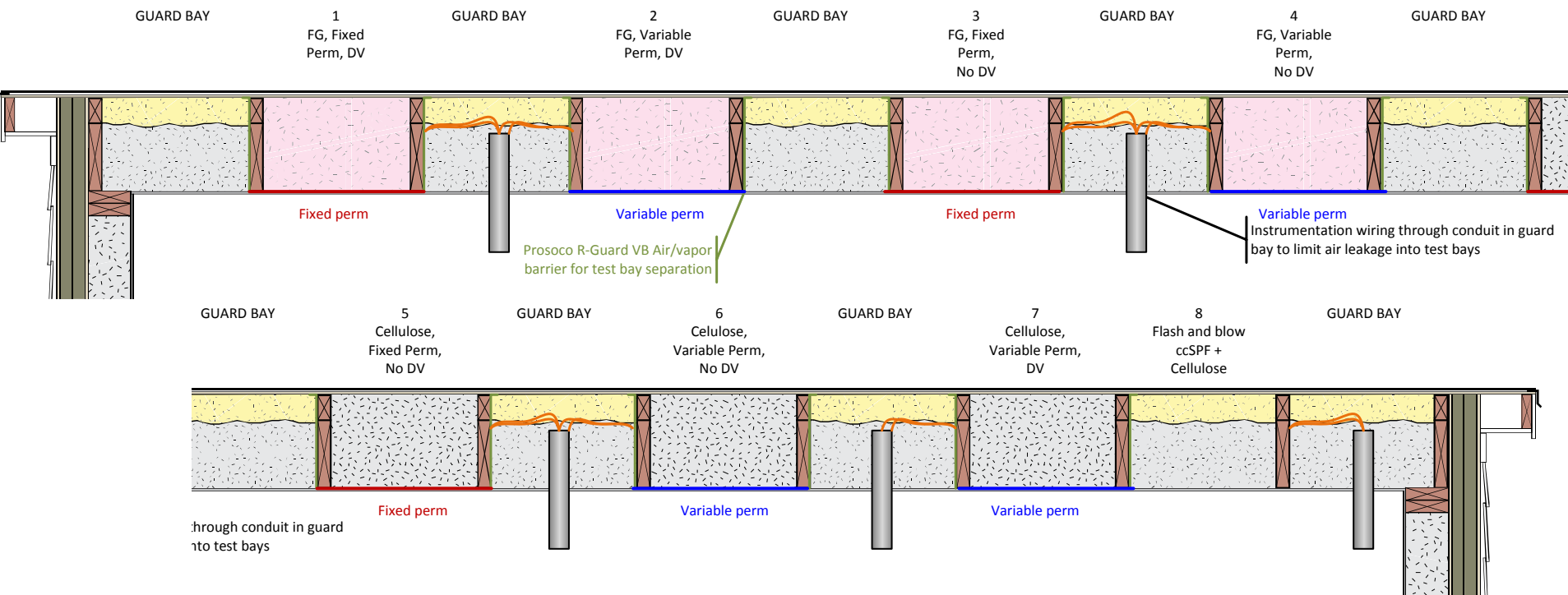
This presentation will be posted at: <https://buildingscience.com/past-events>

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Energy Efficiency &  
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# Experimental Approach: Roof Section



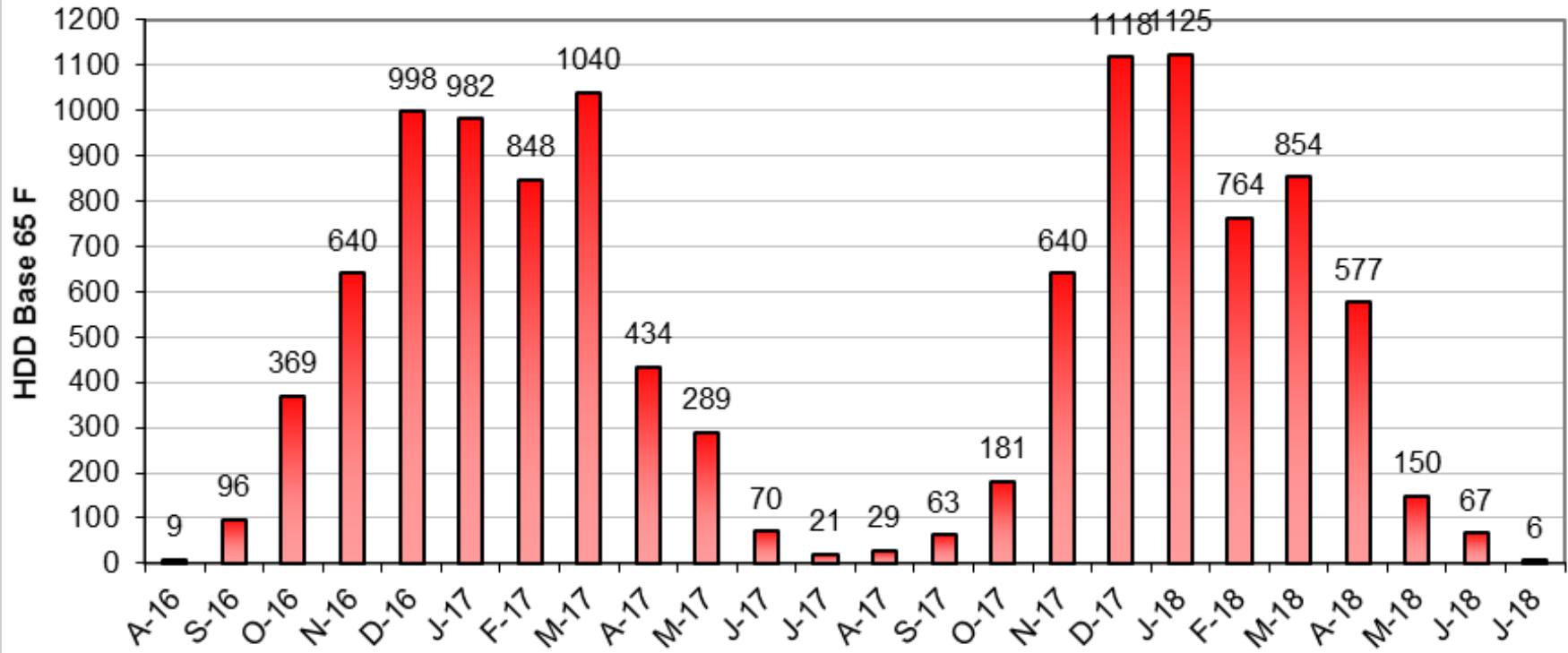
- 4 fiberglass bays
- 3 cellulose bays
- 1 “flash and blow” control comparison



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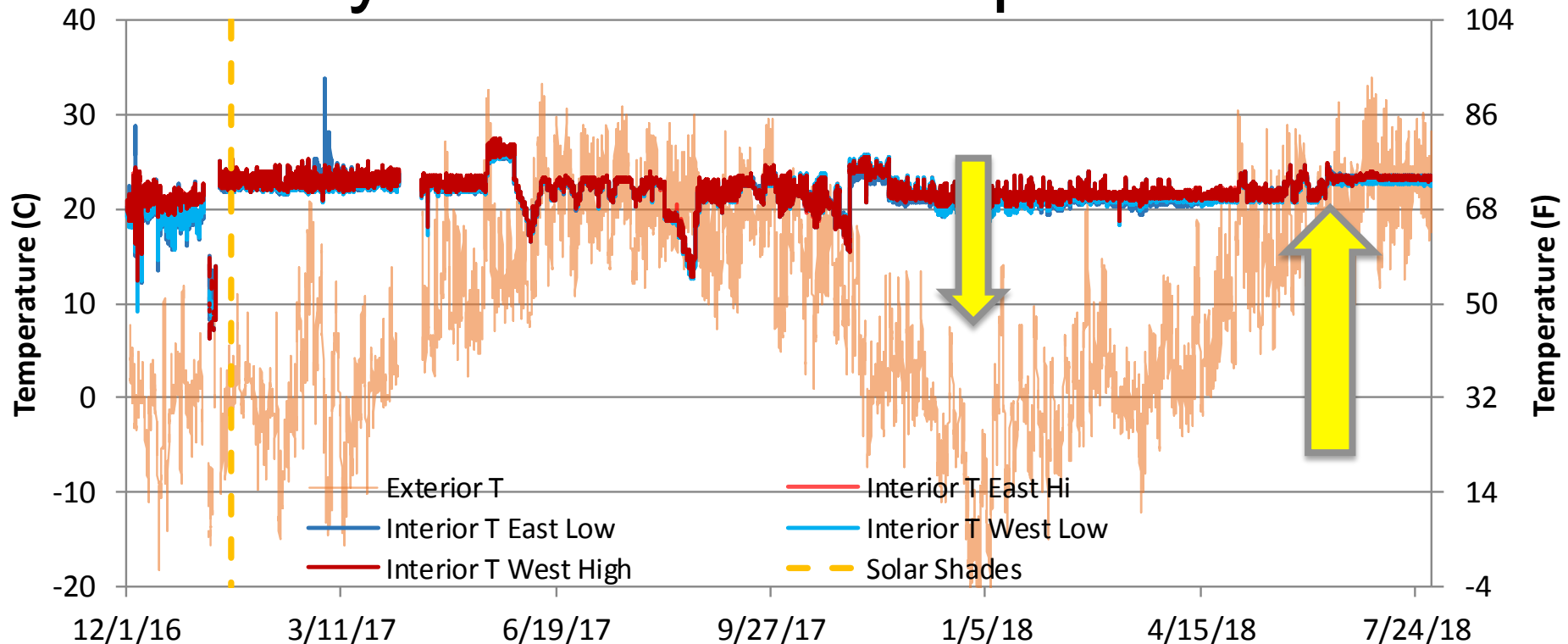
# Results: Boundary Conditions

# Boundary Conditions: Exterior Climate



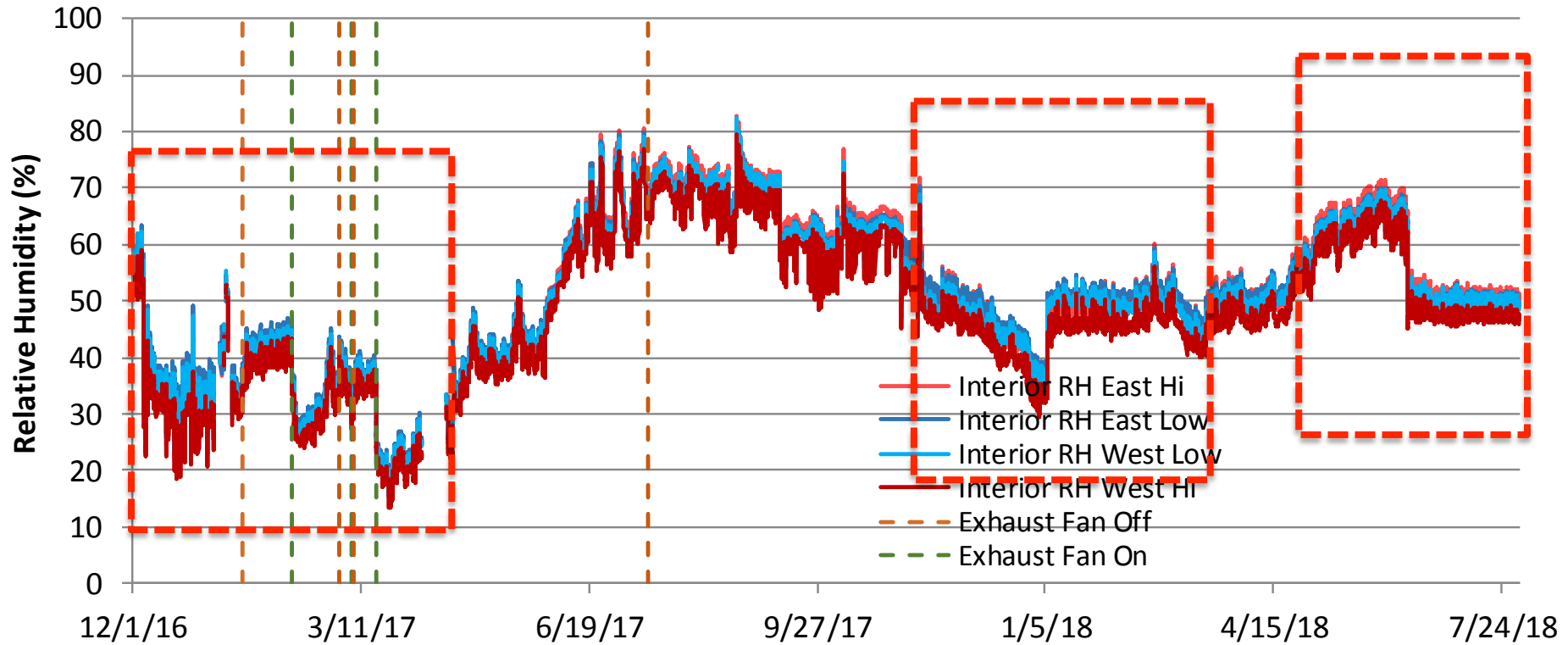
- KLWM (Lawrence MA) airport HDD data
- Winter 2016-2017: 5796 HDD (89% of normal)
- Winter 2017-2018: 5574 HDD (85% of normal)
- KBOS weather 94% & 96% of normal

# Boundary Conditions: Temperature



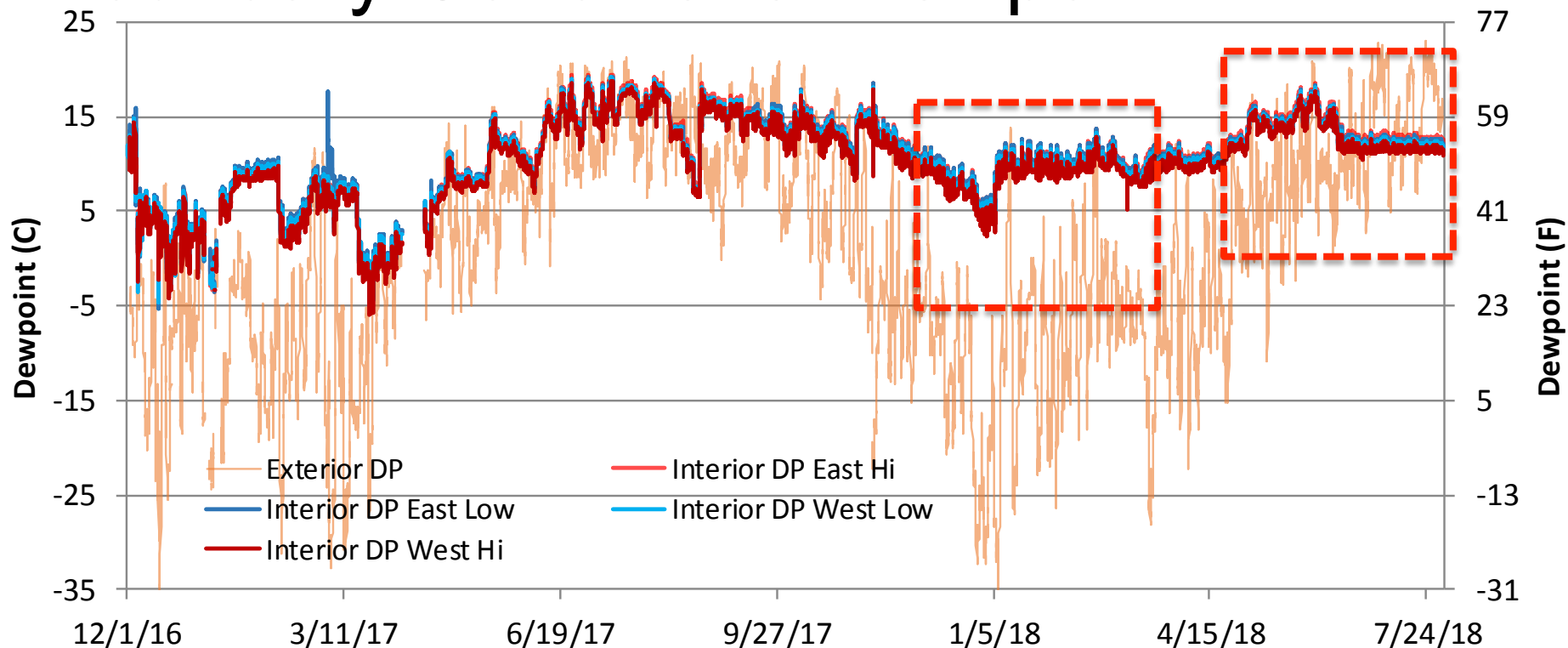
- Data collected December 2016-July 2018
- Winter 2017-2018 similar HDD, more extreme cold
- Interior temperature held near-constant

# 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

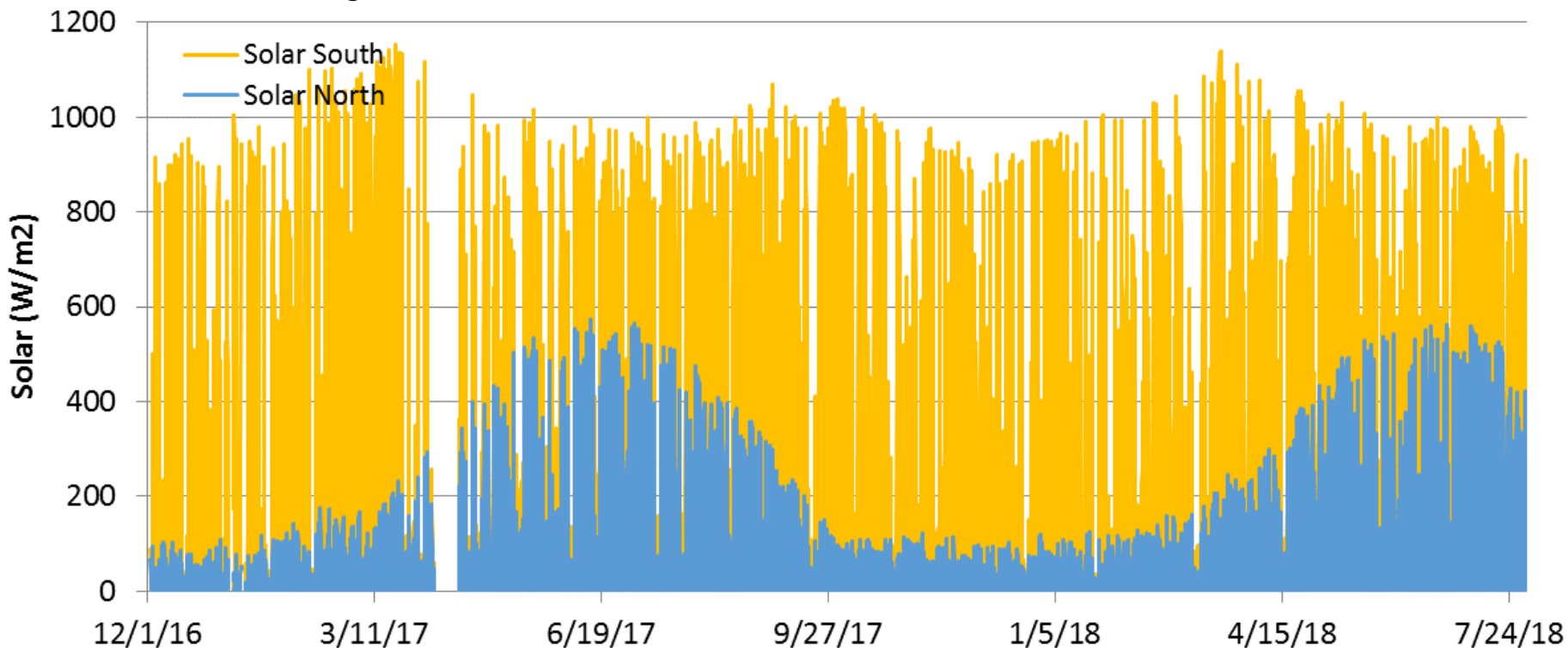
# Humidification

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- Humidification confirmed via direct measurement and experience

# Boundary Conditions: Solar



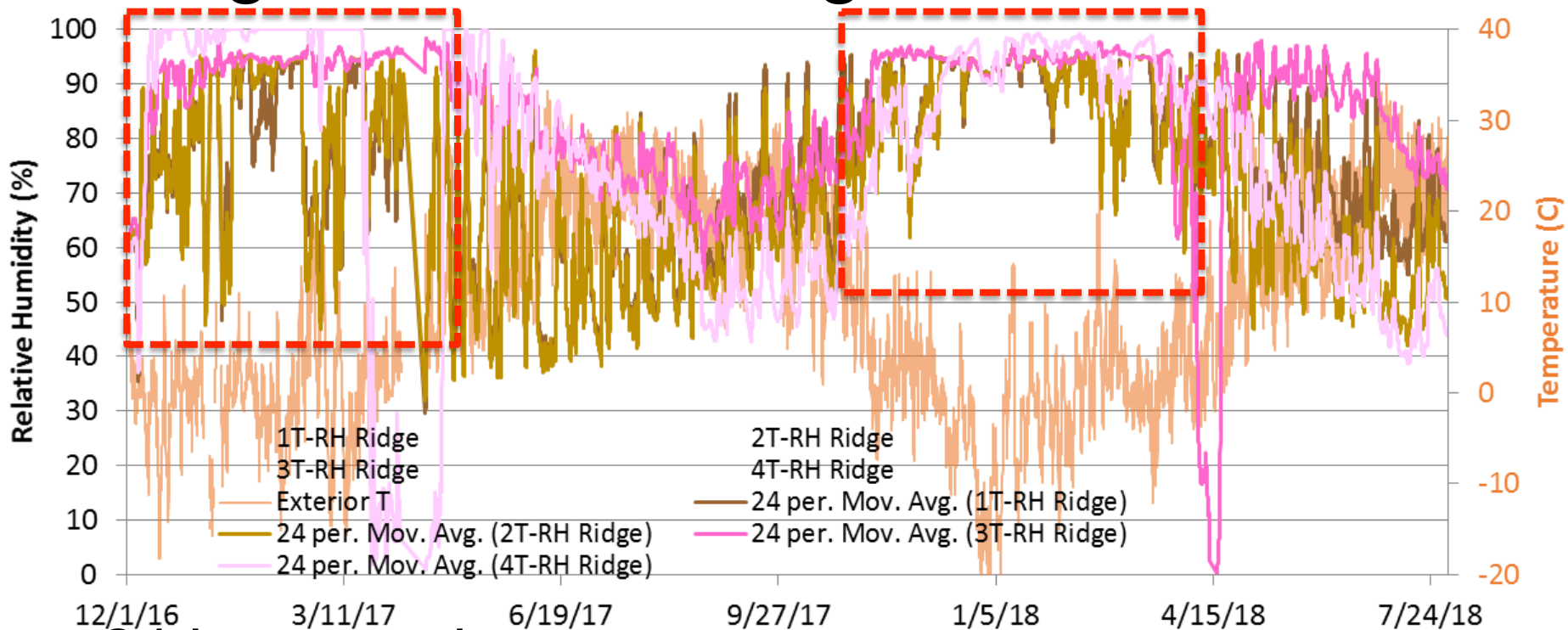
- Solar data primary collected if future modeling work, correlation with events
- North solar on 8:12 roof in MA

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# Results: Fiberglass Roofs



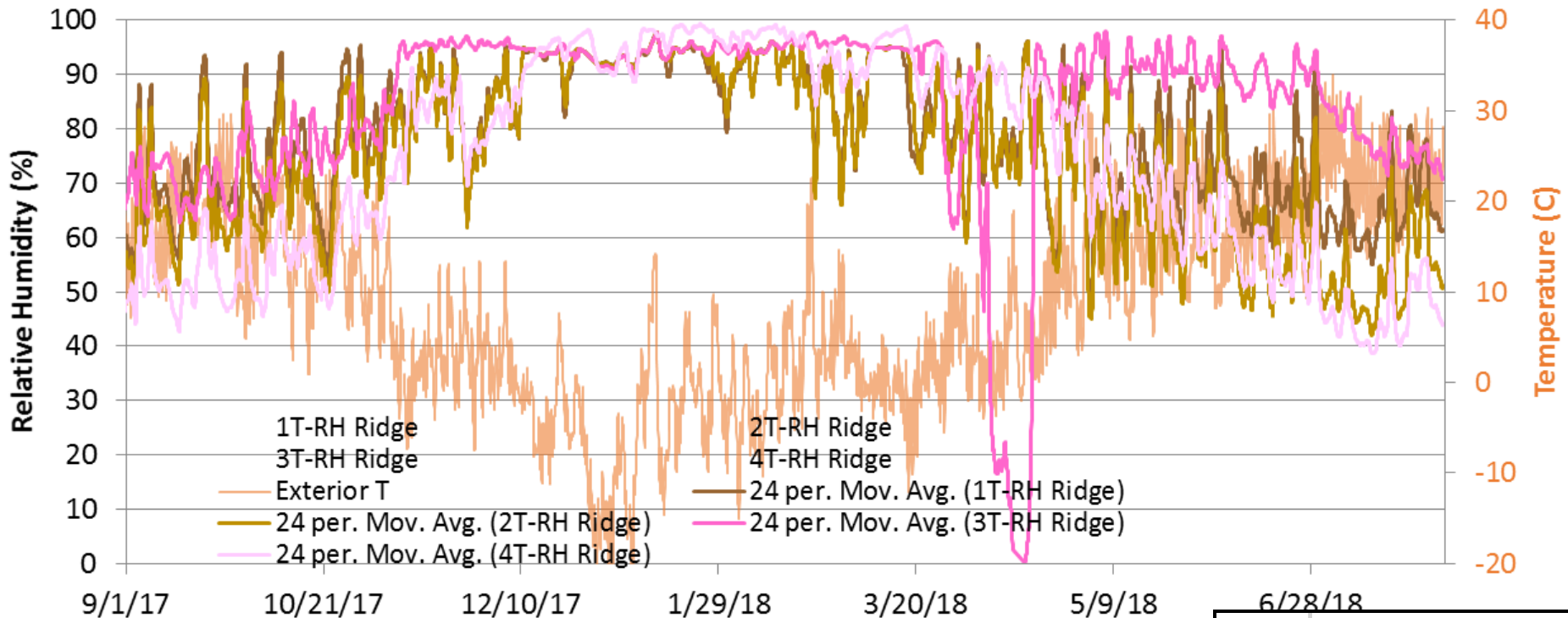
# Fiberglass Roofs: Ridge RH



- 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

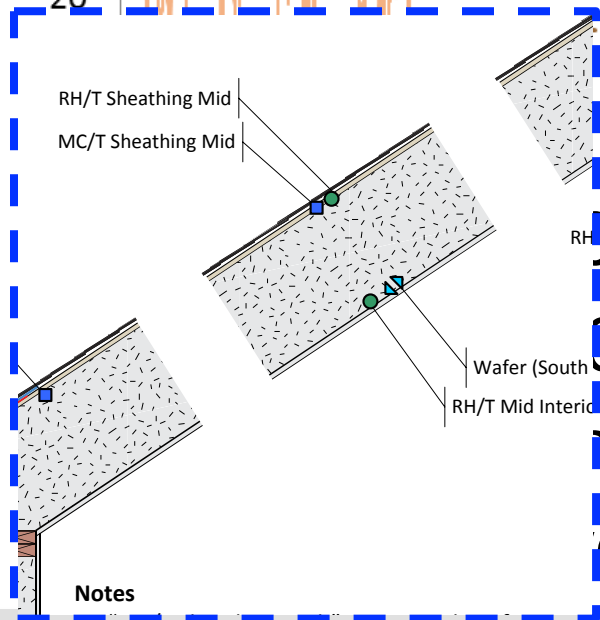
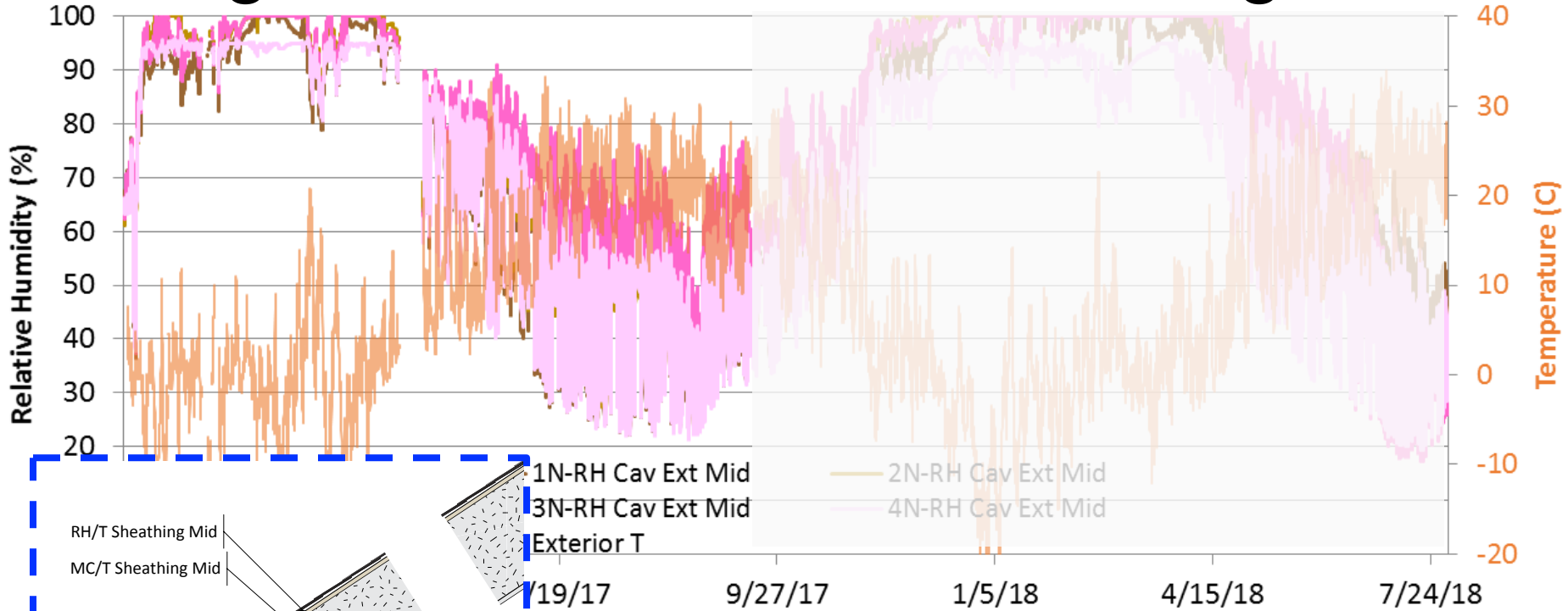
# Fiberglass Roofs: Ridge RH



- 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

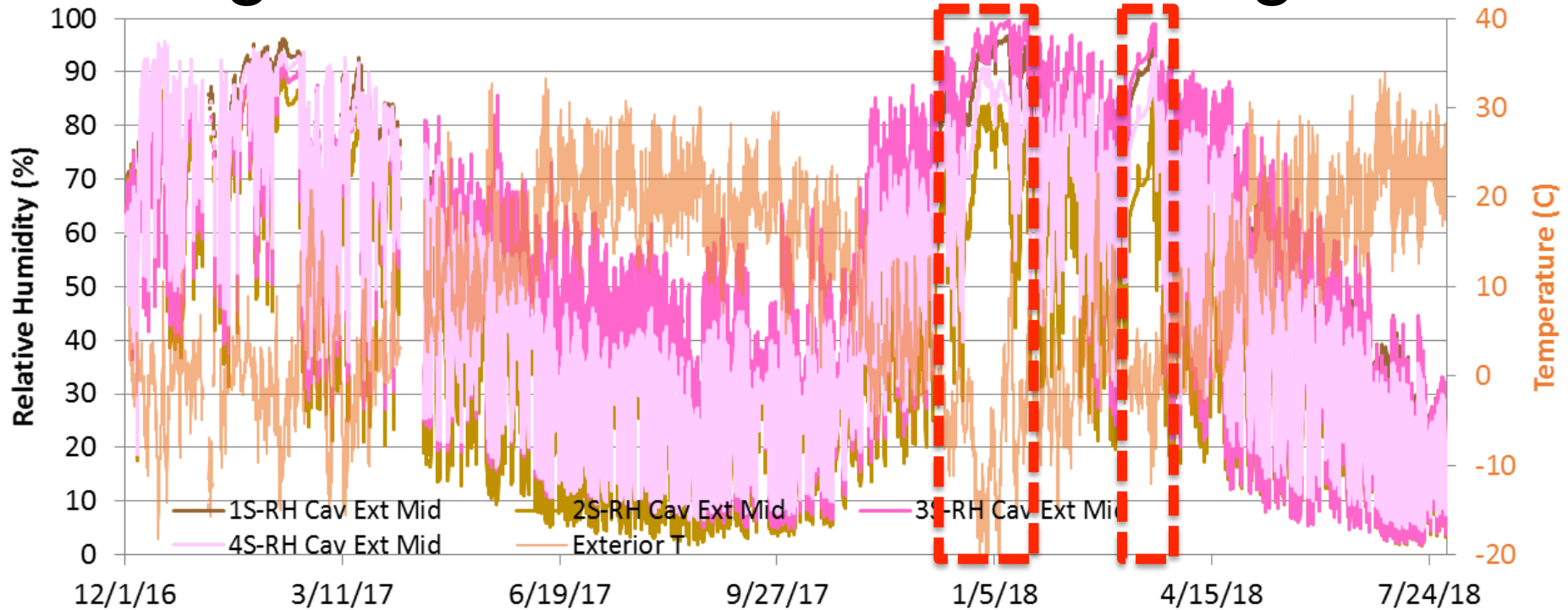
# Fiberglass Roofs: North Sheathing RH



0% Winter 1  
 0% all winter long  
 actually 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

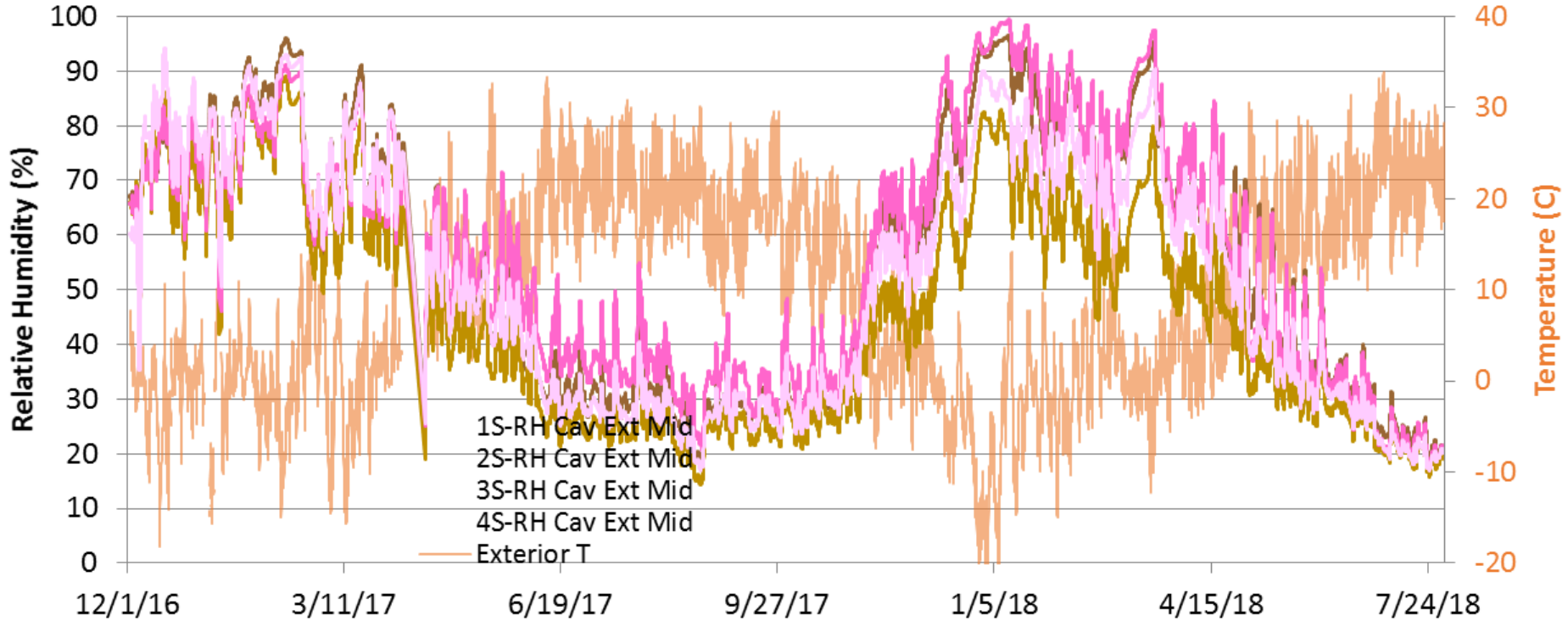
# Fiberglass Roofs: South Sheathing RH



- 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

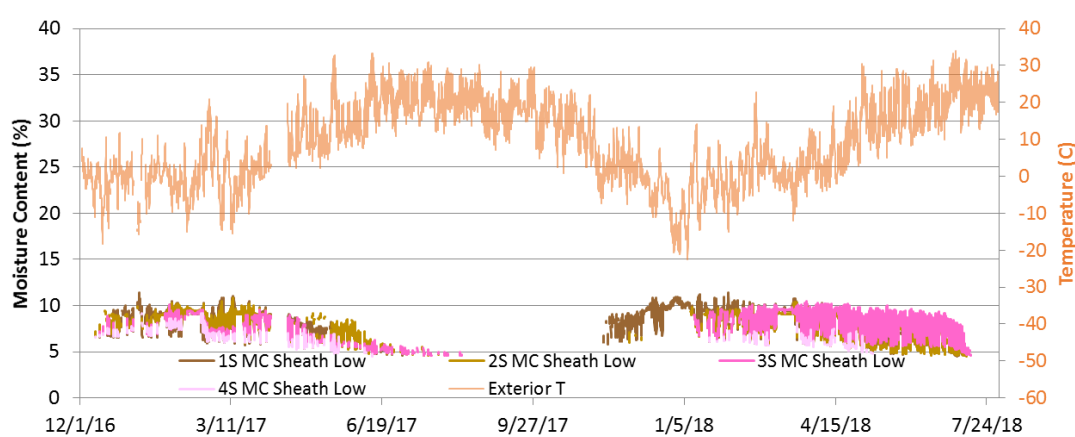
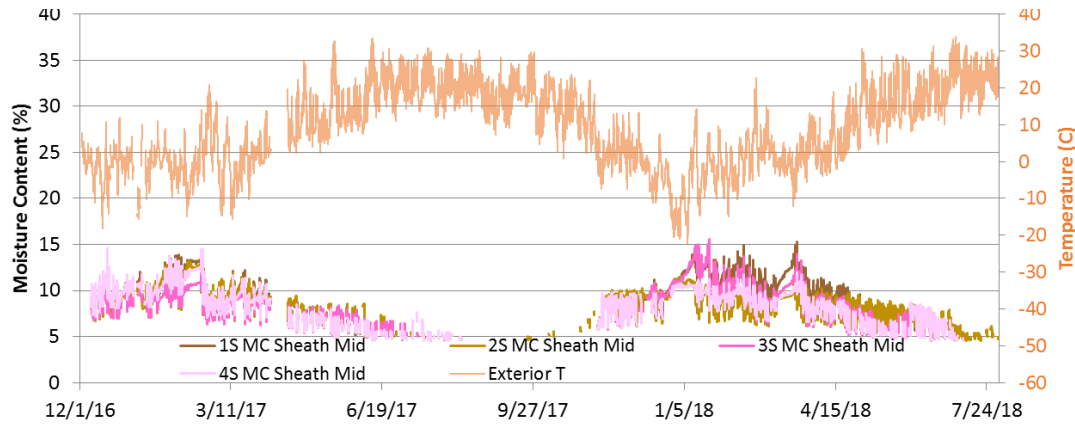
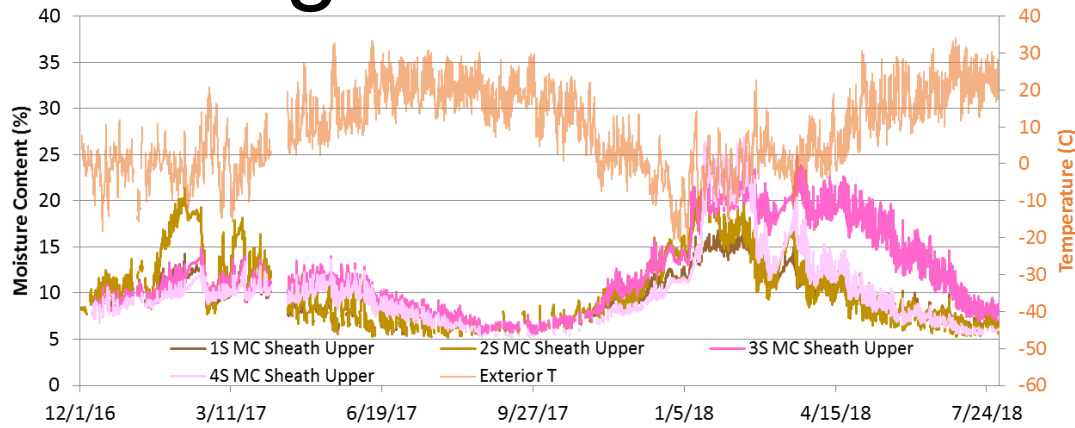
# Fiberglass Roofs: South Sheathing RH



- 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

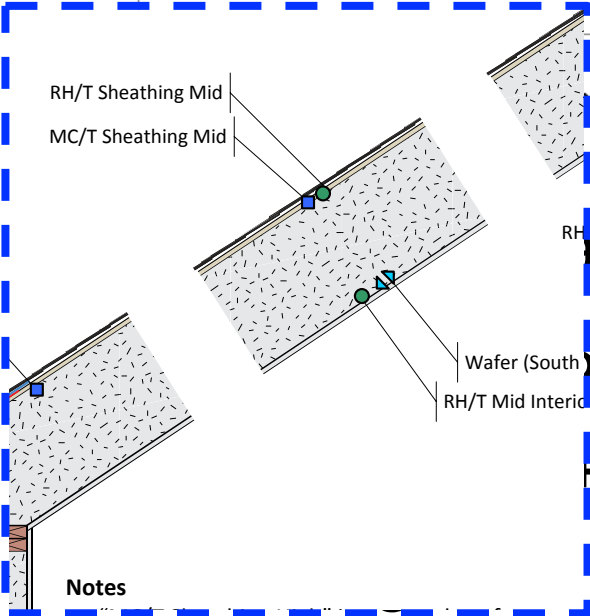
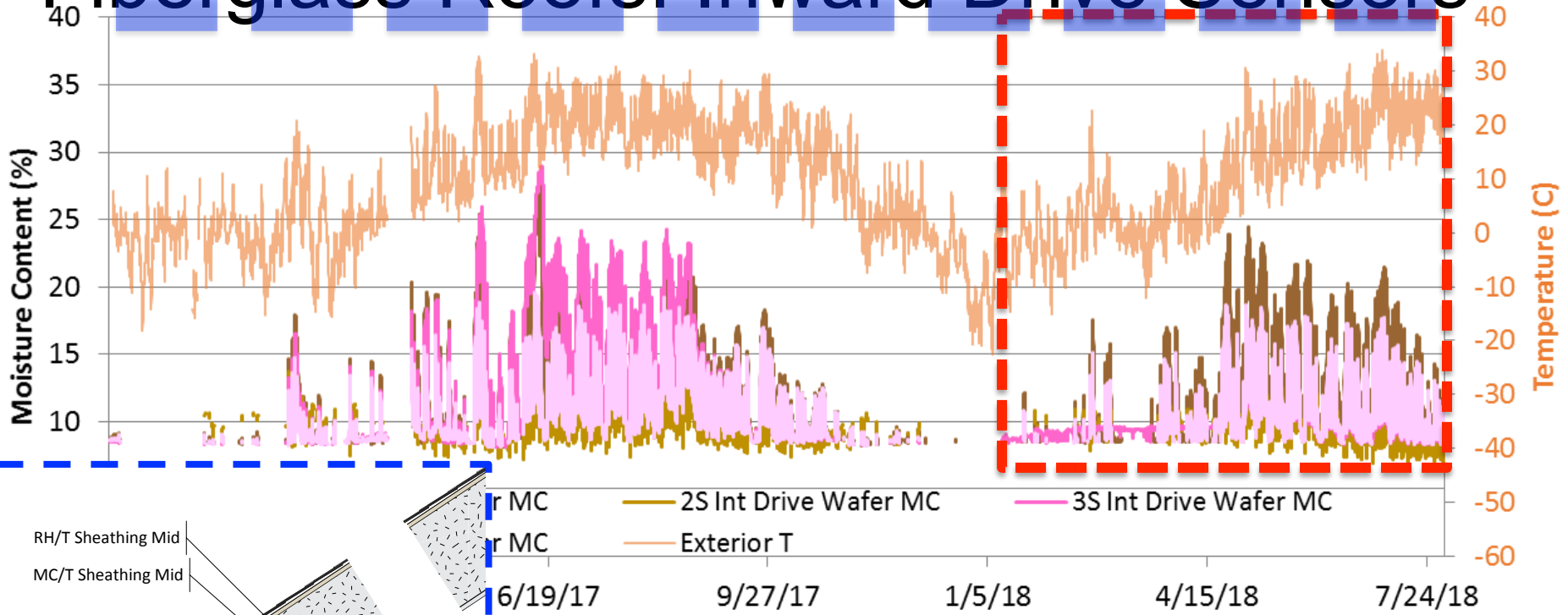
# Fiberglass Roofs: S Sheathing MCs



- 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



Wafer sensors

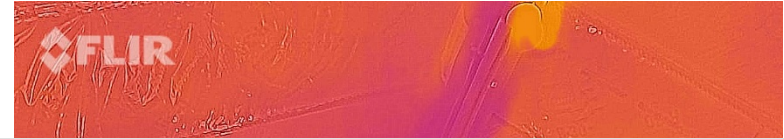
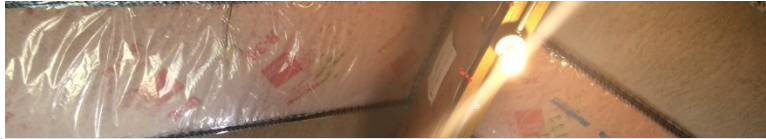
Roofs 1 worst (fixed VB)

5% MC condensation level

not 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

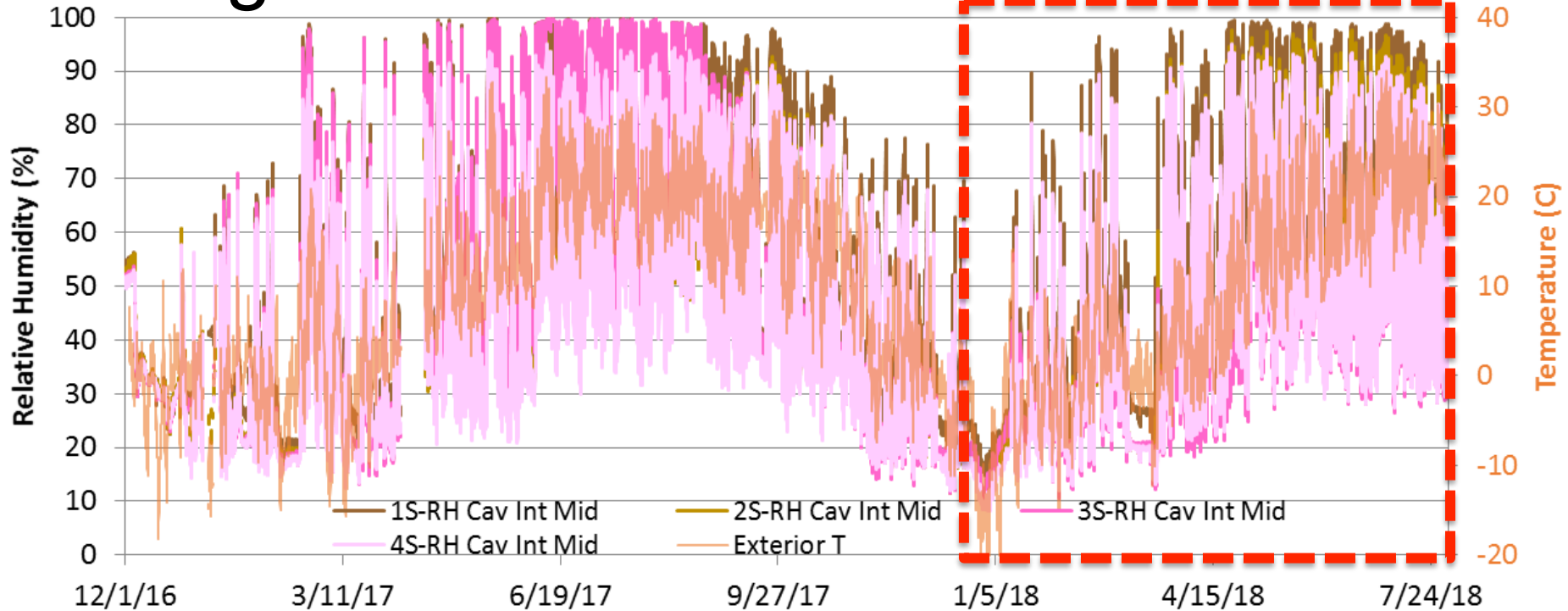


**Inward vapor drive does matter—  
we were just measuring in the  
wrong location!**





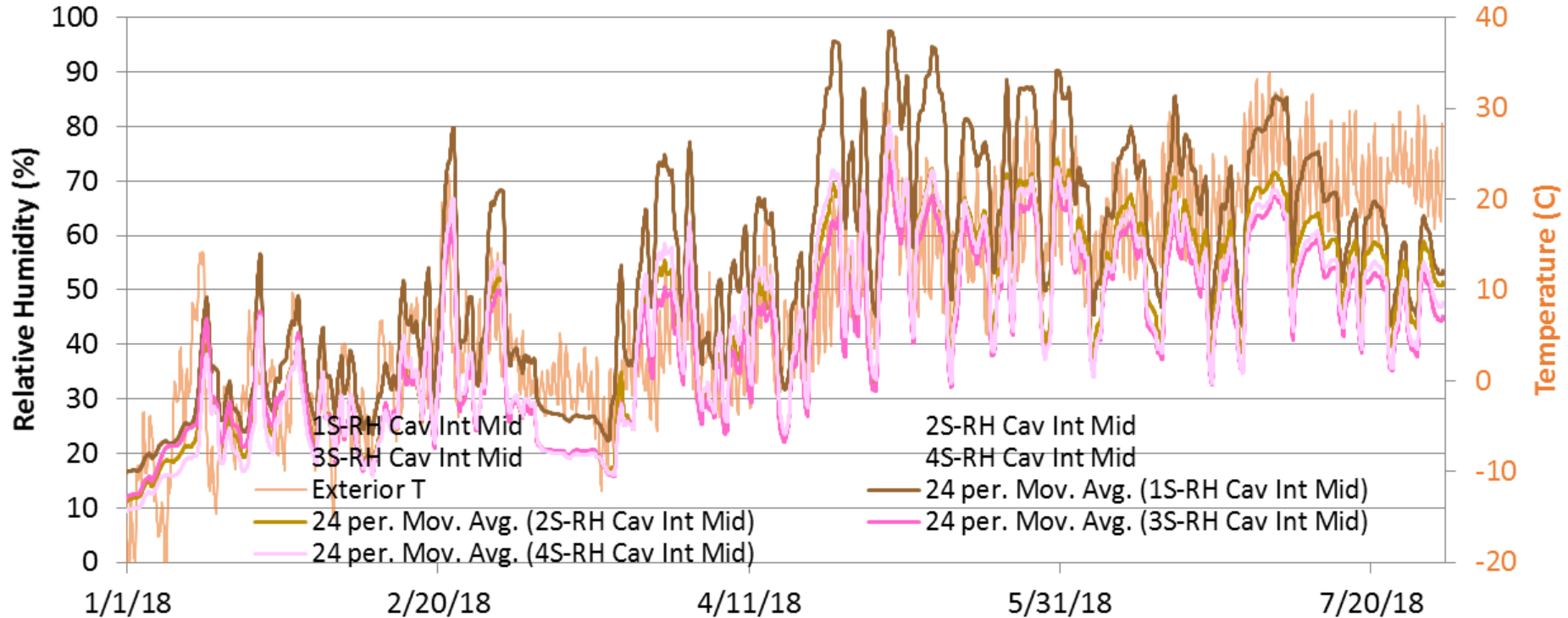
# Fiberglass Roofs: Inward Drive Sensors



- 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

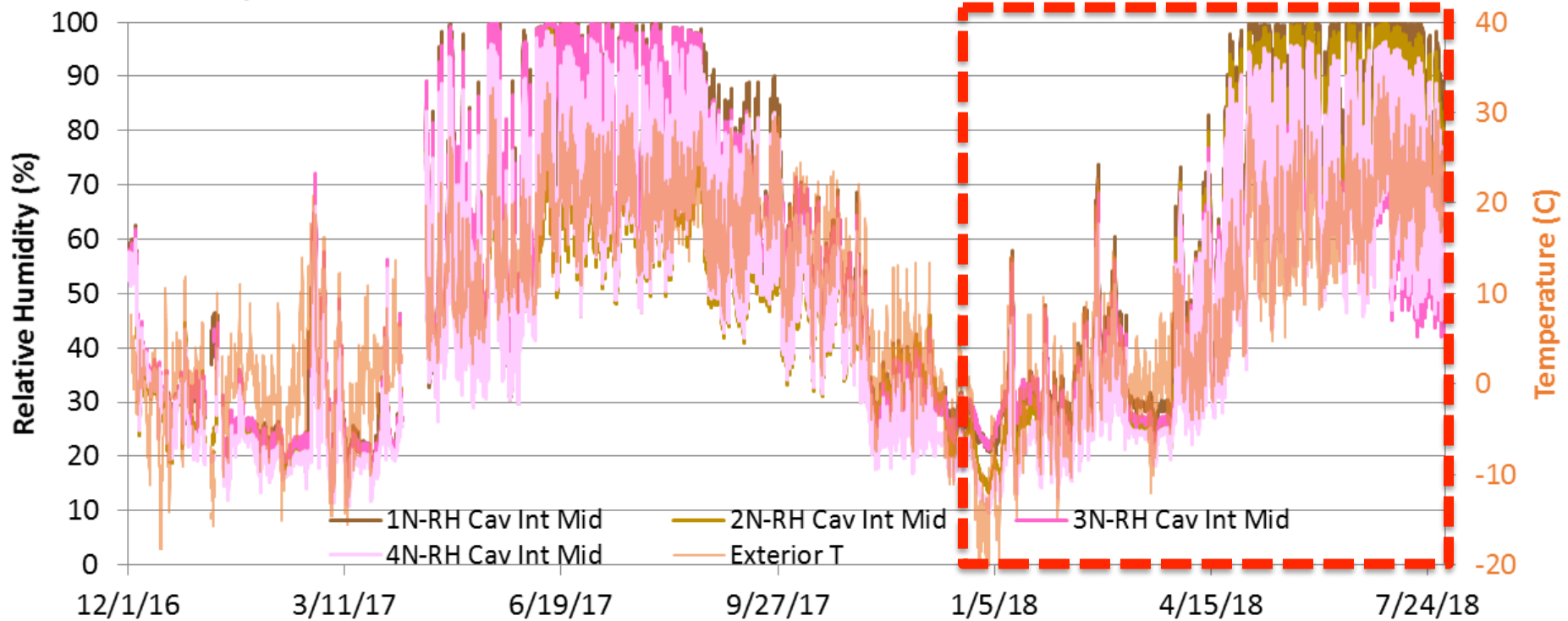
# Fiberglass Roofs: Inward Drive Sensors



- 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

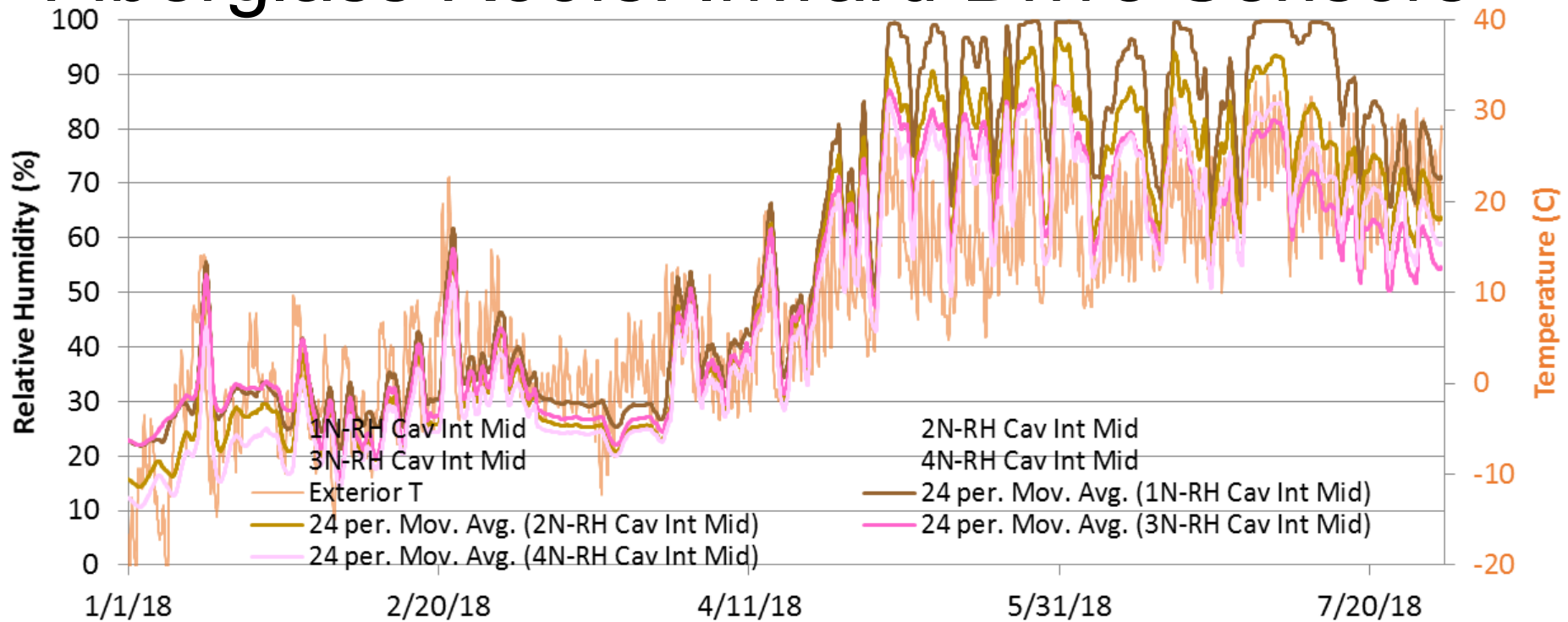
# Fiberglass Roofs: Inward Drive Sensors



- 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

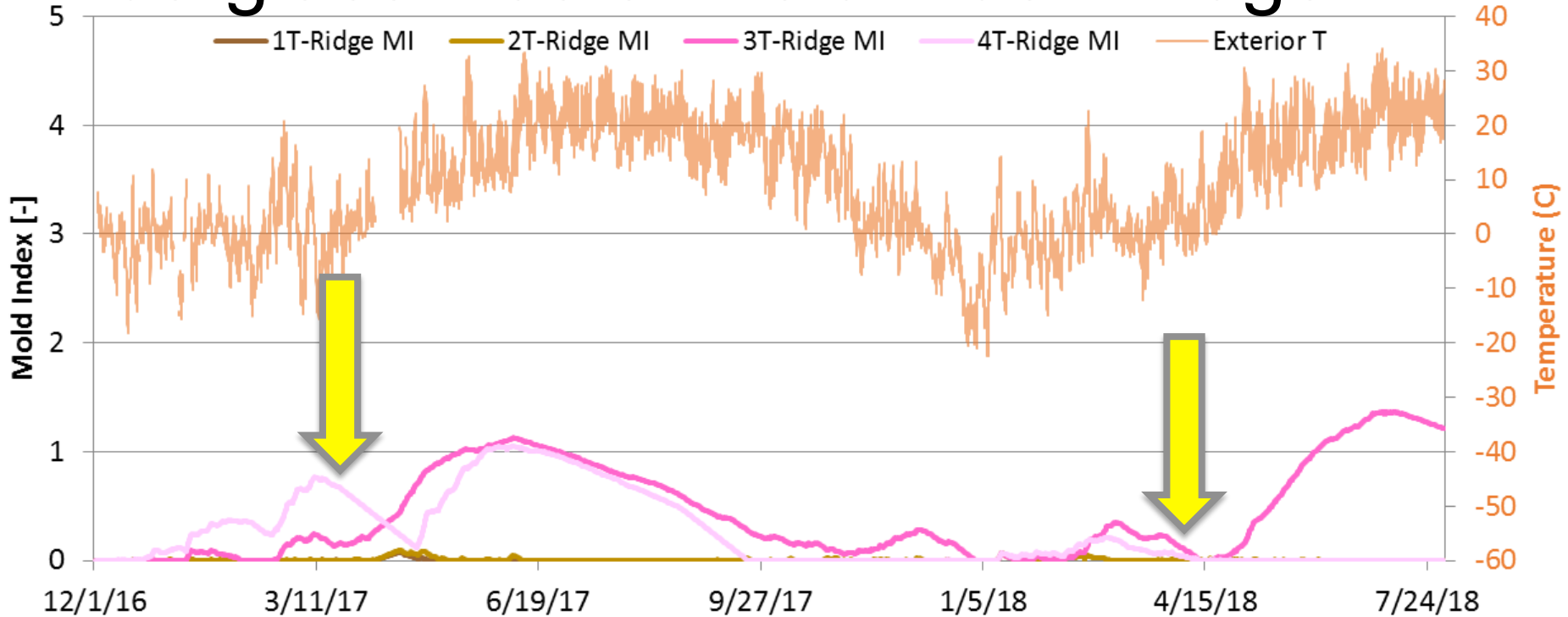
# Fiberglass Roofs: Mold Index Calculations

- 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
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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 < <b>50% coverage of mold (microscope)</b>
4	Visual findings of mold on surface, 10%–50% coverage, or > <b>50% coverage of mold (microscope)</b>
5	Plenty of growth on surface, > 50% coverage (visual)
6	Heavy and tight growth, coverage about 100%

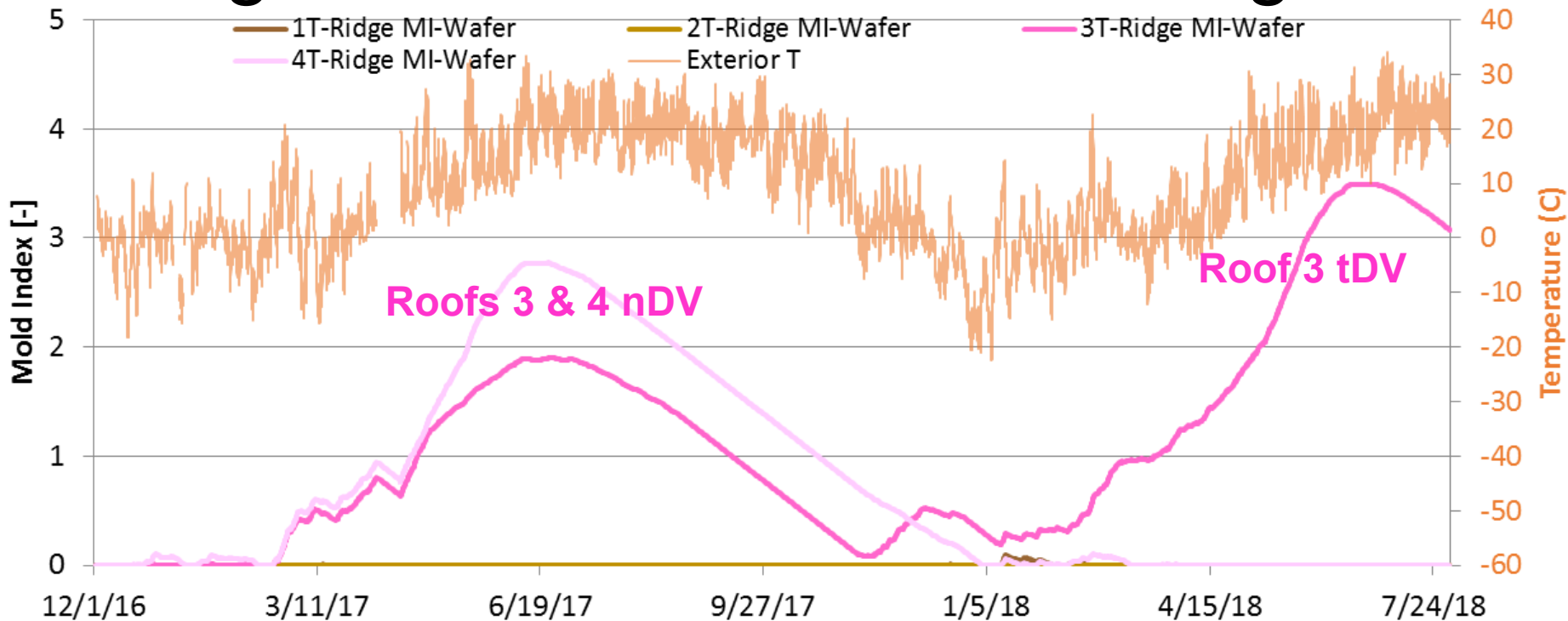
# Fiberglass Roofs: Mold Index-Ridge RH



- 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

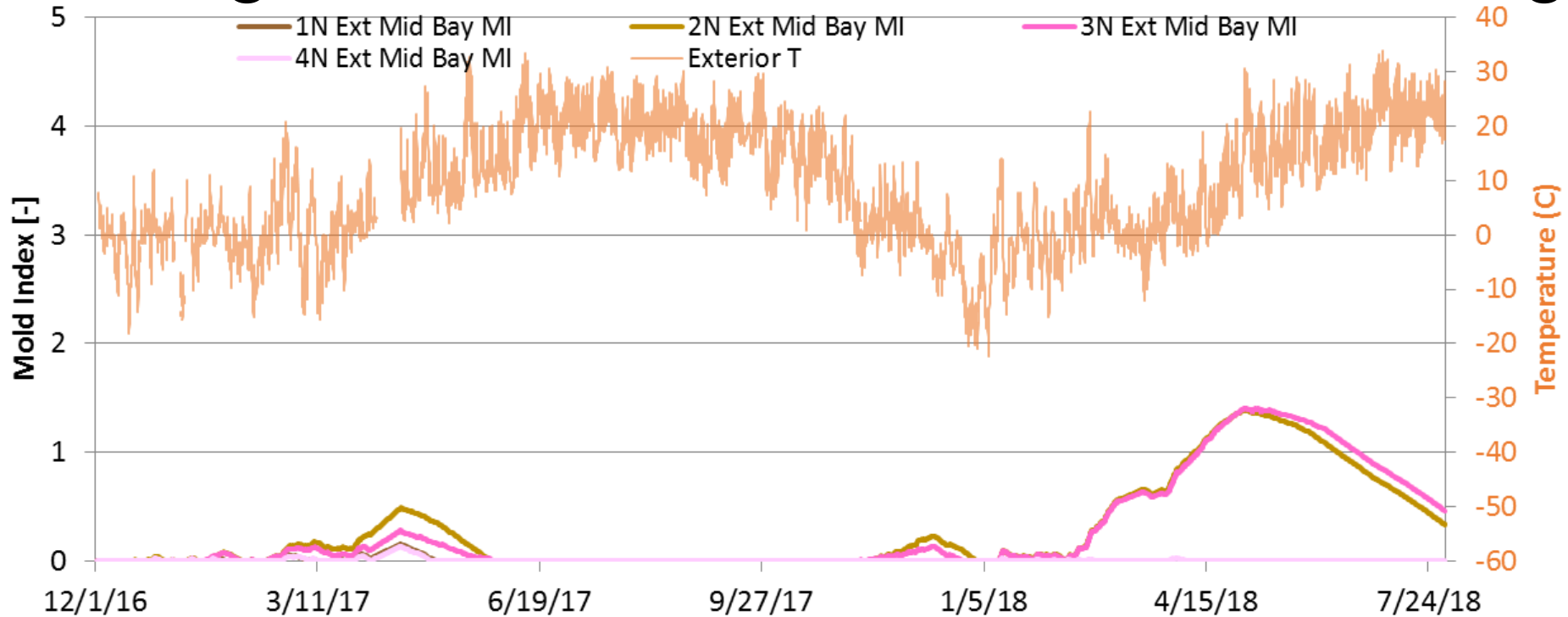
# Fiberglass Roofs: Mold Index-Ridge Wafer



- 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

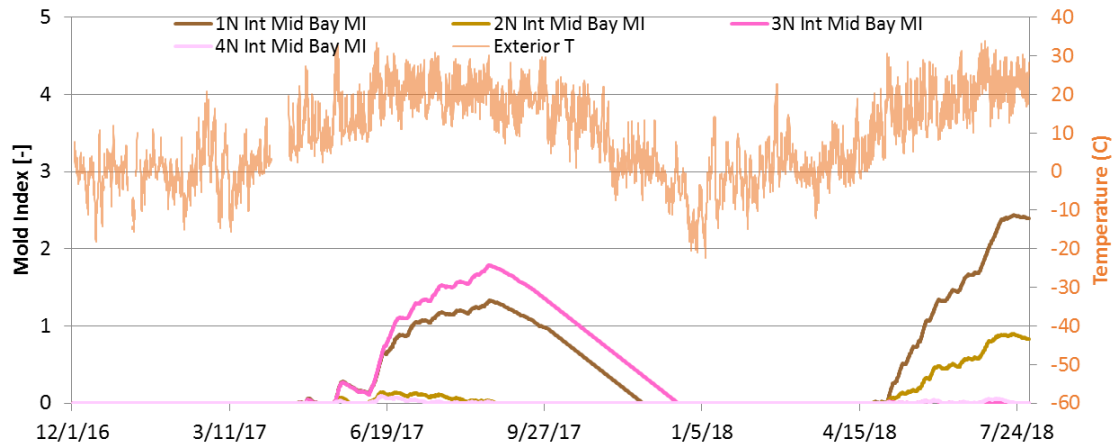
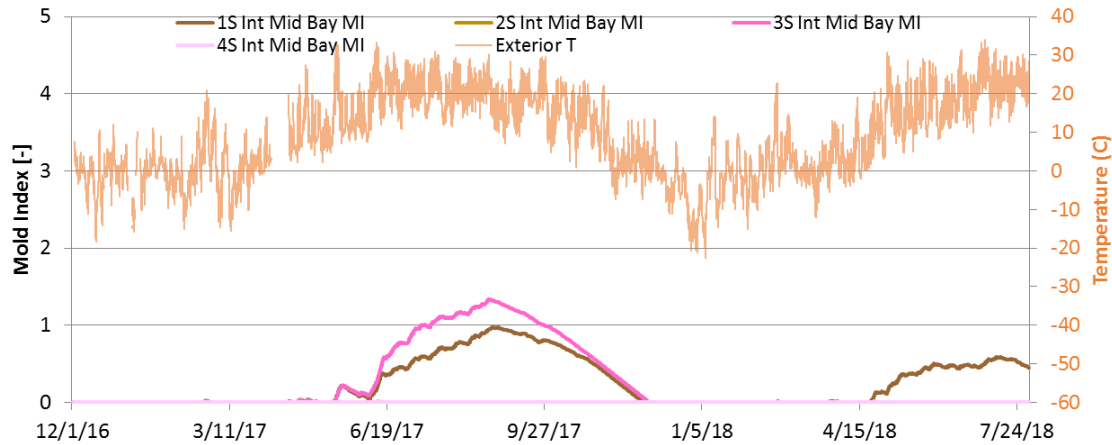


- Higher sheathing MCs Winter 2 (50% RH)
- **Roof 4** RH sensor was drier than 1/2/3 → low MI
  - Ascribed to sensor/installation anomaly
- Mold index remains below 2

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



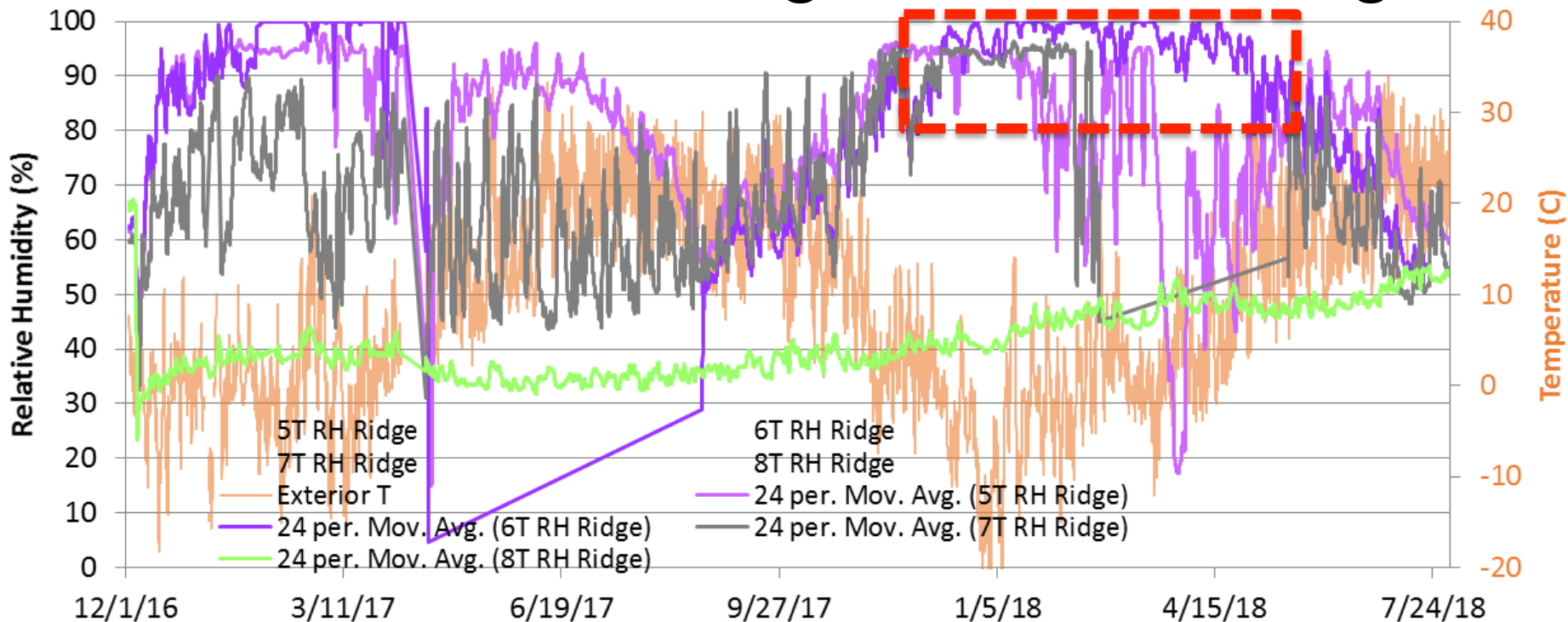
- **Roof 1** (fixed VB) only fixed perm in Winter 2
- Highest MI
- MI stays below 3- barely
- North shows higher peaks than south
  - Stored moisture?

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

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# Results: Cellulose Roofs

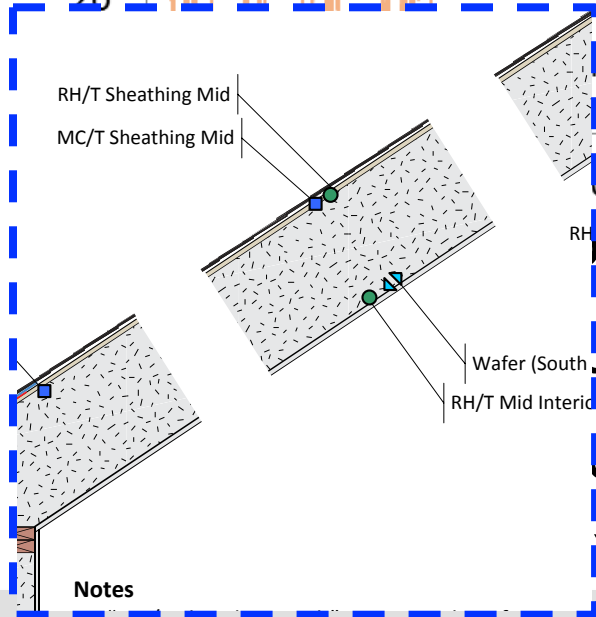
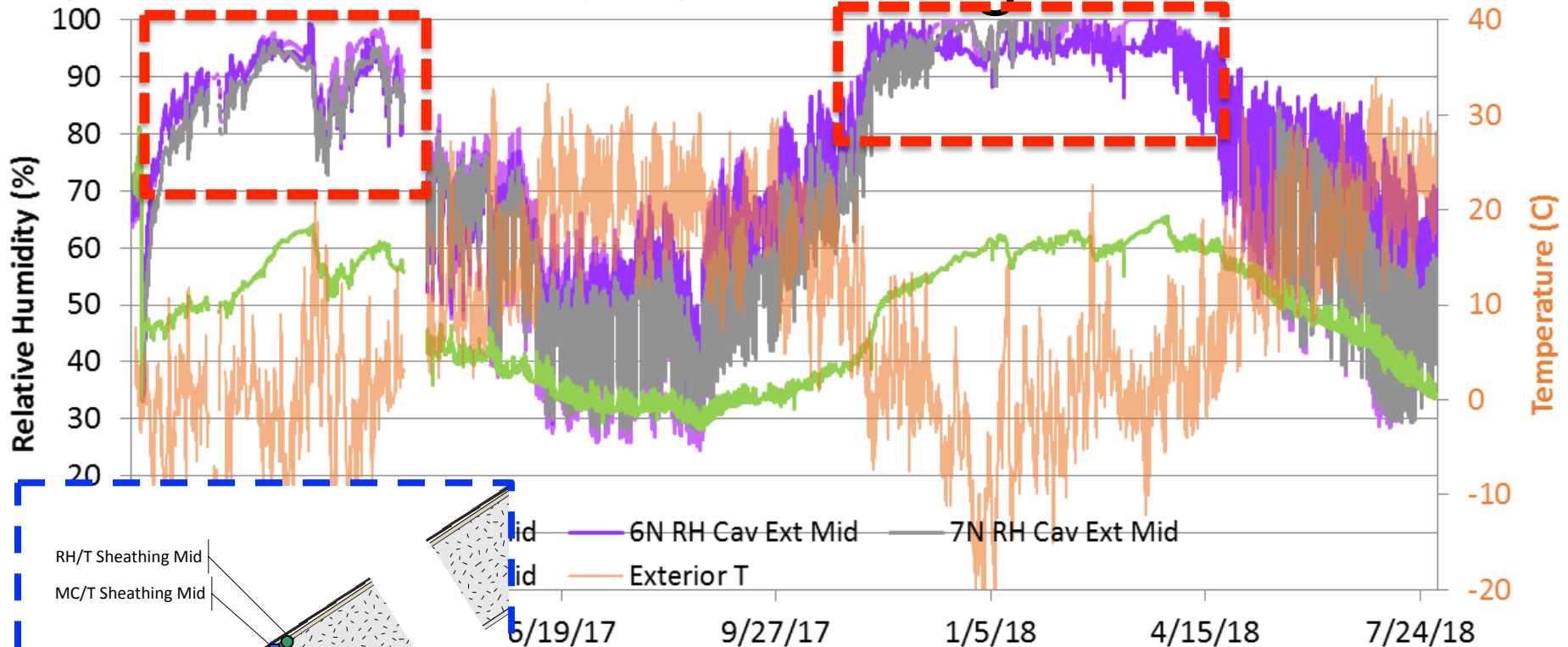
# Cellulose Roofs: Ridge RH 24 hr. Avg.



- **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

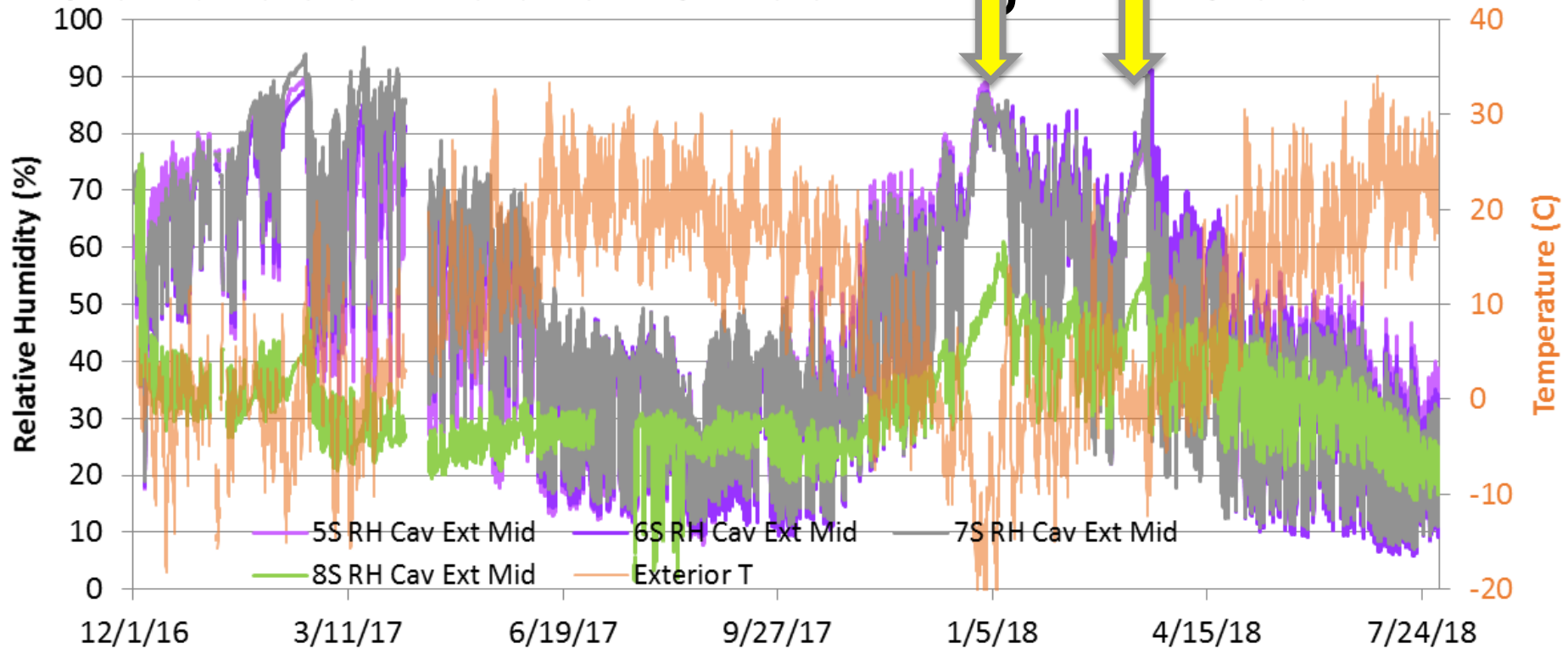
# Cellulose Roofs: Sheathing RH North



-100% RH most of Winter 2  
 Sustained RHs than Winter 1  
 Down 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

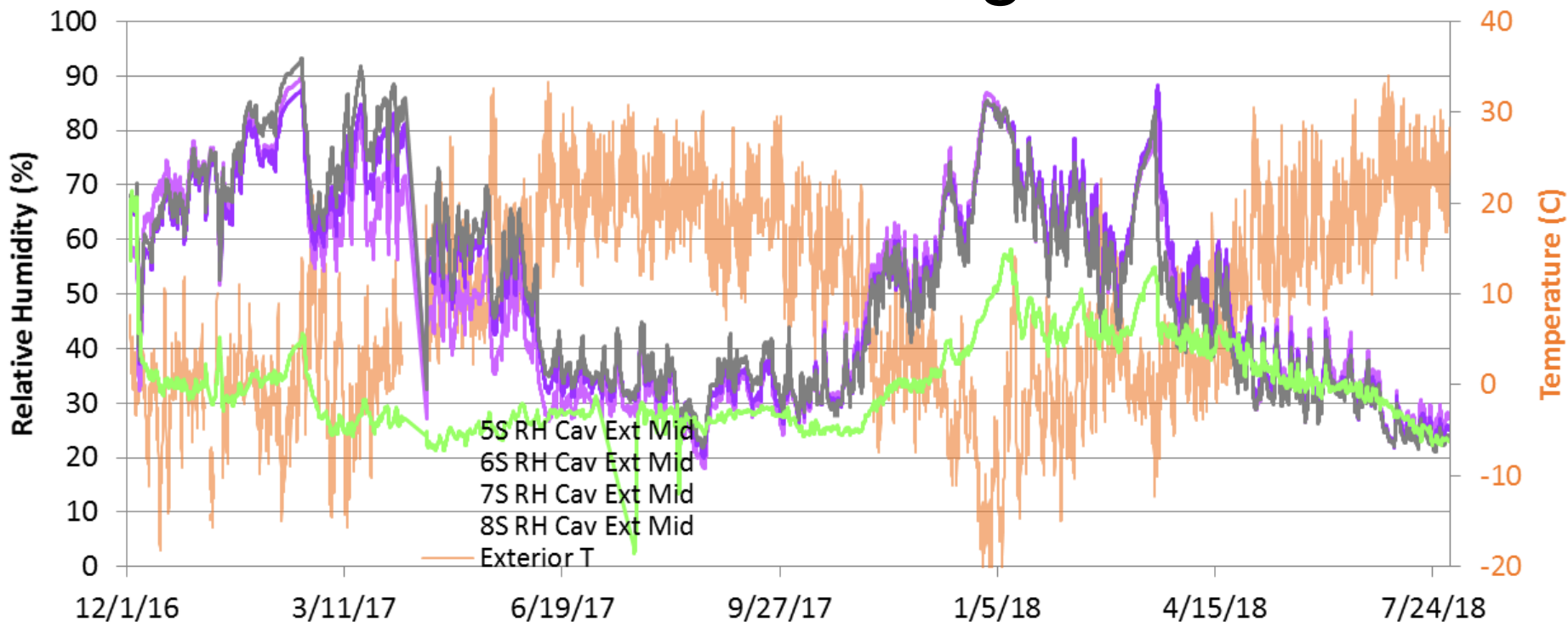
# Cellulose Roofs: Sheathing RH South



- 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

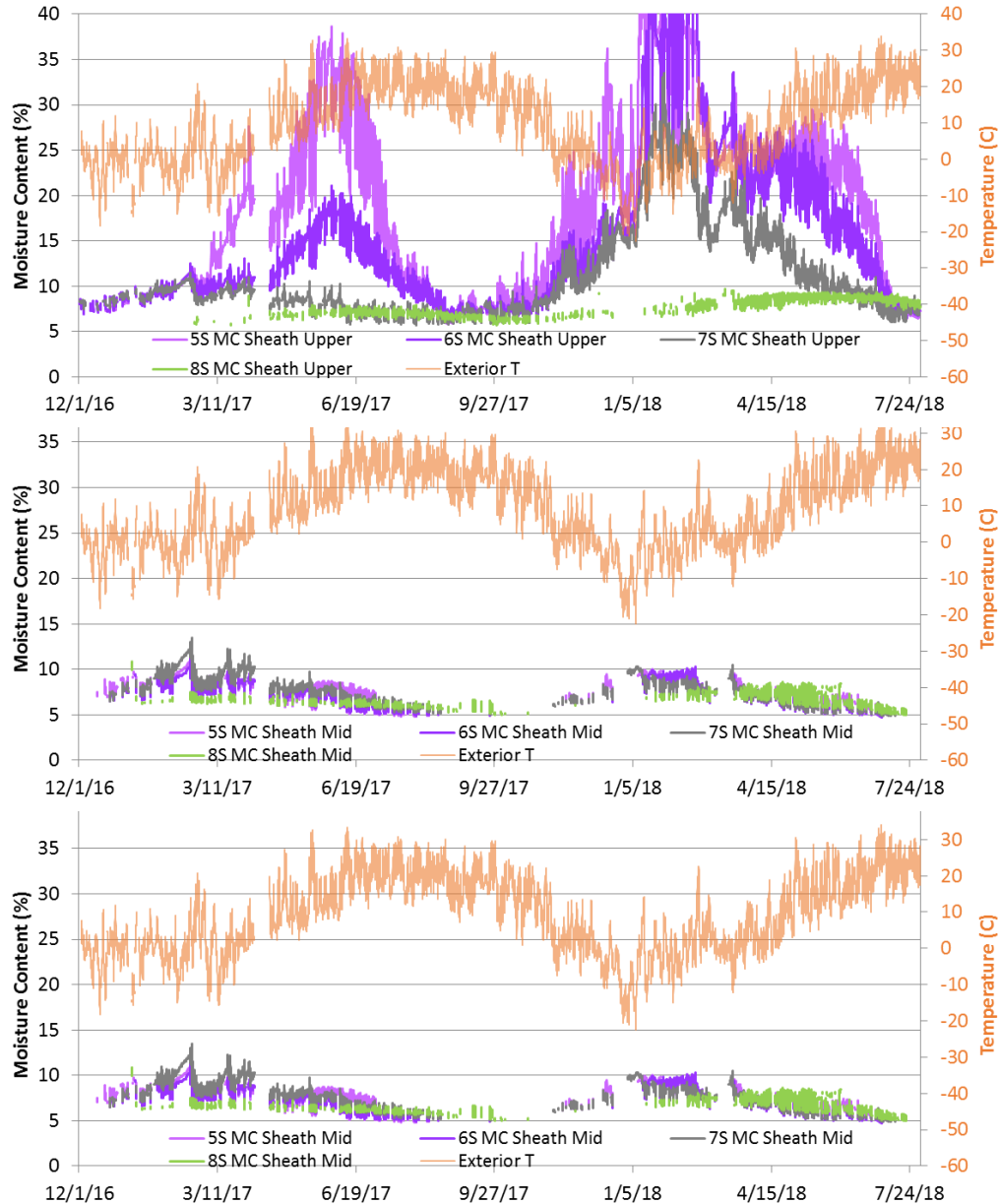
# Cellulose Roofs: Sheathing RH South



- 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

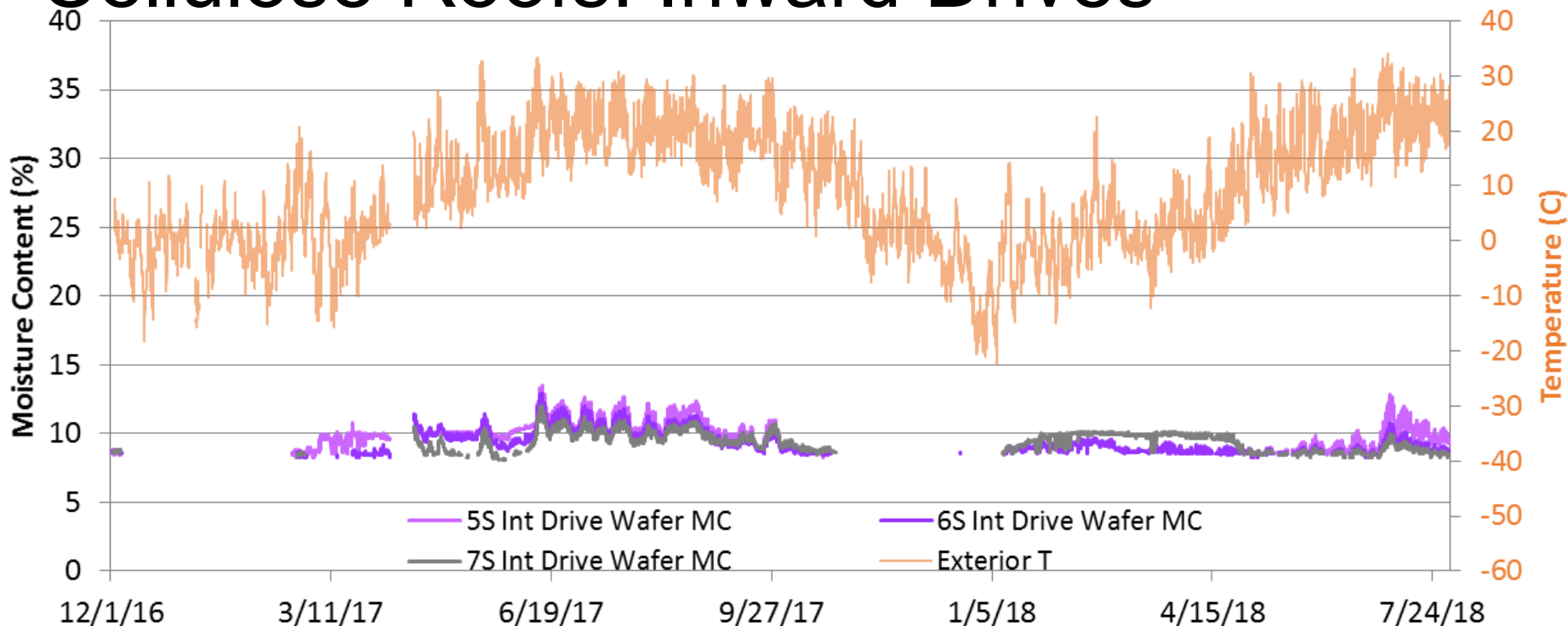
# Cellulose Roofs: S Sheathing MCs



- 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

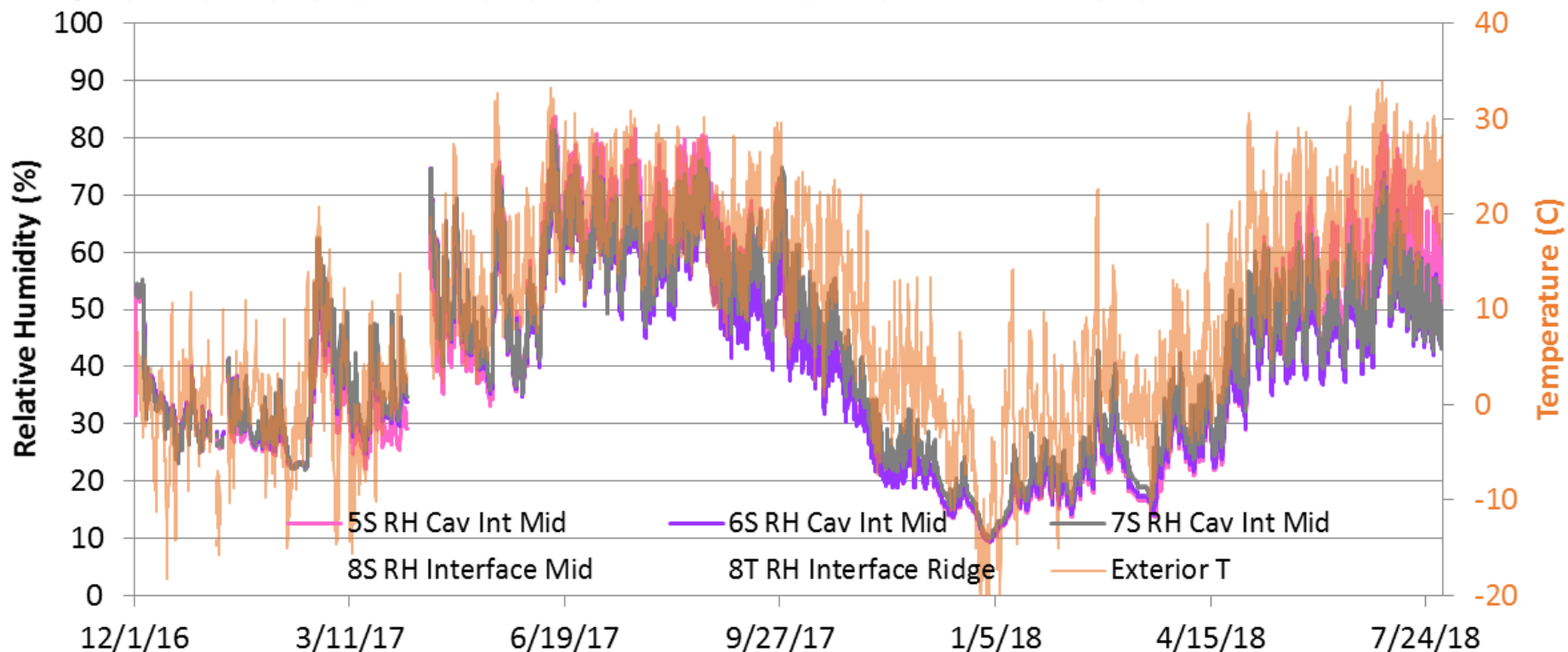


- Inward drive wafer, south
- All well below 15% MC (safe)

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



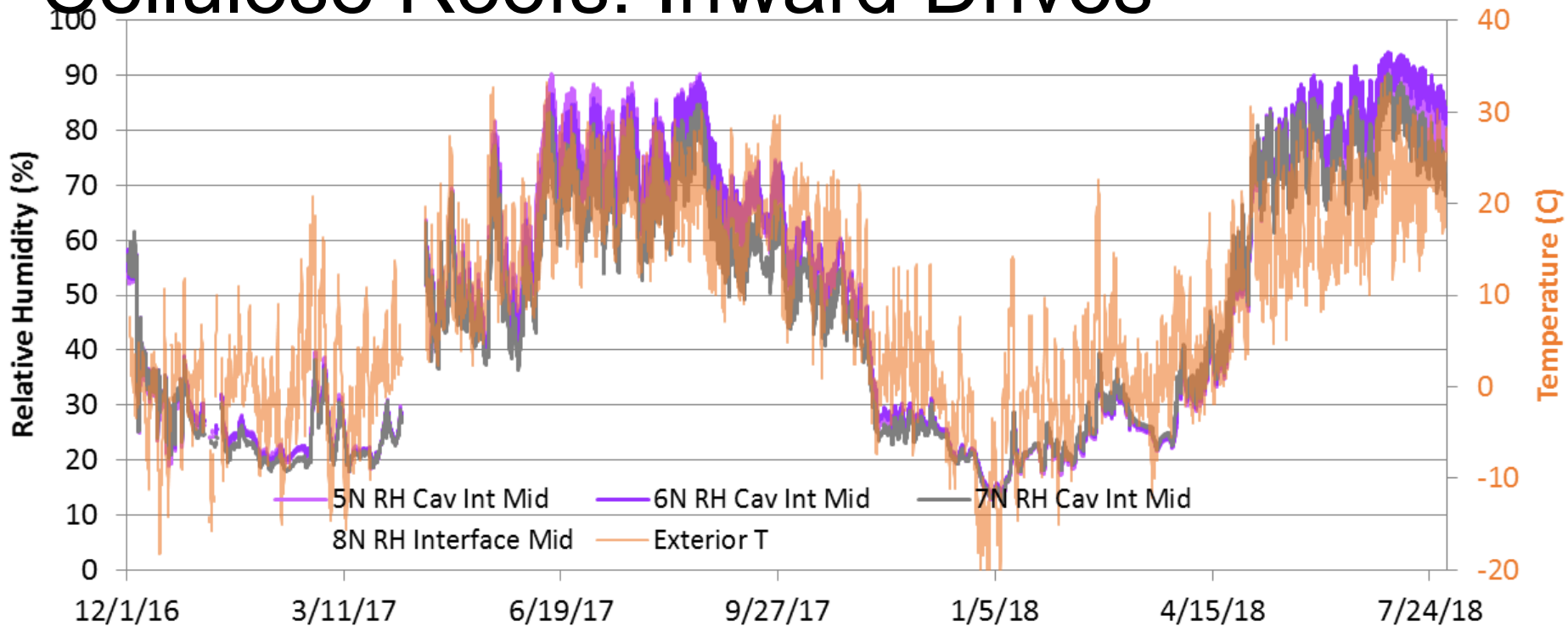
# Cellulose Roofs: Inward Drives



- 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

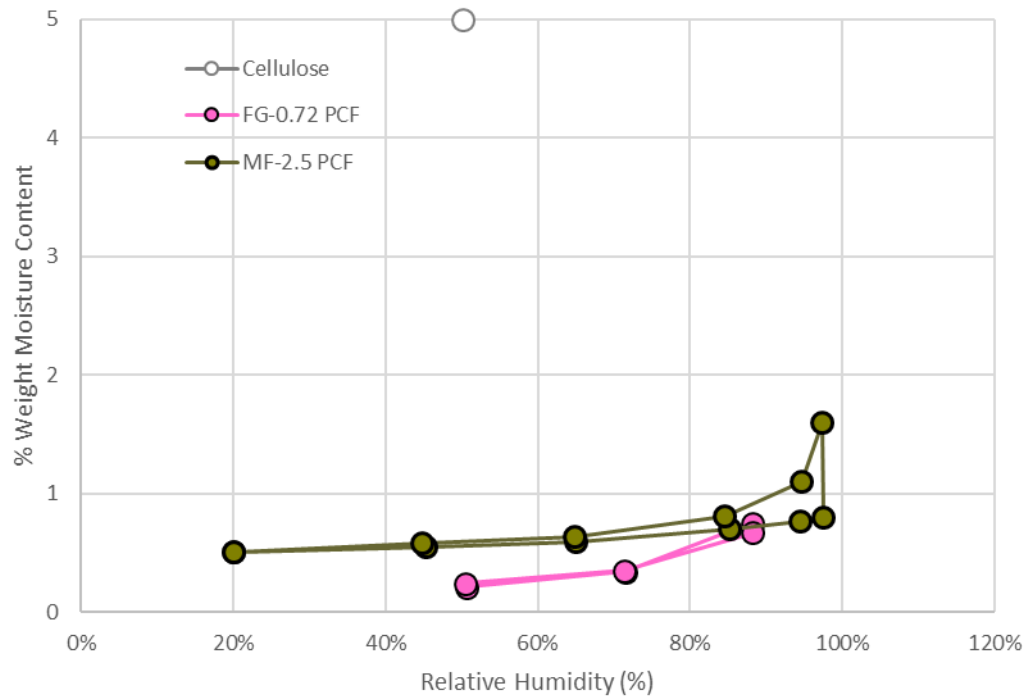
# Cellulose Roofs: Inward Drives



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

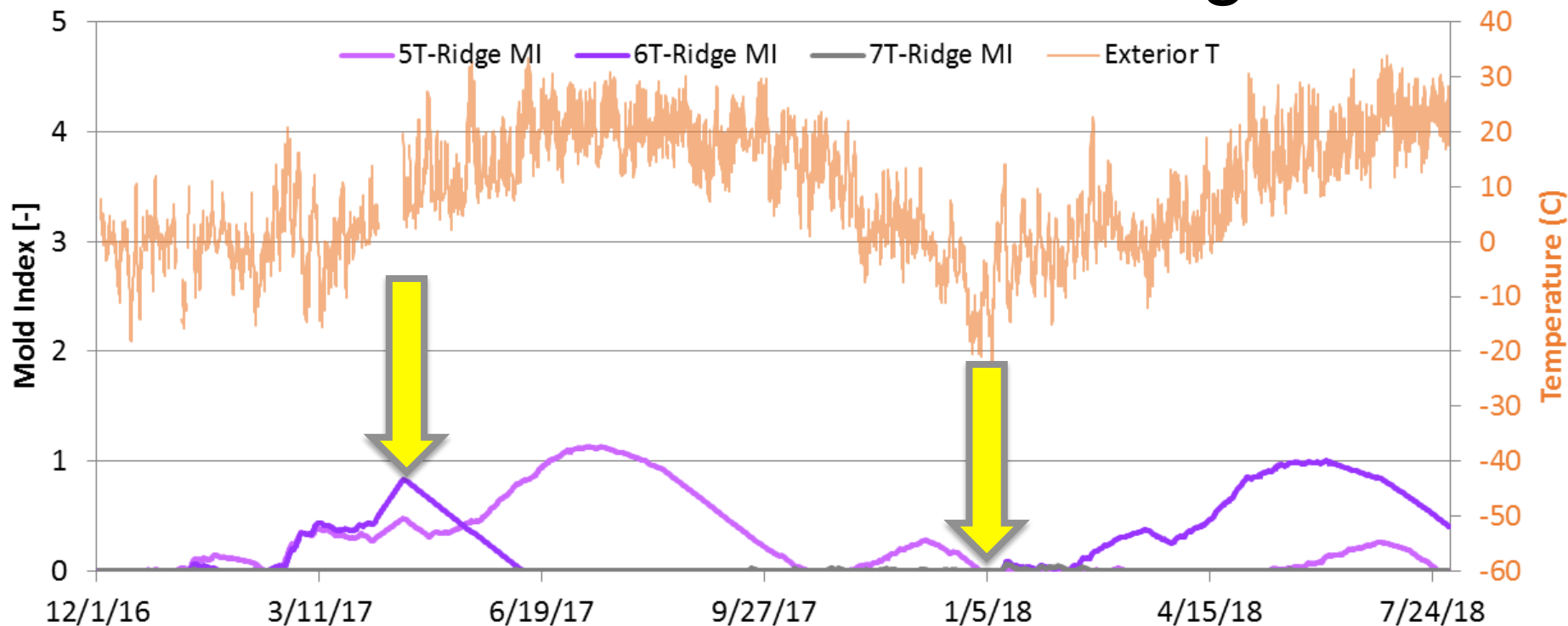
Roof	Short Name
5	Cell-SVR-tDV
6	Cell-SVR-sDV
7	Cell-SVR-DV
8	ccSPF-Cell

# 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)

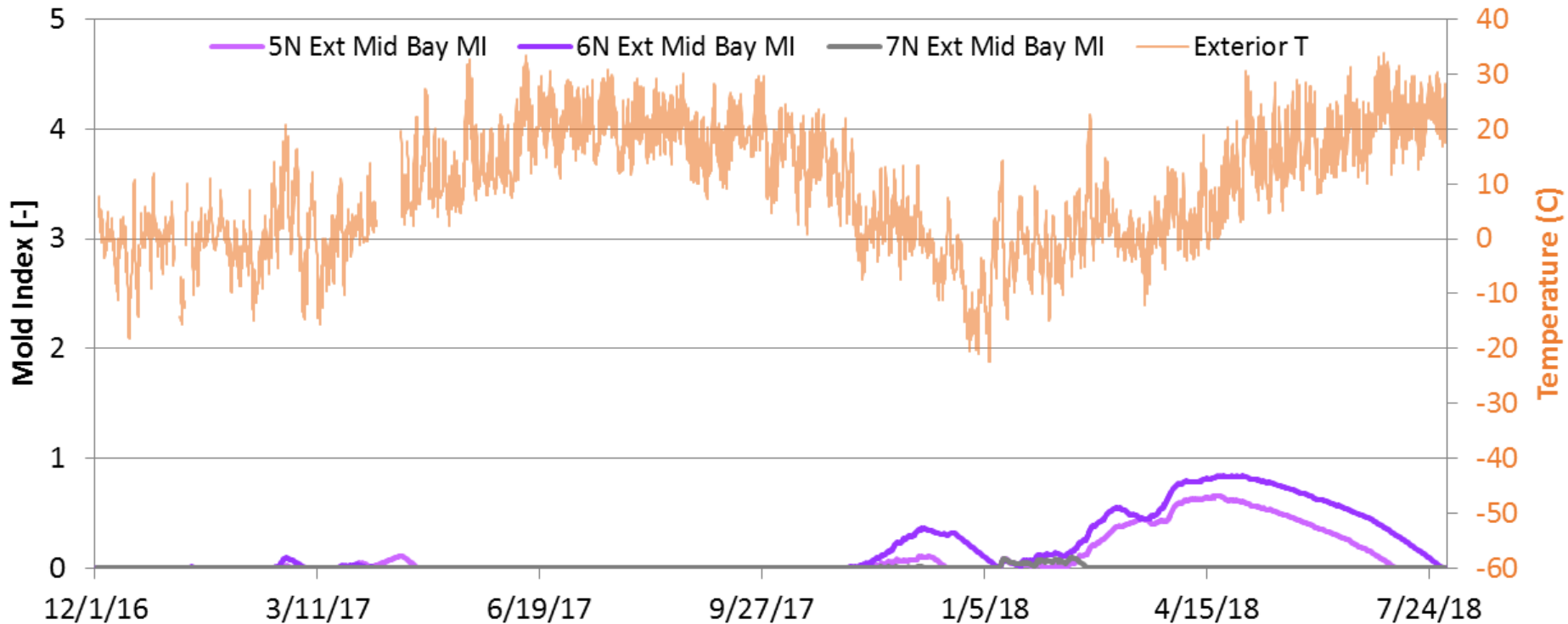
# Cellulose Roofs: Mold Index Ridge



- **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

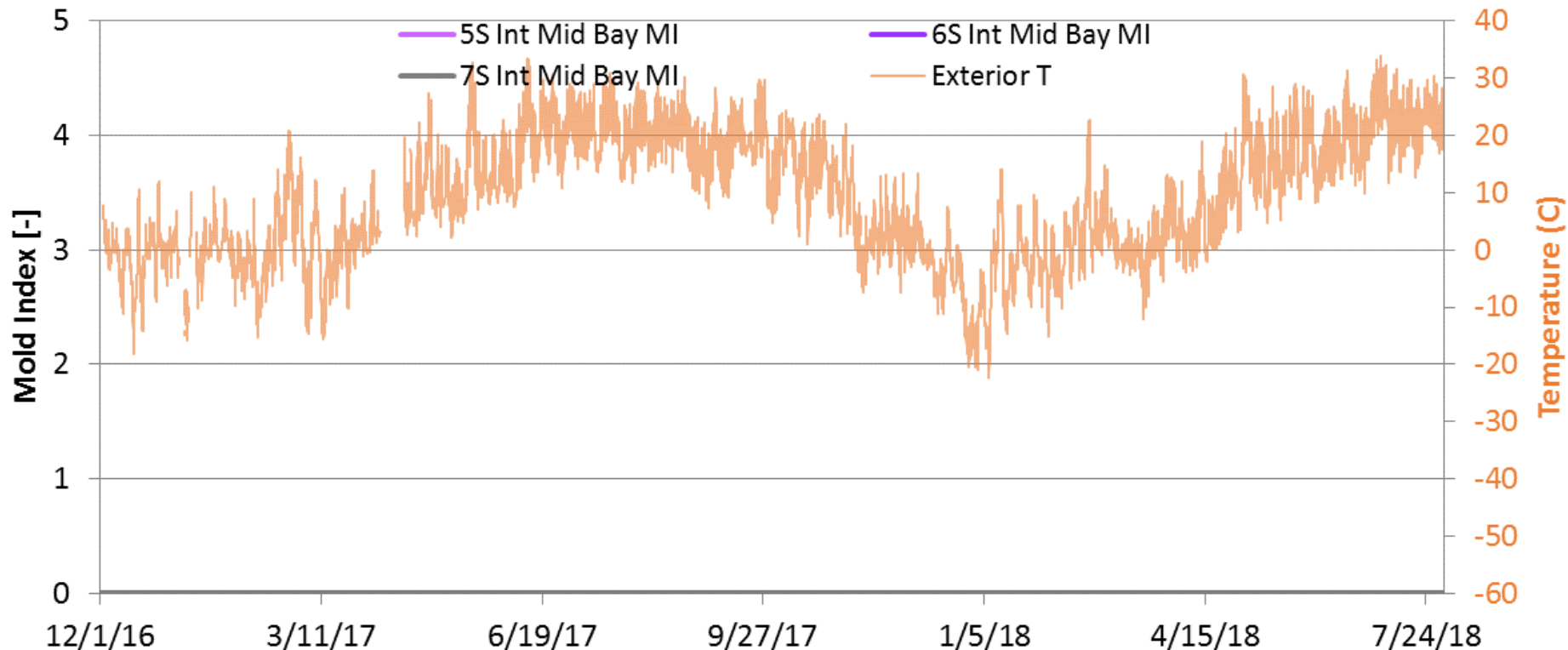
# Cellulose Roofs: Mold Index North Sheath.



- 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



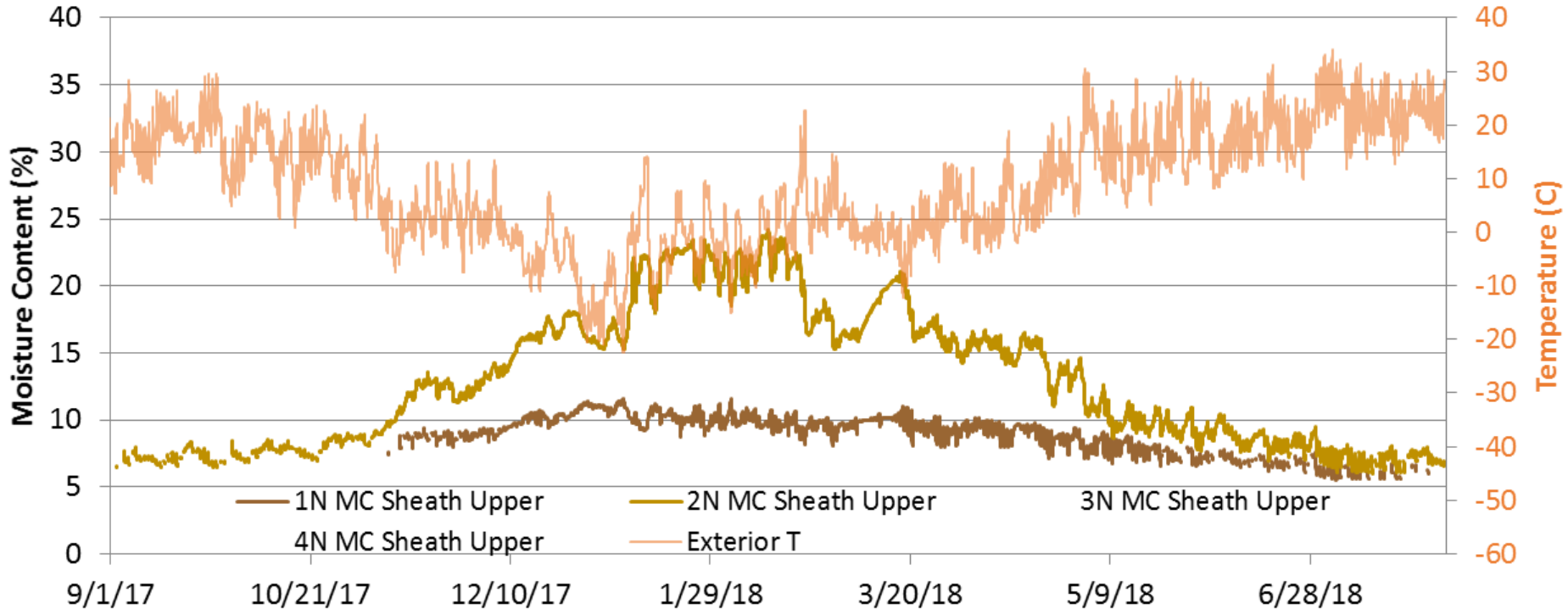
- RH south side inward drive
- Not mis-plotted: max mold index 0.004

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

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# Conclusions and Further Work

# Vapor Retarder Alternative

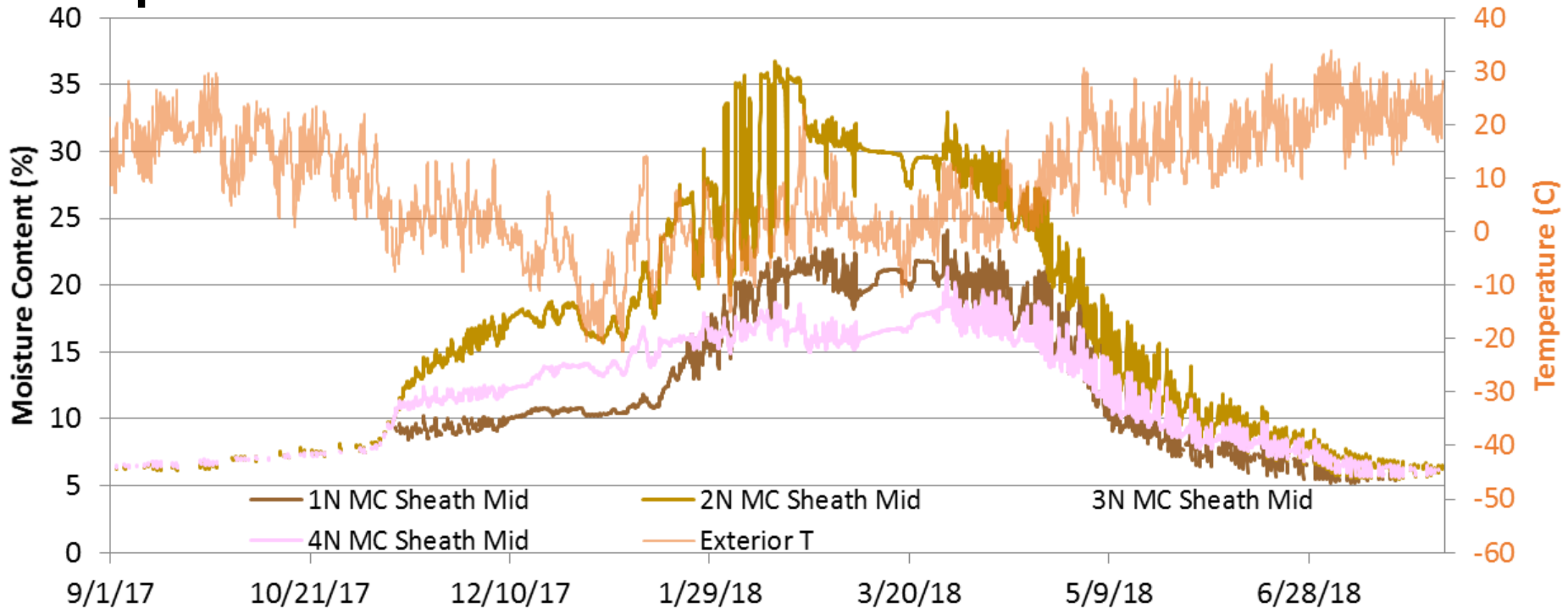


- FG North upper sheathing MC data
- **Roof 3** “tight” **Roof 4** “small”
- Why **Roofs 1** vs. **Roof 2**? VB vs. SVR
- SVR possibly opening up at 50% interior RH?

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



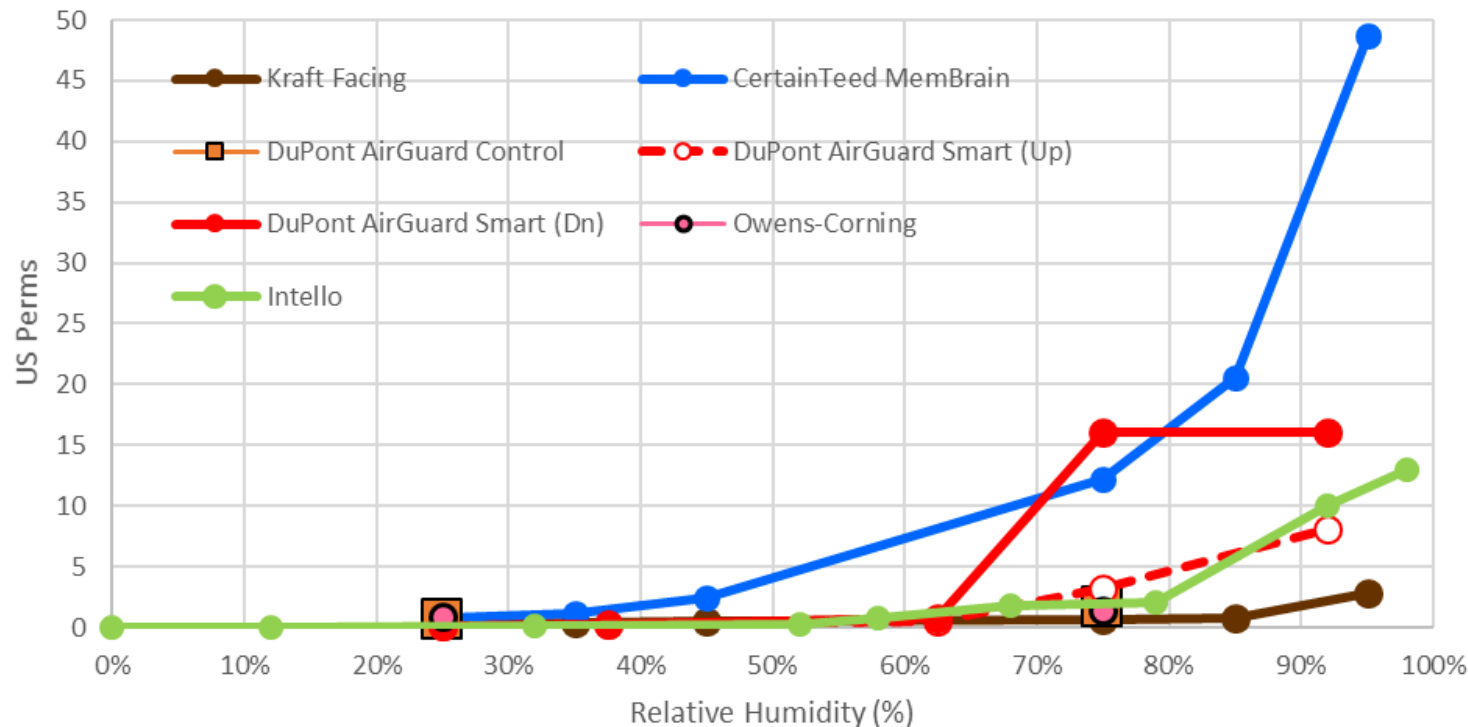
# Vapor Retarder Alternative



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

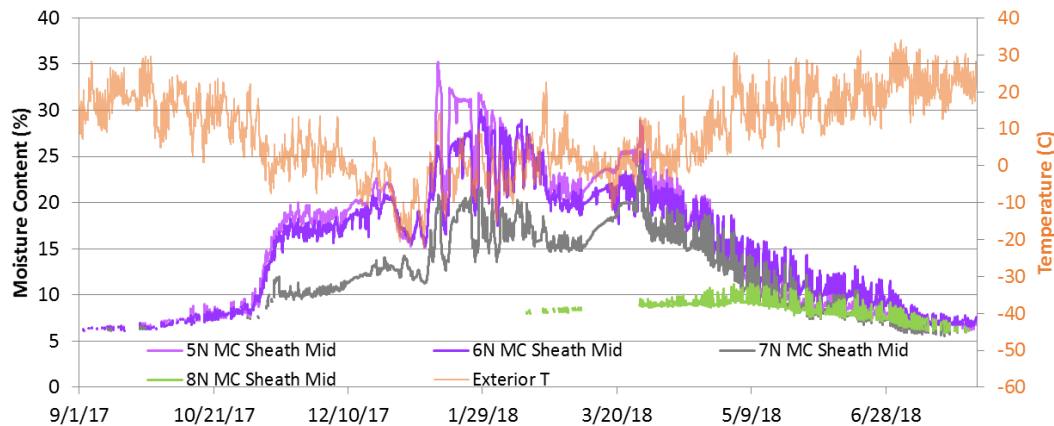
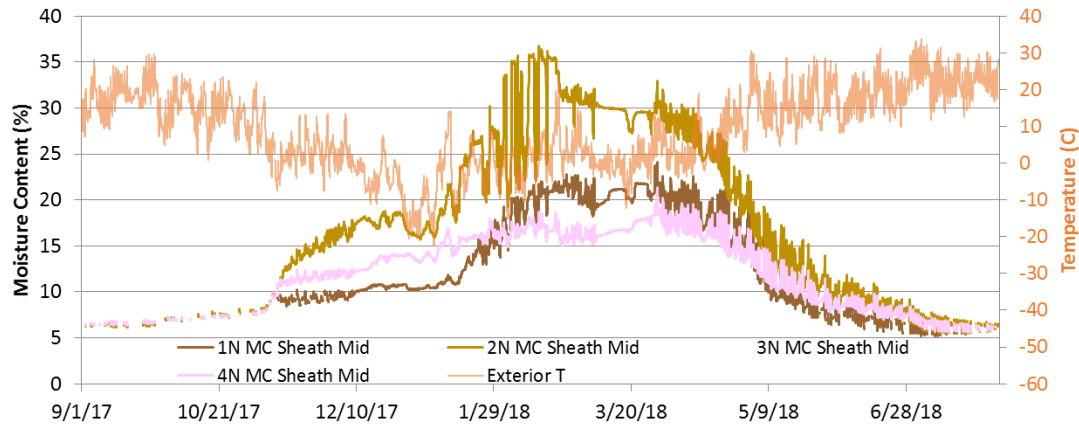
Roof	Short Name
1	FG-VB-DV
2	FG-SVR-DV
3	FG-SVR-tDV
4	FG-SVR-sDV

# 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



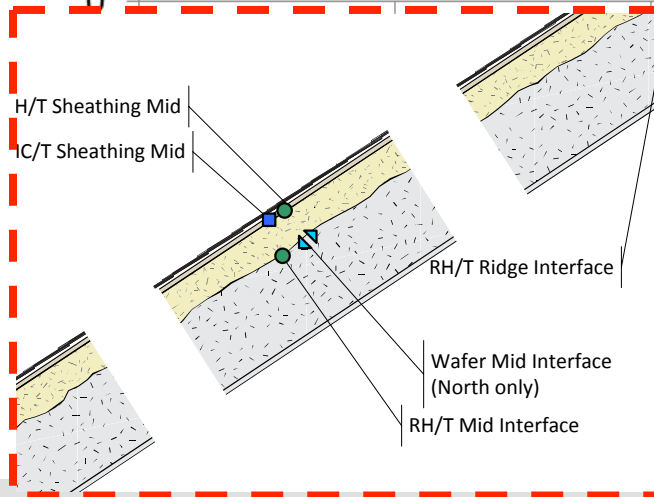
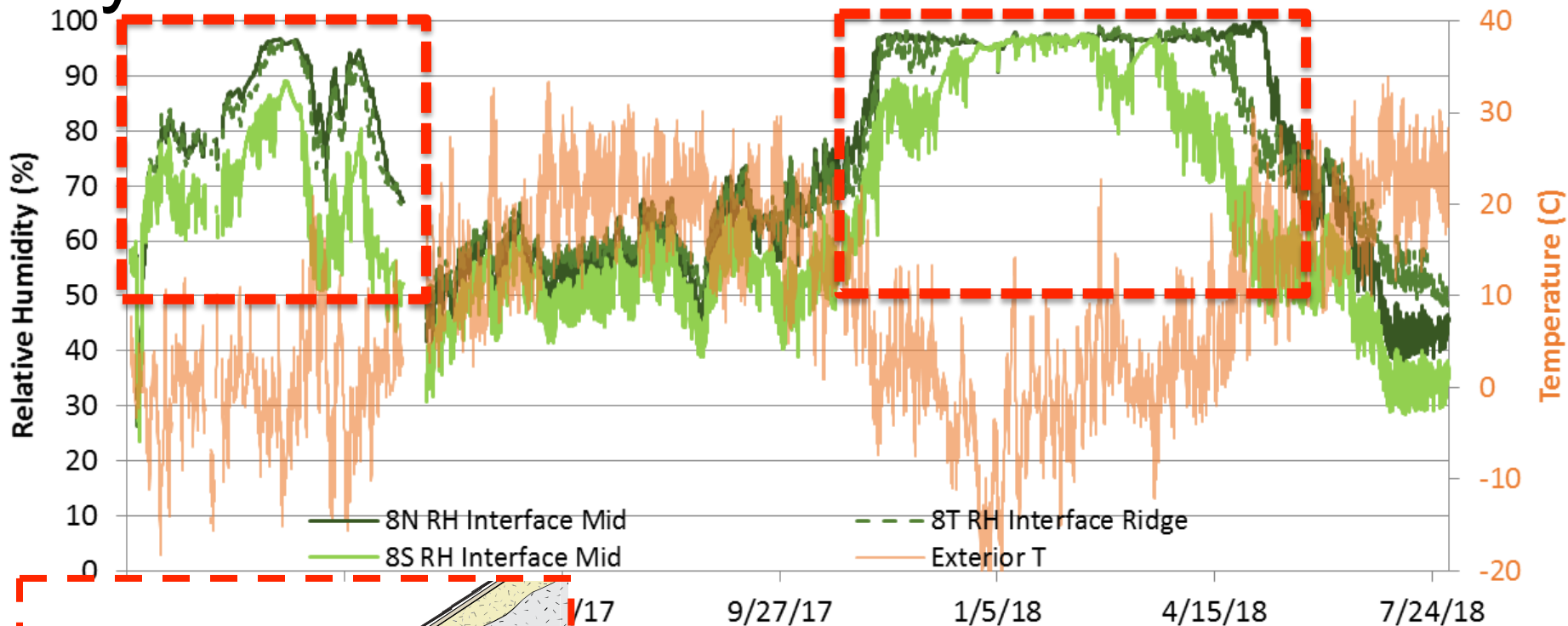
- Upper Graph FG:
  - Roofs 1, 2, 4
  - CertainTeed MemBrain, OC 1 perm
- Lower Graph Cell:
  - Roofs 5, 6, 7
  - DuPont SVR
- Both “Mid” height
- Not a clear signal

Roof	Short Name	Roof	Short Name
1	FG-VB-DV	5	Cell-SVR-tDV
2	FG-SVR-DV	6	Cell-SVR-sDV
3	FG-SVR-tDV	7	Cell-SVR-DV
4	FG-SVR-sDV	8	ccSPF-Cell

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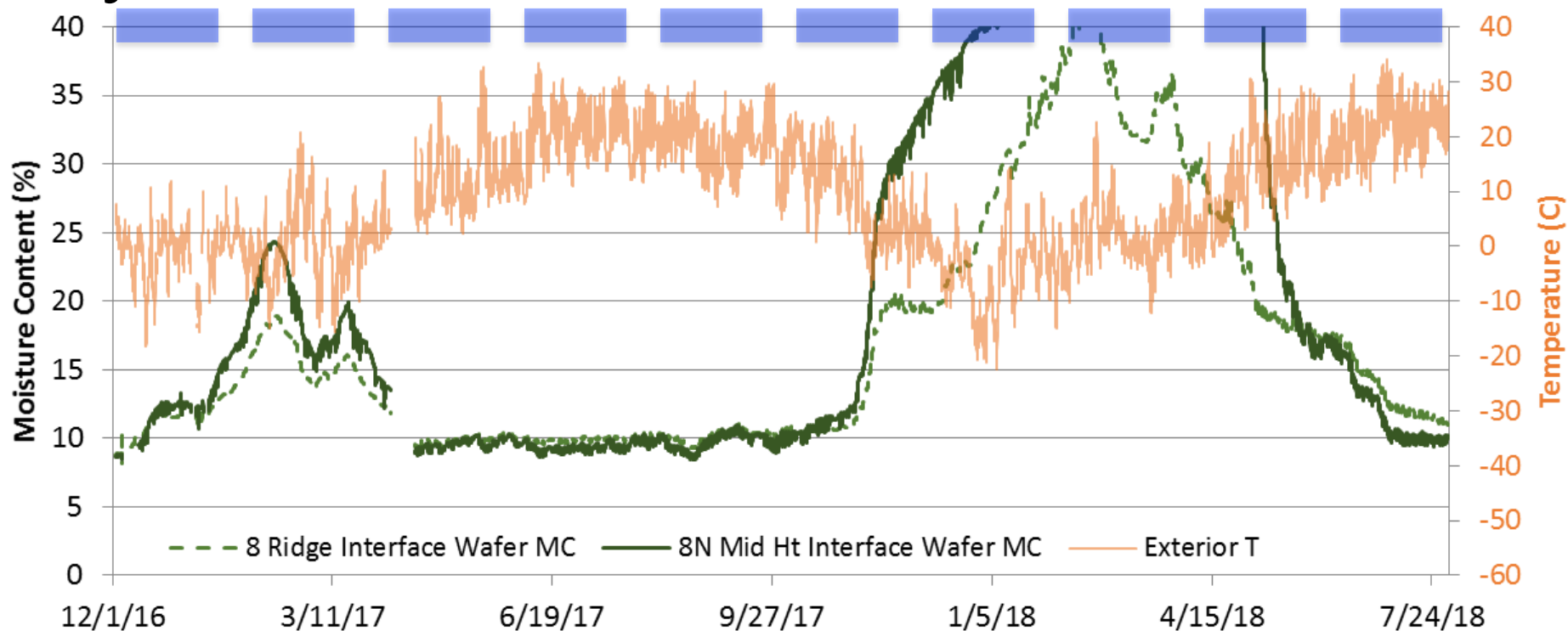
# Hybrid Roofs (ccSPF & cellulose)

# Hybrid Roof Interface: RH



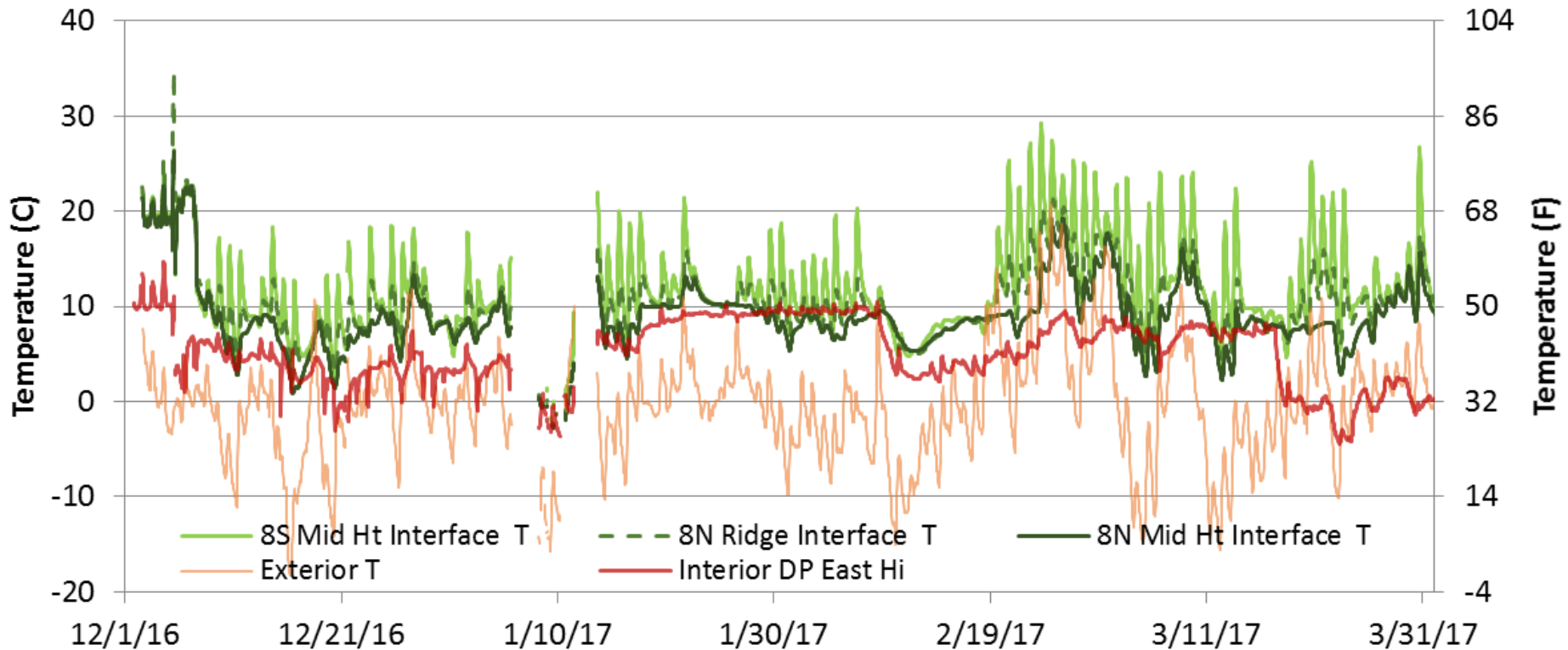
ons to 90-95% RH  
 (interior RH): 95-100% RH all winter  
 from interior (cellulose storage)

# Hybrid Roof Interface: Wafer



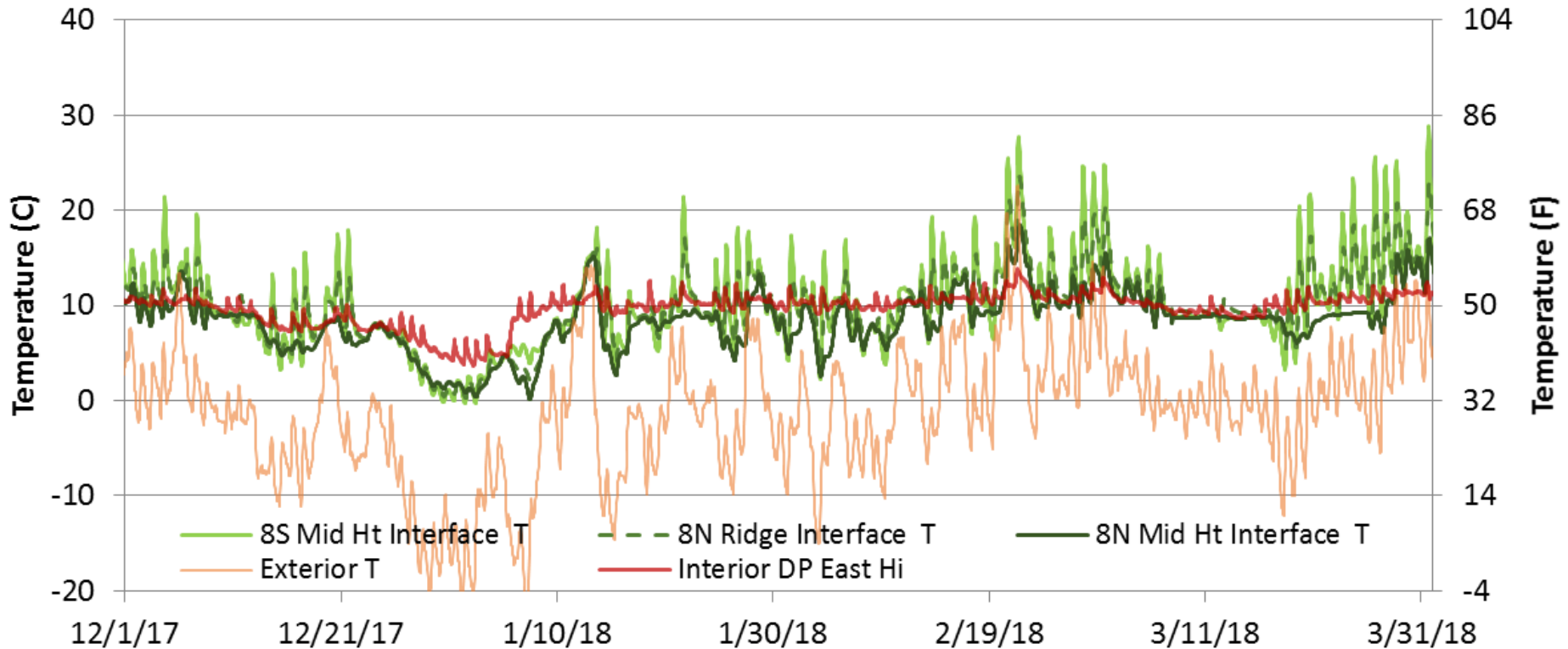
- Winter 2 interface possibly in condensation range
- But also possibly borate contamination

# 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