DuPont Safety & Construction

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Multifamily Case Study in Midland Michigan

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R&D Research Scientist
Residential Application Development

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- Dow Building Solutions since 2010
- Primary: Residential Application Development
- Secondary: U.S. & Canada Fire Specialist
- 25 Years in Production Homebuilding
- BS from University of Wisconsin - Stout

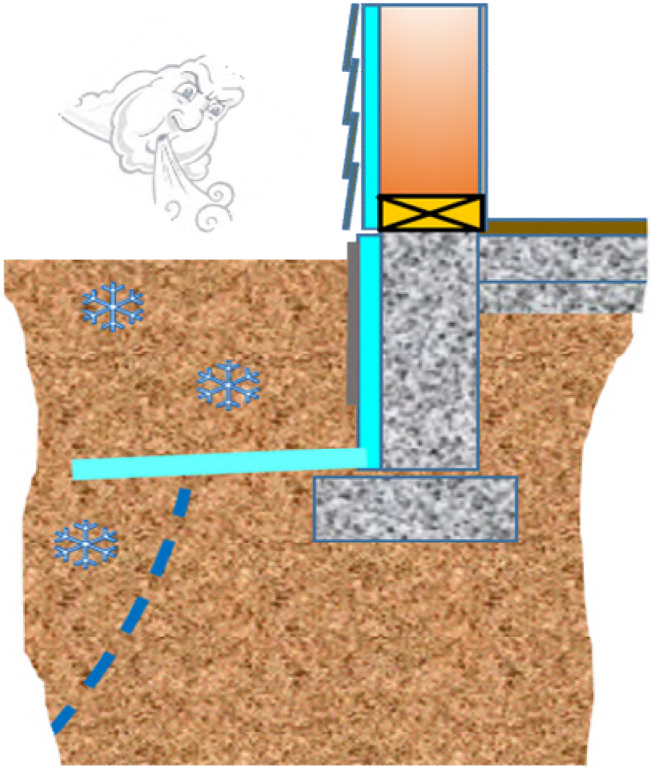
Multifamily Case Study

Midland, MI Climate Zone 5

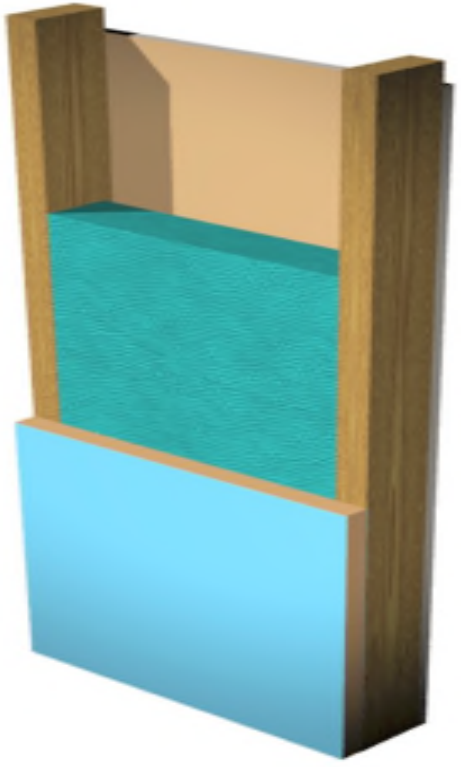
- Collaboration between Redwood Living & DowDuPont
- Redwood builds single story apartment homes on slab foundations
- Build & Rent
  - Durability & Maintenance
  - Promote Energy Efficiency
- 5-Year, two building research project

Focus of Research

Frost Protected Shallow Foundation



2x4 ci vs. 2x6 cavity only insulation



Why Frost Protected Shallow Foundation (FPSF)?

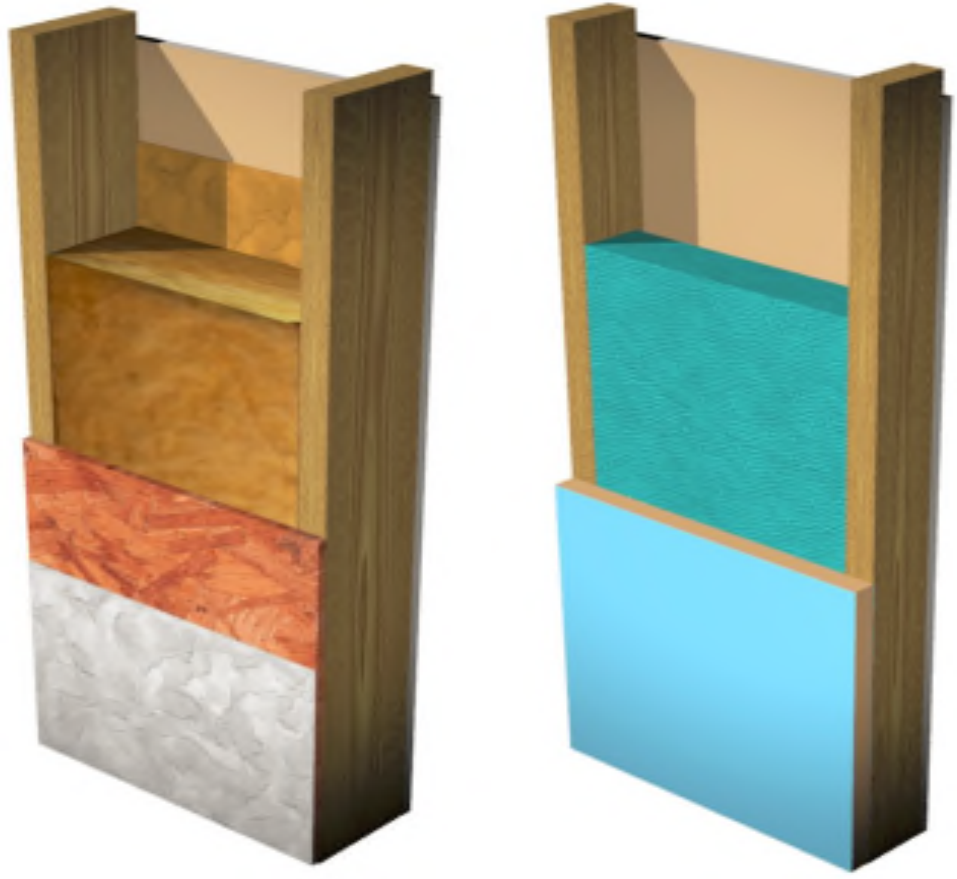
- FPSF have been around for a long time
- They should be able to save money
  - Habitat for Humanity Michigan affiliates
- Why not more popular?

Figure 6. Photograph of the Fargo, North Dakota site (home #1).

Why compare 2x4 ci vs. 2x6 cavity only?

12 Home research (TEETH) project hindsight

- 2x4 ci with SPF in the cavity better hygrothermal performance
  - How much did the SPF impact results?
- 2x6 R-19 OSB went above 20% moisture content each winter
  - Forensic investigation showed signs of moisture
  - No discernable fungal decay
  - Bending strength test of OSB implied a strength loss (no control sample)



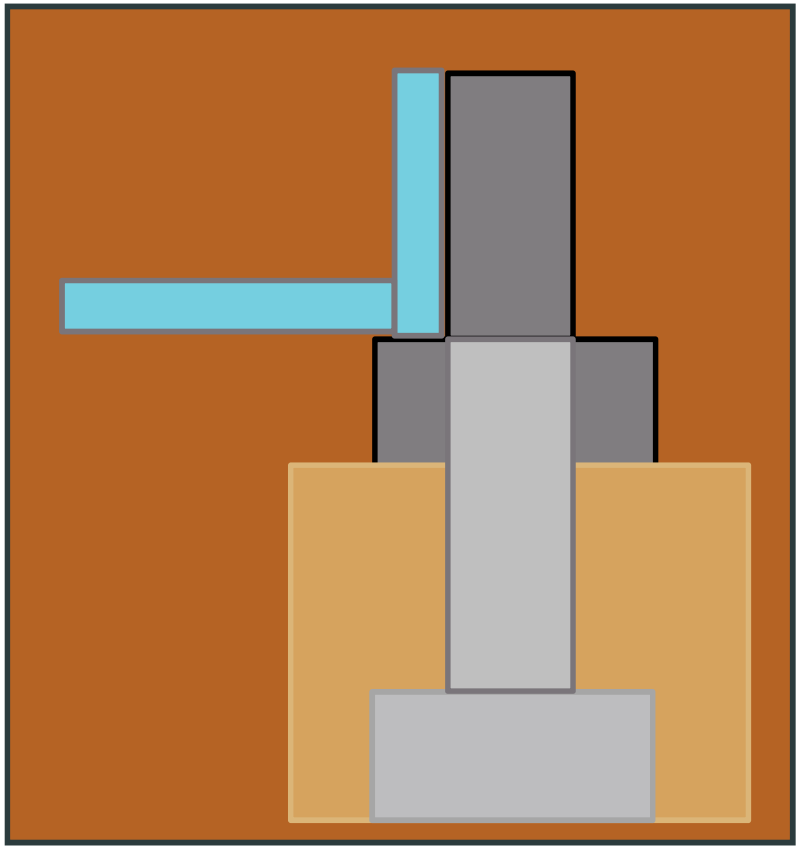
Frost Protected Shallow Foundation

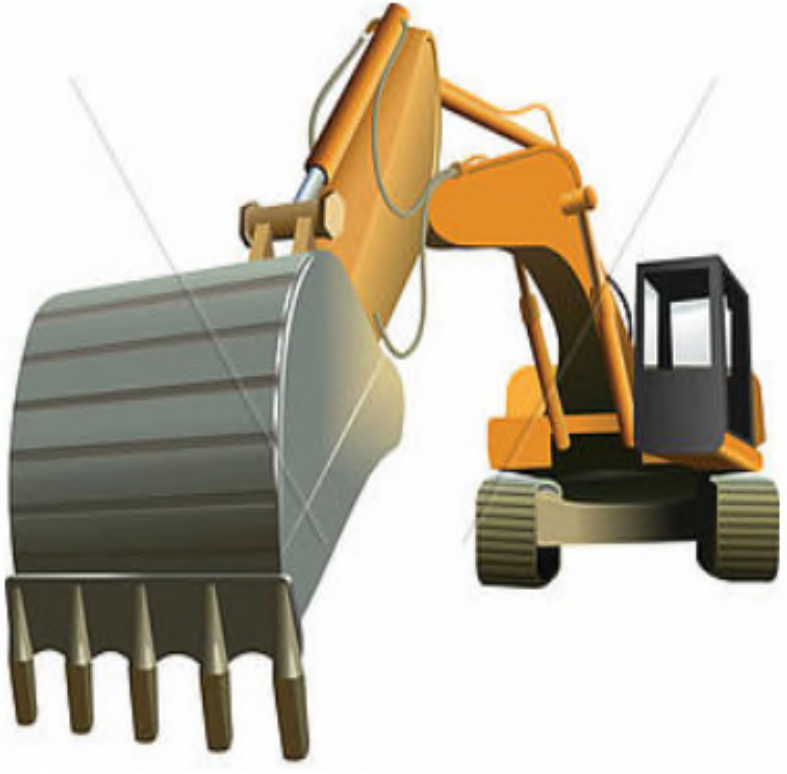
FPSF Research Questions

- Why are FPSF not more common?
- Does FPSF construction realize cost saving potential?
- How does energy transfer differ between FPSF vs. stem wall?
- Does FPSF provide a slab edge comfort advantage over Redwood standard stem wall?

Benefits of FPSF

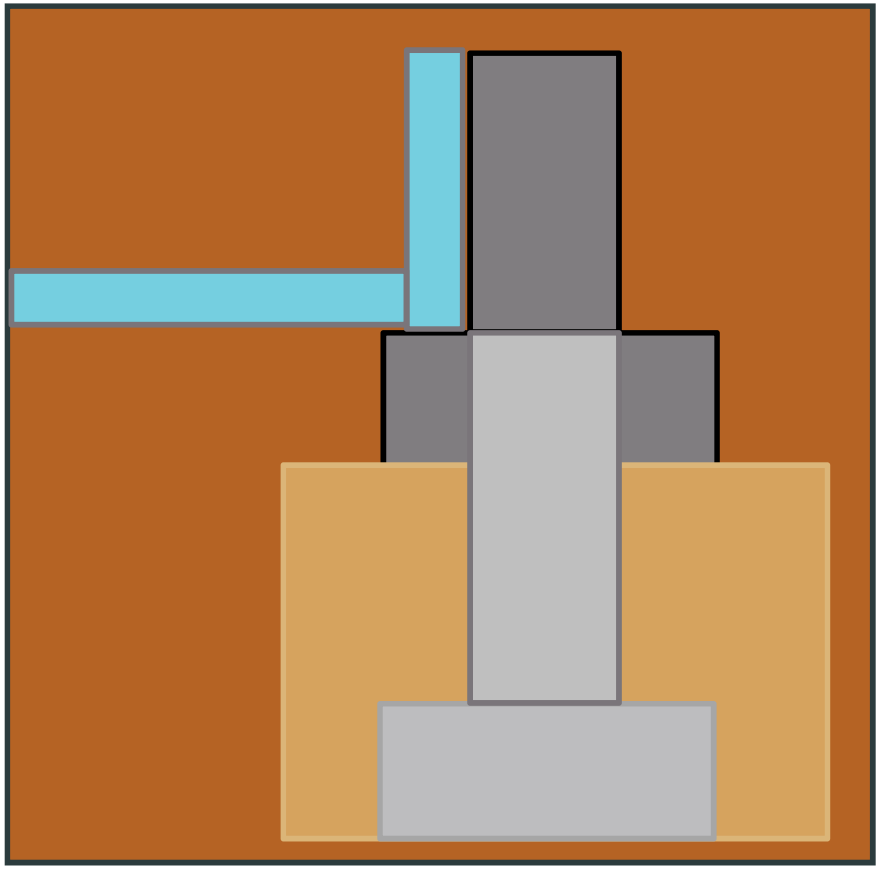
Excavation Savings $





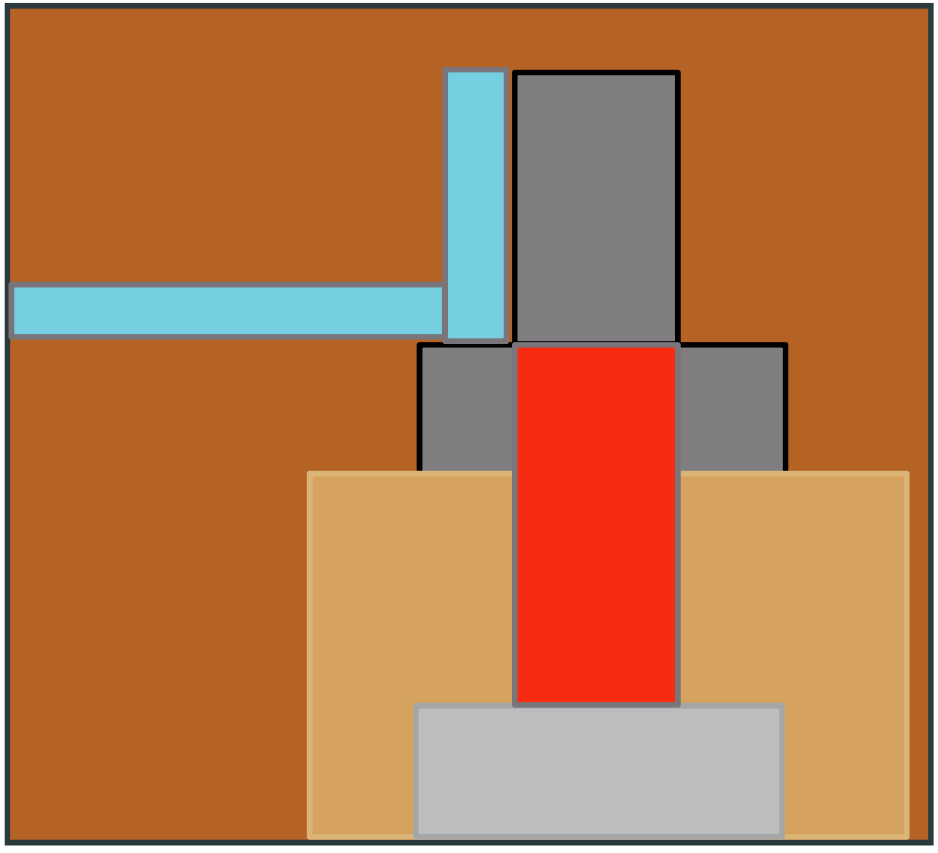
Benefits of FPSF

Hauling or Site Grading Savings $



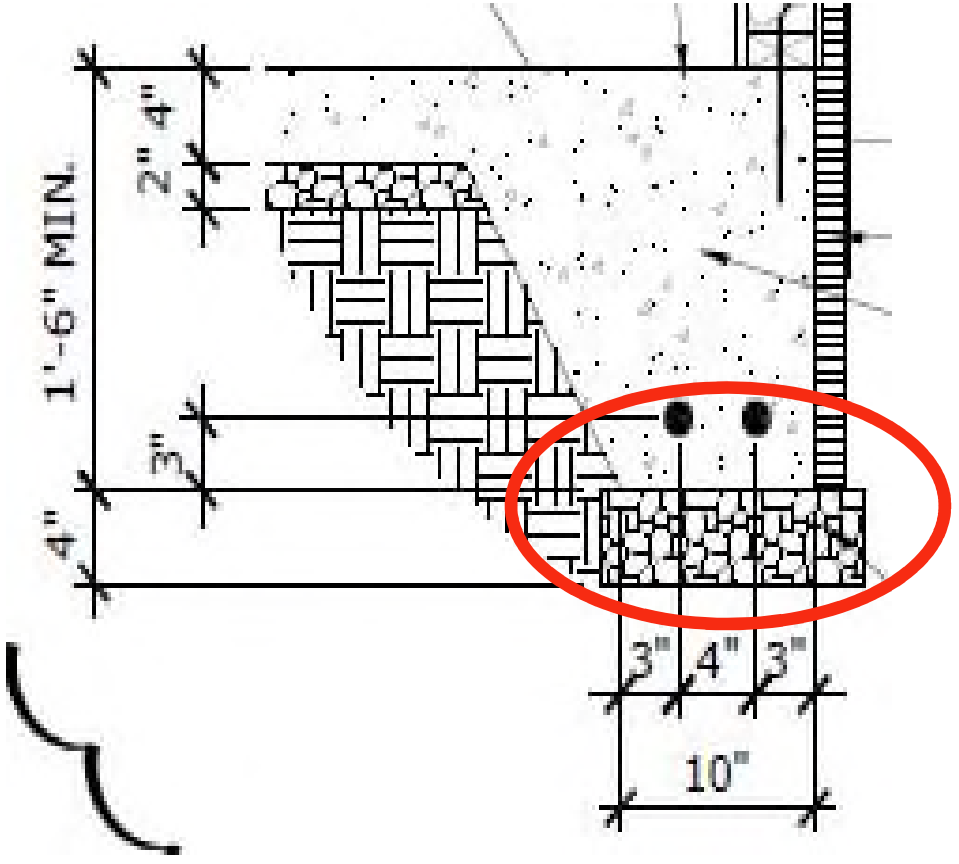
Benefits of FPSF

Concrete Savings $



Added Cost of FPSF

Additional Gravel $



Added Cost of FPSF

Additional Insulation

FPSF Requirements often less than IECC

TABLE R403.3(1)
MINIMUM FOOTING DEPTH AND INSULATION REQUIREMENTS FOR FROST-PROTECTED FOOTINGS IN HEATED BUILDINGS[a]

AIR FREEZING INDEX (°F-days)[b]	MINIMUM FOOTING DEPTH, D (inches)	VERTICAL INSULATION R-VALUE[c, d]	HORIZONTAL INSULATION R-VALUE[c, e]		HORIZONTAL INSULATION DIMENSIONS PER FIGURE R403.3(1) (inches)		
			Along walls	At corners	A	B	C
1,500 or less	12	4.5	Not required	Not required	Not required	Not required	Not required
2,000	14	5.6	Not required	Not required	Not required	Not required	Not required
2,500	16	6.7	1.7	4.9	12	24	40
3,000	16	7.8	6.5	8.6	12	24	40
3,500	16	9.0	8.0	11.2	24	30	60
4,000	16	10.1	10.5	13.1	24	36	60

TABLE N1102.1.2 (R402.1.2)
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION *U*-FACTOR[b]	SKYLIGHT[b] *U*-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING *R*-VALUE	WOOD FRAME WALL *R*-VALUE	MASS WALL *R*-VALUE[i]	FLOOR *R*-VALUE	BASEMENT[c] WALL *R*-VALUE	SLAB[d] *R*-VALUE & DEPTH	CRAWL SPACE[c] WALL *R*-VALUE
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13 + 5[h]	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49	20 or 13 + 5[h]	8/13	19	10 /13	10, 2 ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13 + 5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.32	0.55	NR	49	20 + 5 or 13 + 10[h]	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.32	0.55	NR	49	20 + 5 or 13 + 10[h]	19/21	38[g]	15/19	10, 4 ft	15/19

Added Cost of FPSF

Additional Insulation

- Non-conditioned areas
  - Front porches
- Semi-conditioned areas
  - Garages

Case Study – Habitat for Humanity (MI)

	Total Cost
Basement	$33,284
Crawl Space	$18,235
FPSF Slab	$10,800

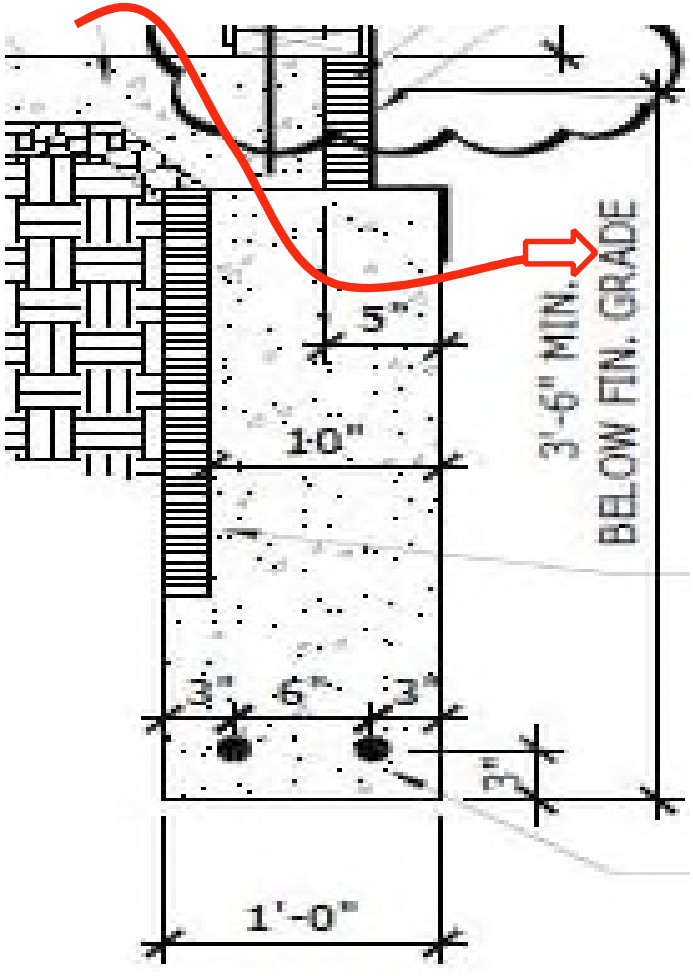
	Total Cost
Crawl vs. Basement	$15,049
FPSF vs. Basement	$22,484
FPSF vs. Crawl	$7,435

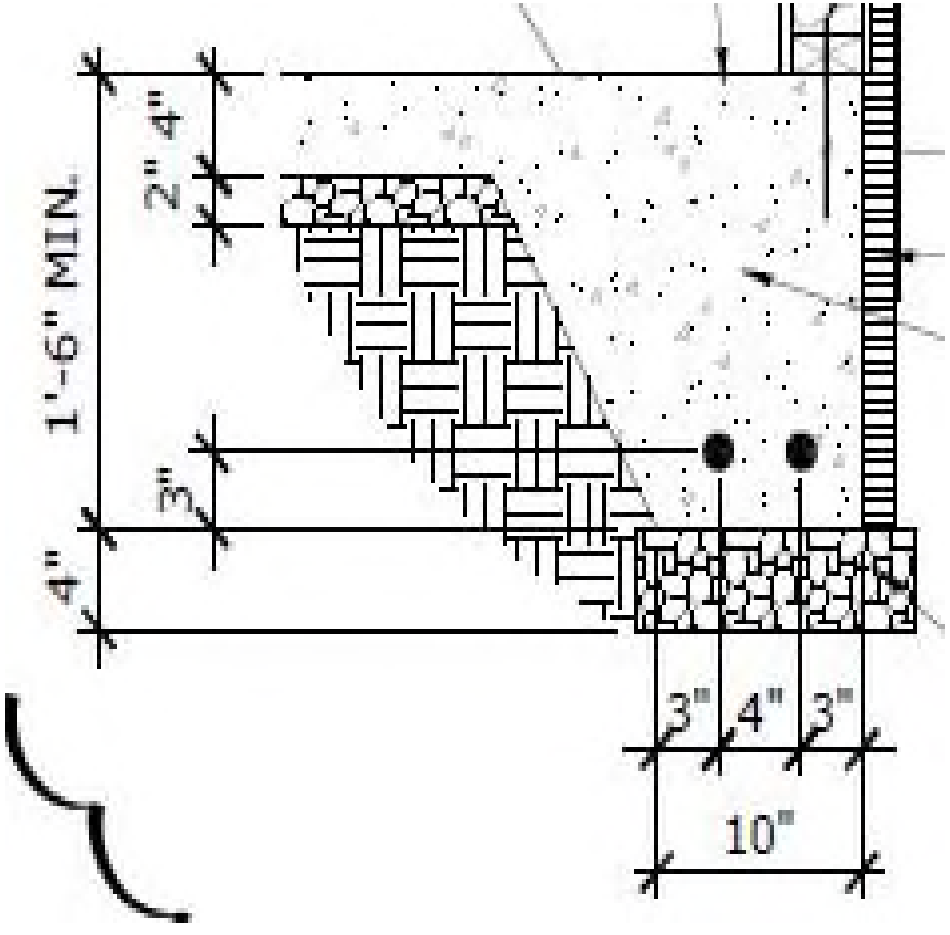
Redwood Multi-Family in Midland, MI

- Shared Habitat for Humanity savings of FPSF
- Redwood estimated they too could save money
- Ideal site for FPSF
  - Flat site
  - Engineered soils
- Also shared hygrothermal data from our 12-home research project
- Interested in comparing 2x4 ci vs 2x6 cavity only

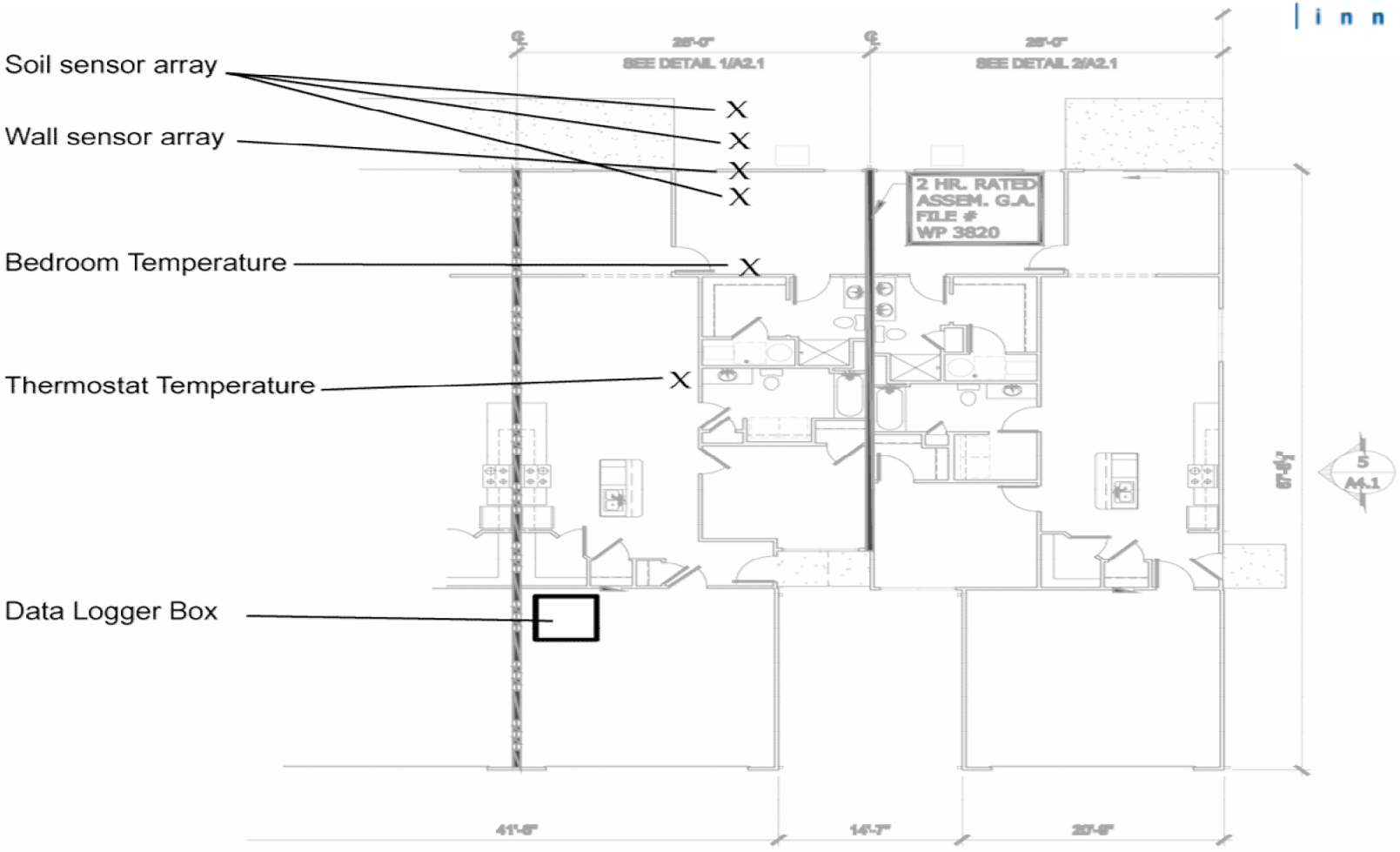
Research Homes Site Location

Stem wall vs. FPSF Design

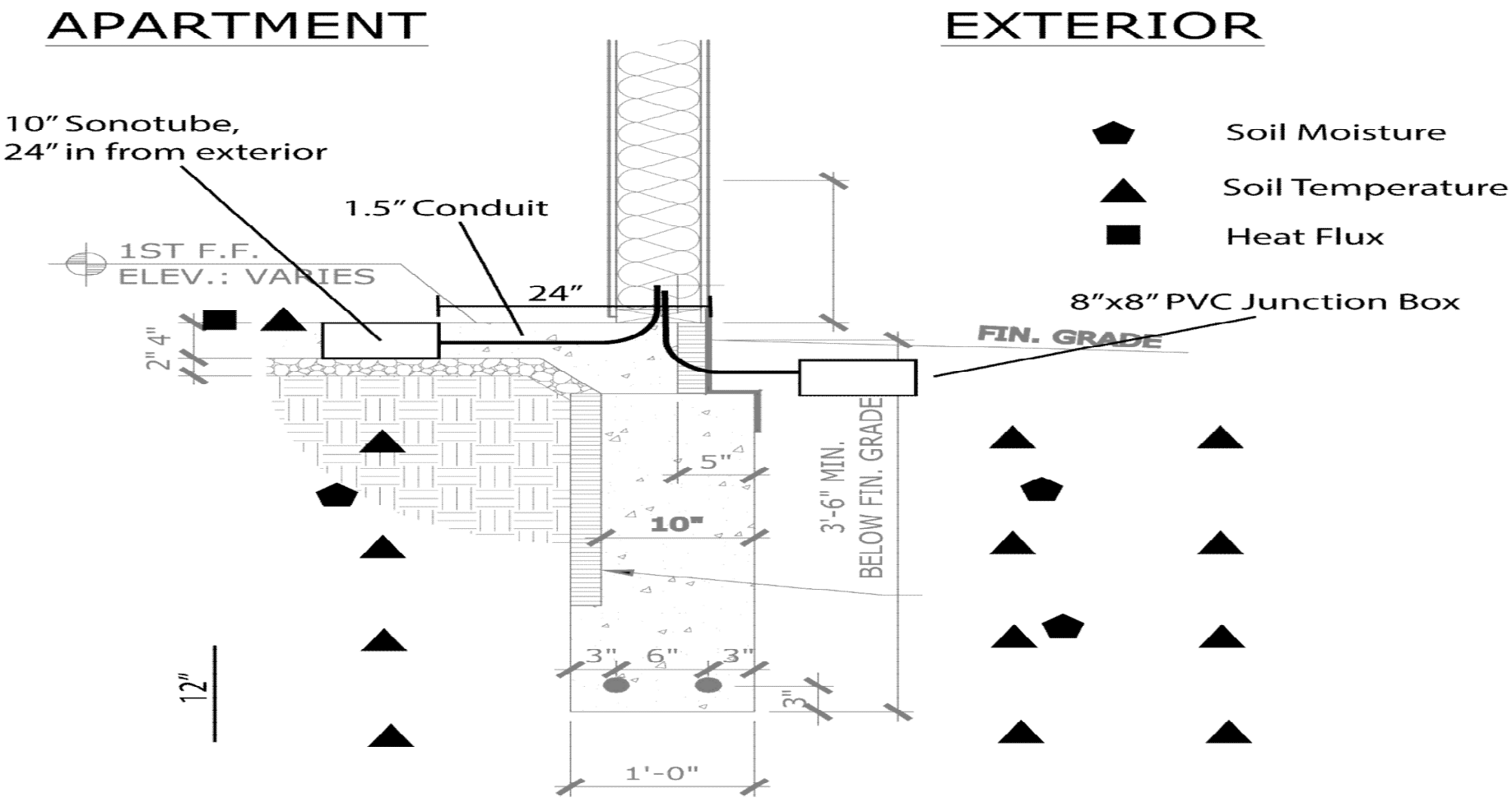




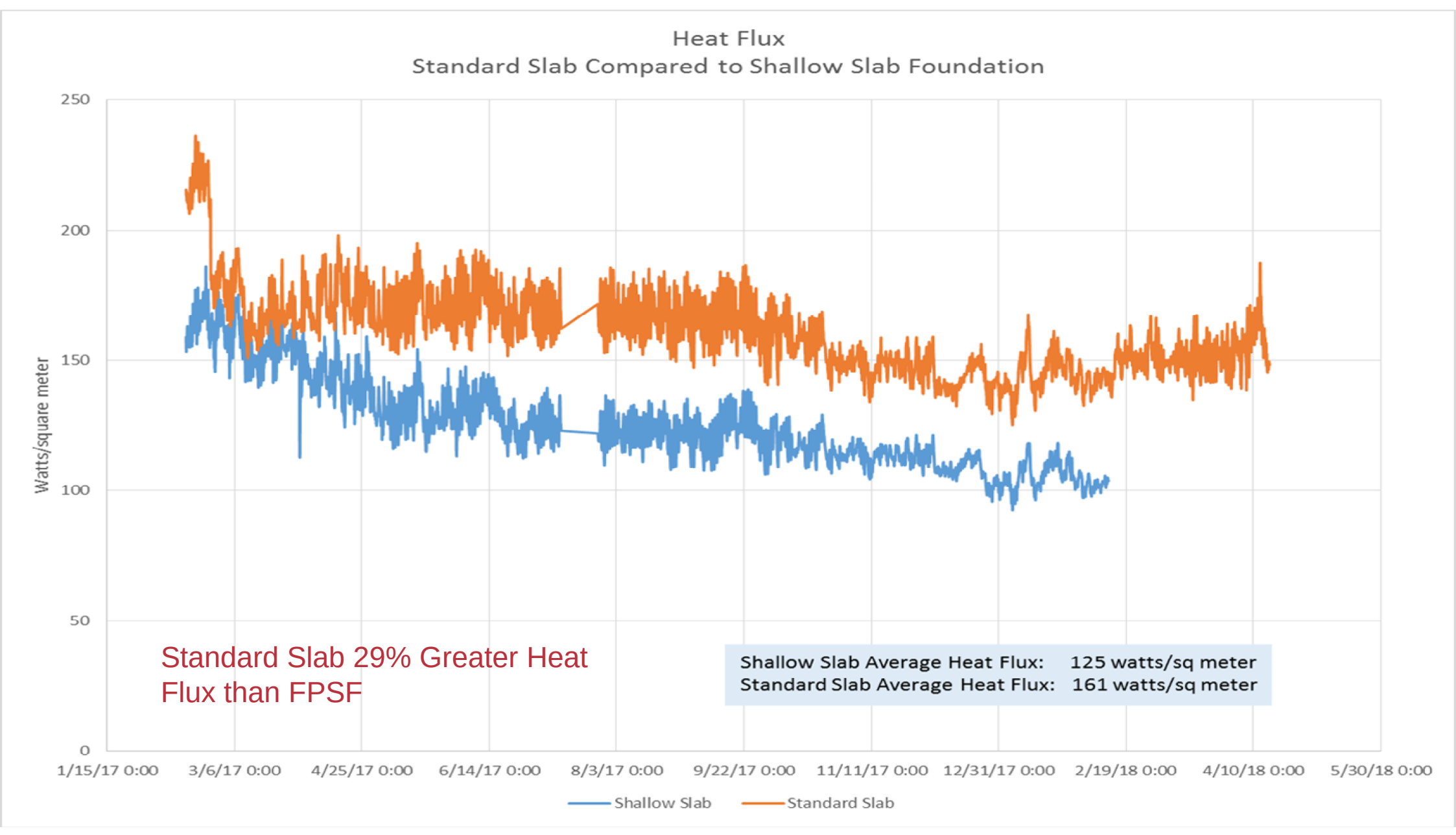
Sensor Locations

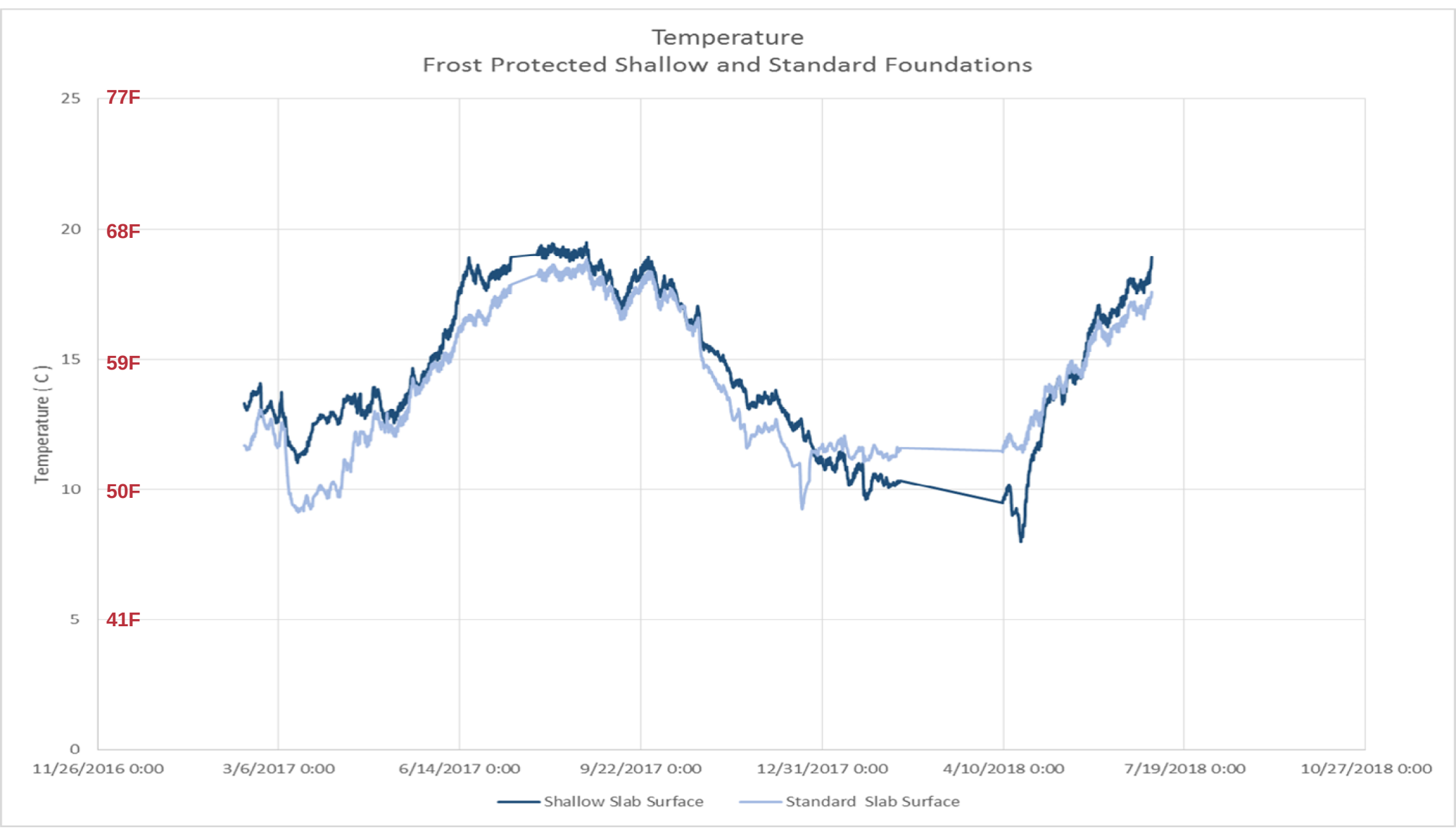


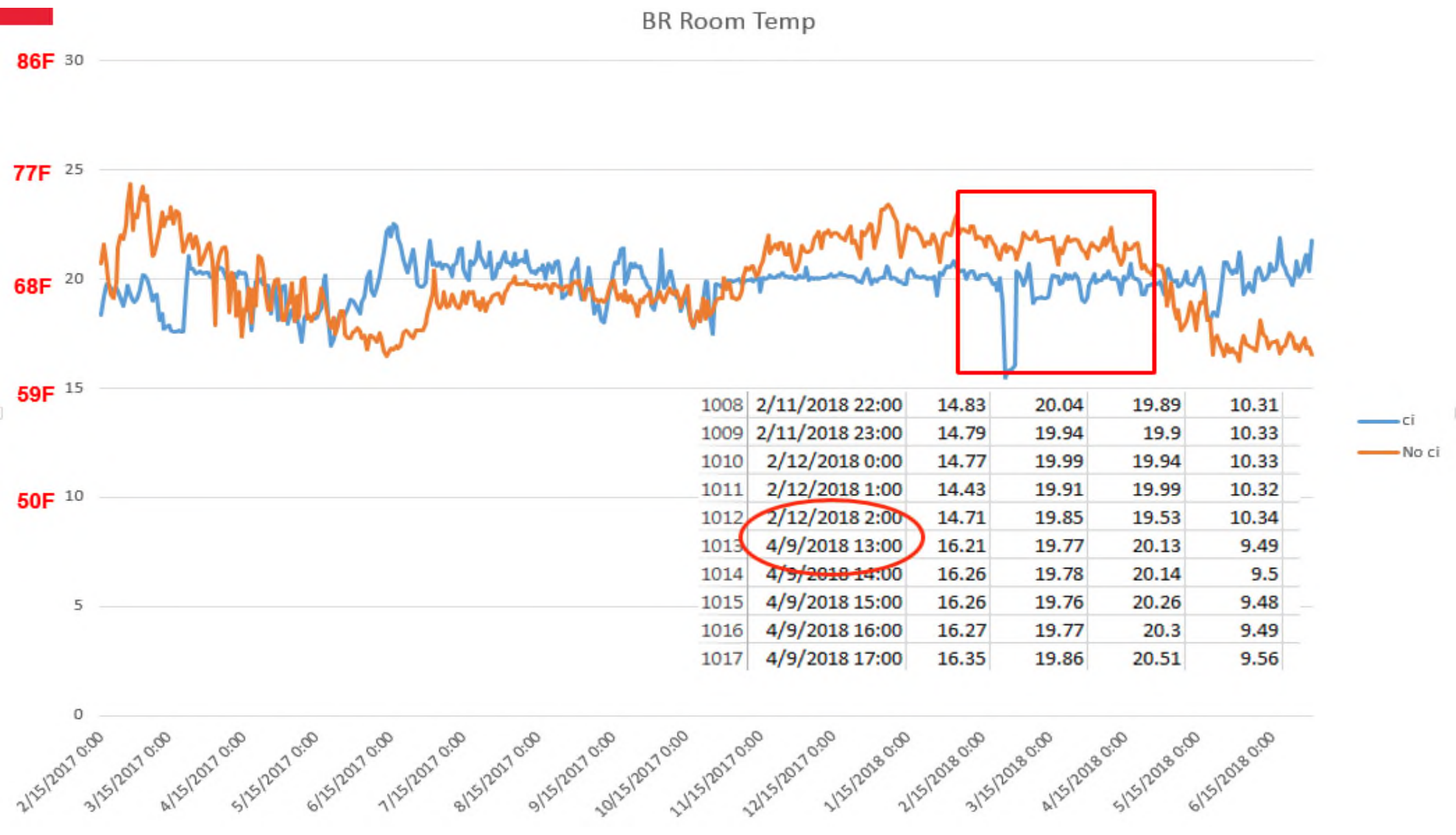
Below Grade Sensor




SHALLOW
0174

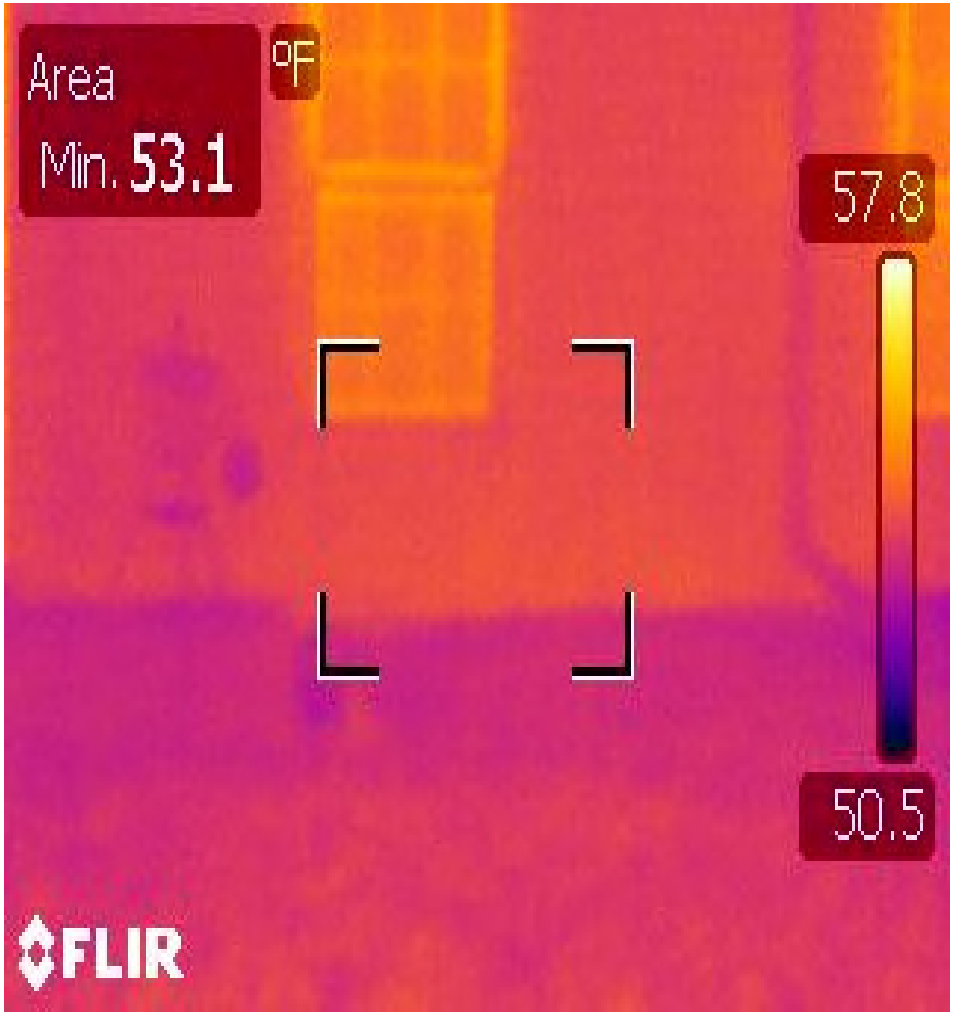

Heat Flux
Standard Slab Compared to Shallow Slab Foundation
Watts/square meter
250
200
150
100
50
0
1/15/17 0:00
3/6/17 0:00
4/25/17 0:00
6/14/17 0:00
8/3/17 0:00
9/22/17 0:00
11/11/17 0:00
12/31/17 0:00
2/19/18 0:00
4/10/18 0:00
5/30/18 0:00
Shallow Slab
Standard Slab
Standard Slab 29% Greater Heat Flux than FPSF
Shallow Slab Average Heat Flux: 125 watts/sq meter
Standard Slab Average Heat Flux: 161 watts/sq meter


Temperature
Frost Protected Shallow and Standard Foundations
77F
68F
59F
50F
41F
25
20
15
10
5
0
Temperature (C)
11/26/2016 0:00
3/6/2017 0:00
6/14/2017 0:00
9/22/2017 0:00
12/31/2017 0:00
4/10/2018 0:00
7/19/2018 0:00
10/27/2018 0:00
Shallow Slab Surface
Standard Slab Surface

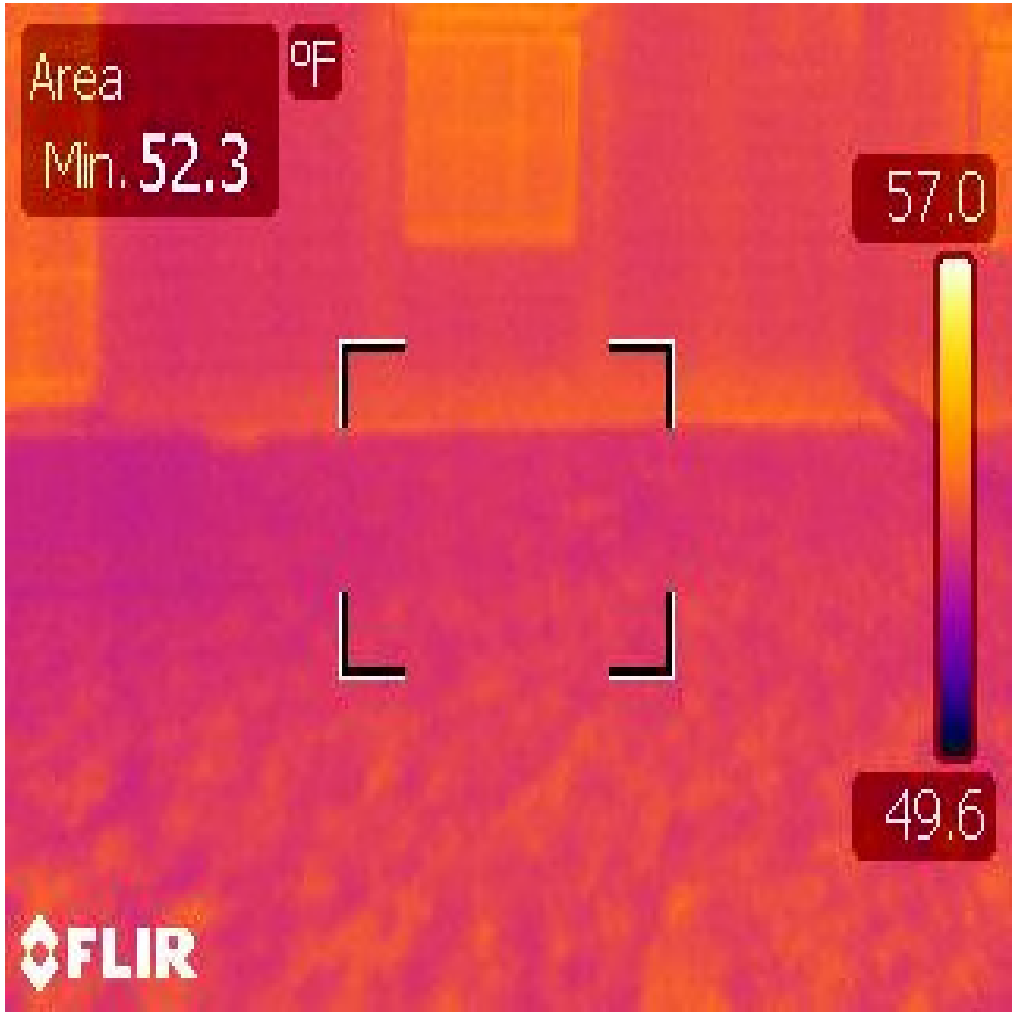


1008	2/11/2018 22:00	14.83	20.04	19.89	10.31
1009	2/11/2018 23:00	14.79	19.94	19.9	10.33
1010	2/12/2018 0:00	14.77	19.99	19.94	10.33
1011	2/12/2018 1:00	14.43	19.91	19.99	10.32
1012	2/12/2018 2:00	14.71	19.85	19.53	10.34
1013	4/9/2018 13:00	16.21	19.77	20.13	9.49
1014	4/9/2018 14:00	16.26	19.78	20.14	9.5
1015	4/9/2018 15:00	16.26	19.76	20.26	9.48
1016	4/9/2018 16:00	16.27	19.77	20.3	9.49
1017	4/9/2018 17:00	16.35	19.86	20.51	9.56

FPSF



Standard Foundation



Cost Comparison

Phase	FPSF Foundation	Standard Foundation
Additional Excavation	NA	$600
BG Insulation	$2,991	$1,641
Additional Insulation Labor	$360	NA
Concrete	$3,585	$6,576
Additional Gravel & Placement	$600	NA
TOTAL	$7,536	$8,817
BUILDING DIFFERENCE	**[$1,281]**	
PER UNIT DIFFERENCE (6 units per building)	**[$213]**	

Why is FPSF not more common?

- FPSF cost savings not fully realized
- People like basements
- Bearing soil depth
- Sloped lots
- The colder the climate the more potential savings

Feasibility of FPSF

- **FPSF can save $ but you must consider:**
  - Frost Depth ⇨ Colder = greater savings
  - Depth of bearing soil ⇨ Shallower or compacted = better
  - Slope of lot ⇨ Flatter = better
  - Unconditioned areas (porches) ⇨ smaller = better
  - Semi-conditioned areas (garages) ⇨ smaller or none = better

FPSF Summary

Learnings to Date

- Better understanding of why FPSF are not more common
- Understand the variables that can make FPSF feasible
- FPSF has a lower heat flux than Redwood standard foundation

More Research

- Need to better understand slab temperature inversion
- Need cold temperature IR photos
- Compare ground temperature and moisture content data

2x4 ci vs. 2x6 Cavity only Insulation

Above Grade Wall Research Questions

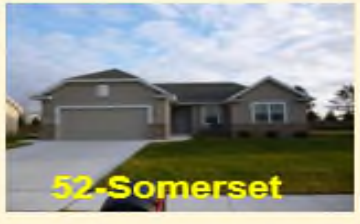
1. How does 2x4 R5 ci with R14 cellulose compare hygrothermally to 2x6 R21 cellulose in the cavity only insulation?
2. Does XPS ci trap moisture?
3. What is the cost to build each strategy?
4. How does moisture cycling of OSB impact strength over time?

Research Neighborhood (TEETH Project)

Midland, Michigan Climate Zone 5-6

2006 IECC

2012 IECC



2012 IECC CI

Beyond 2012 IECC

Moisture Content - Housewrap Houses
Interior Sheathing Surface - Above Grade Cavity

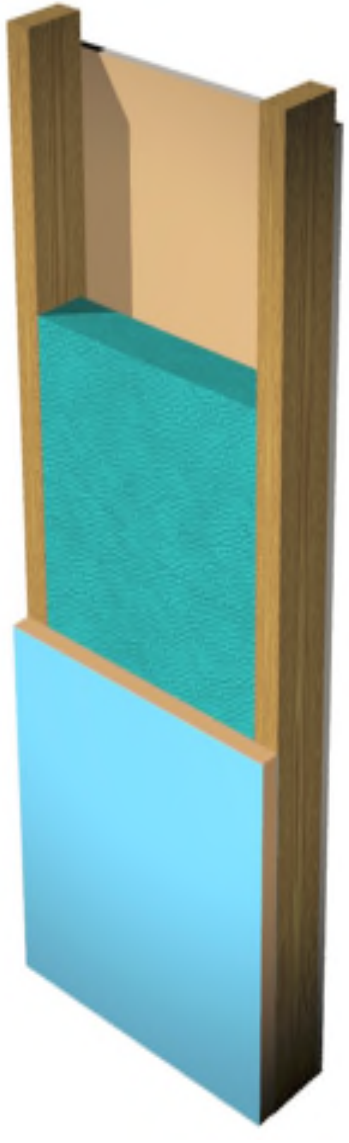
Moisture Content (%)

35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00

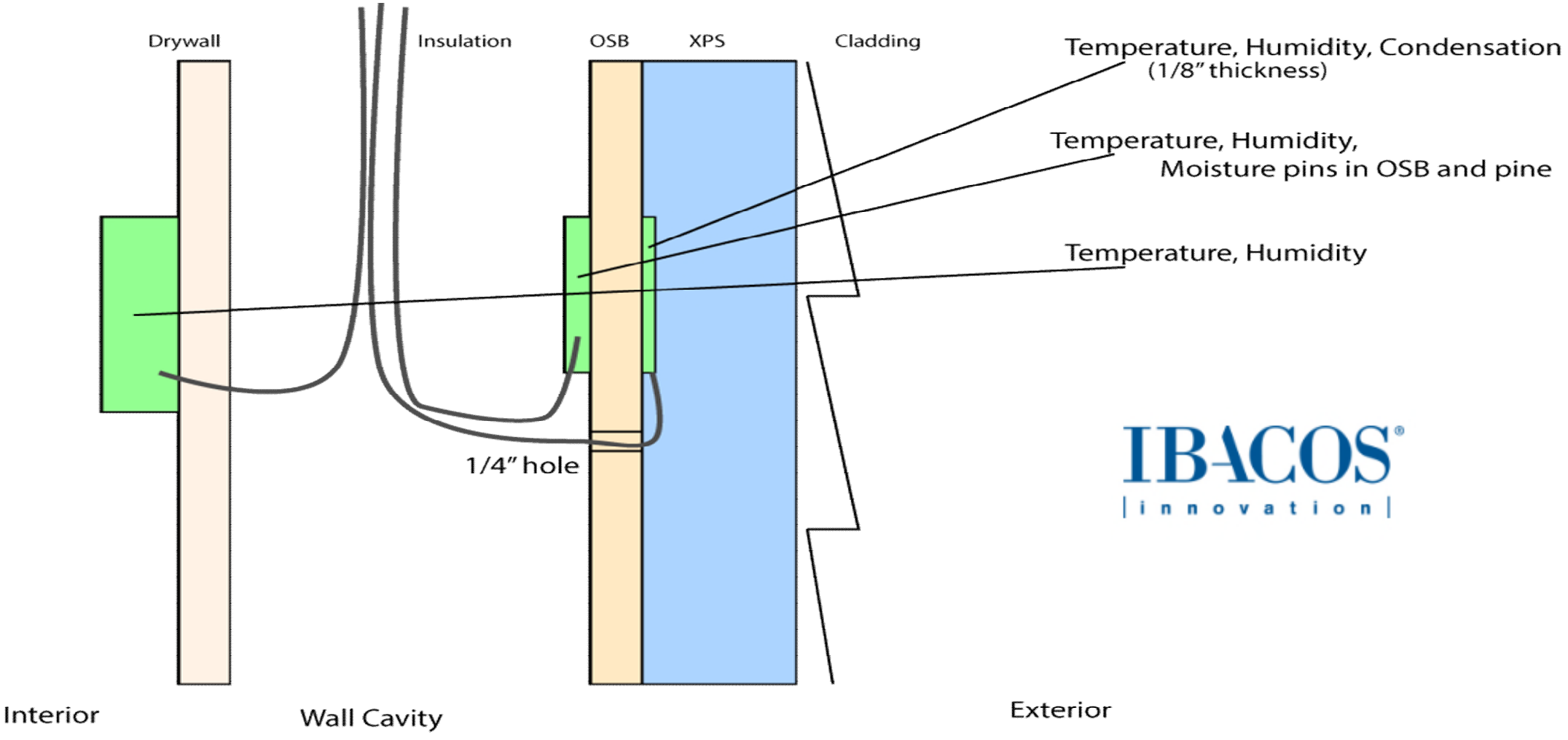
10/2/2012
11/2/2012
12/2/2012
1/2/2013
2/2/2013
3/2/2013
4/2/2013
5/2/2013
6/2/2013
7/2/2013
8/2/2013
9/2/2013
10/2/2013
11/2/2013
12/2/2013
1/2/2014
2/2/2014
3/2/2014
4/2/2014
5/2/2014
6/2/2014
7/2/2014
8/2/2014
9/2/2014
10/2/2014
11/2/2014
12/2/2014
1/2/2015
2/2/2015
3/2/2015
4/2/2015
5/2/2015
6/2/2015

H2 new tenant
H2 Vacant
H2 new tenant

House 1 HW
House 2 HW
House 3 HW
House 4 HW
House 5 HW
House 6 HW
Housewrap Group Avg



AG Wall Sensors



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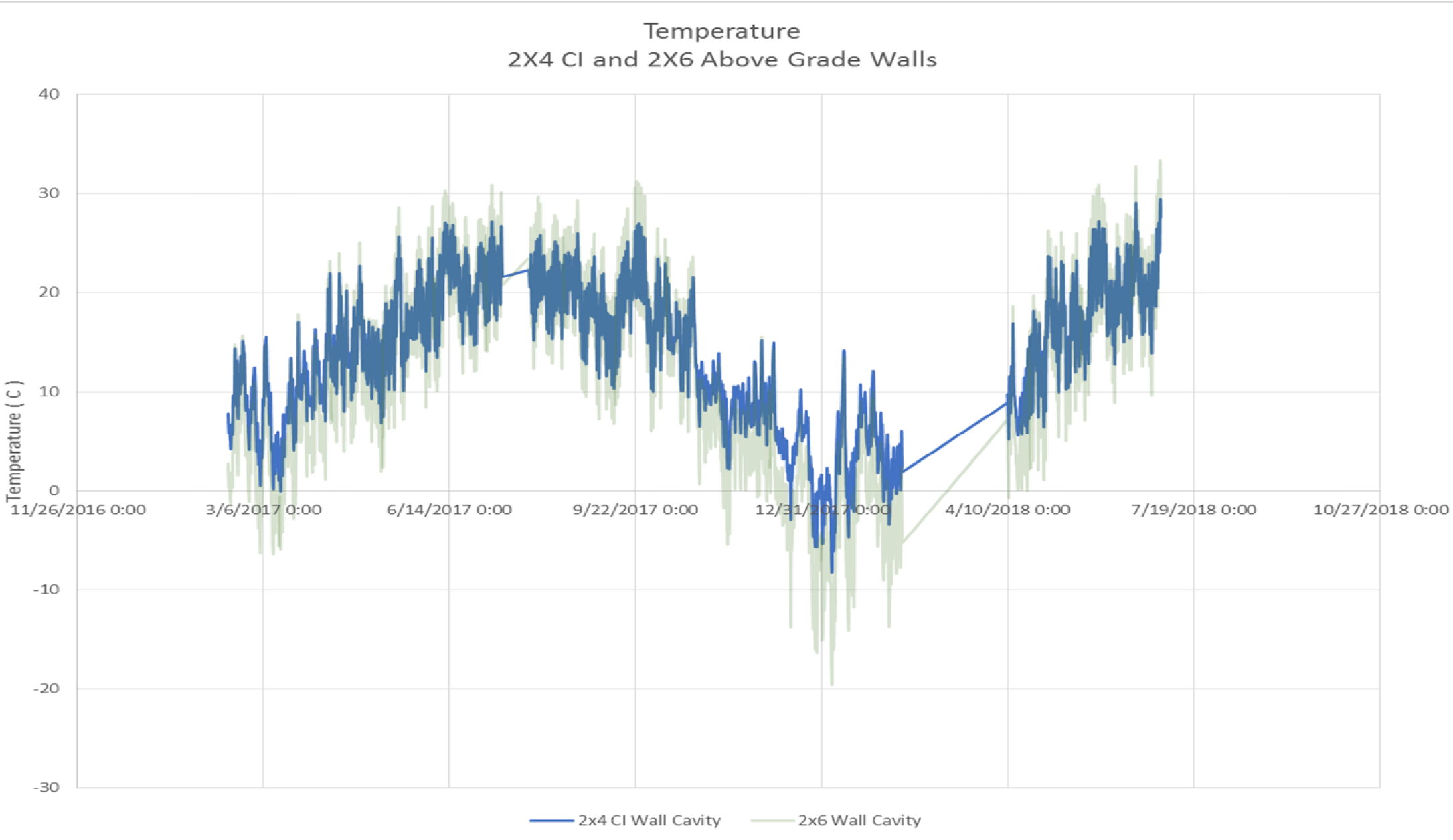
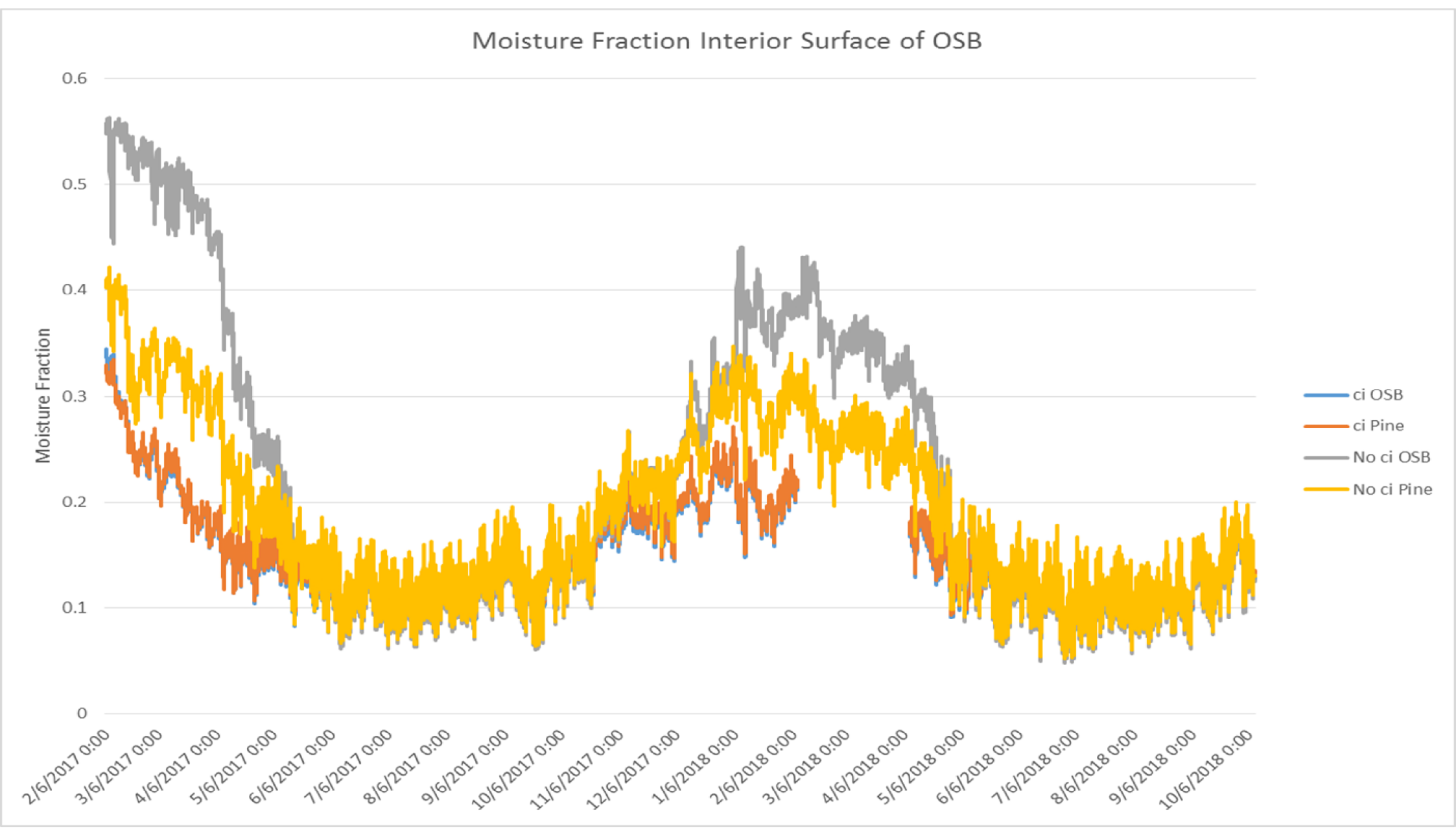
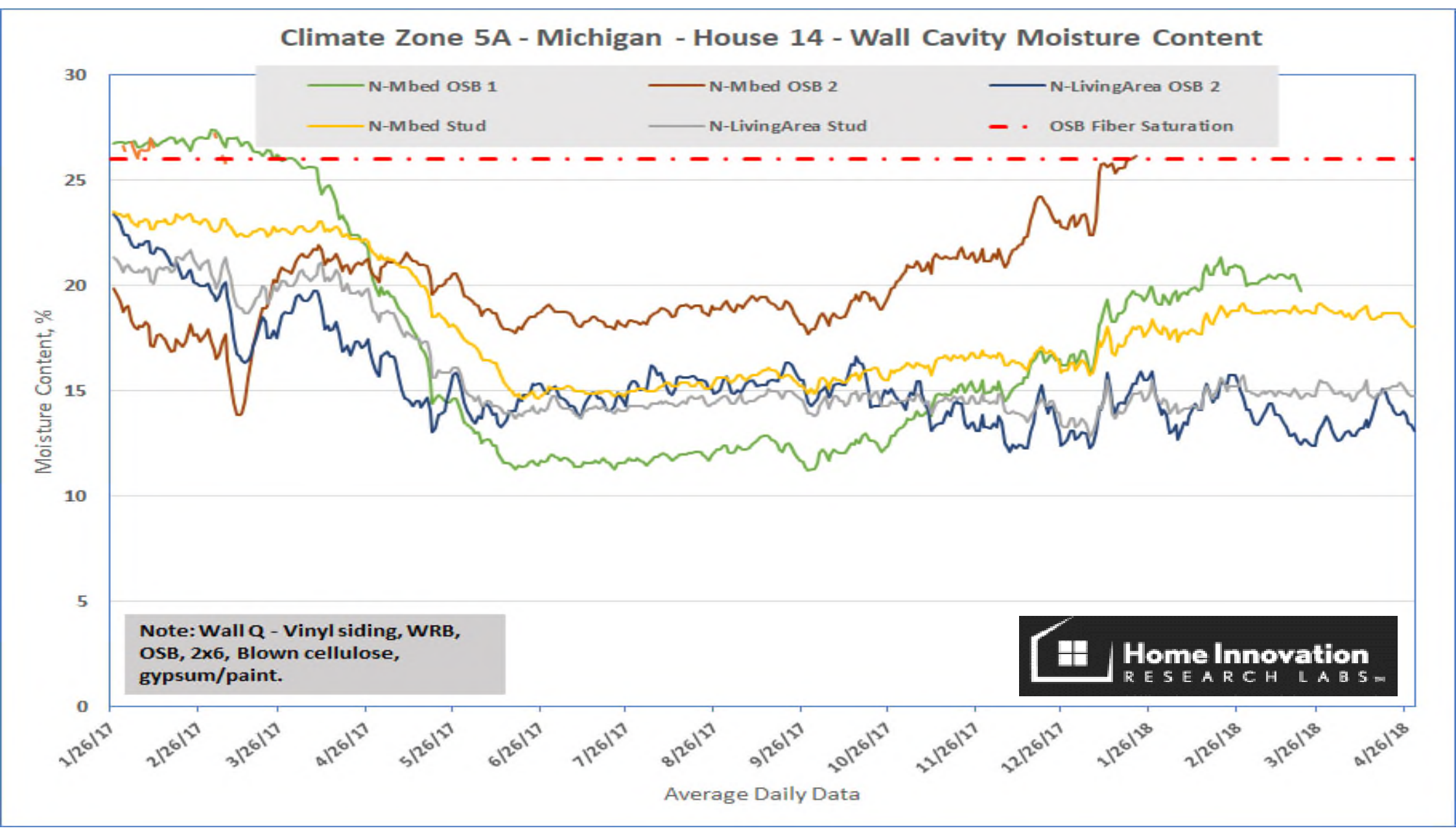
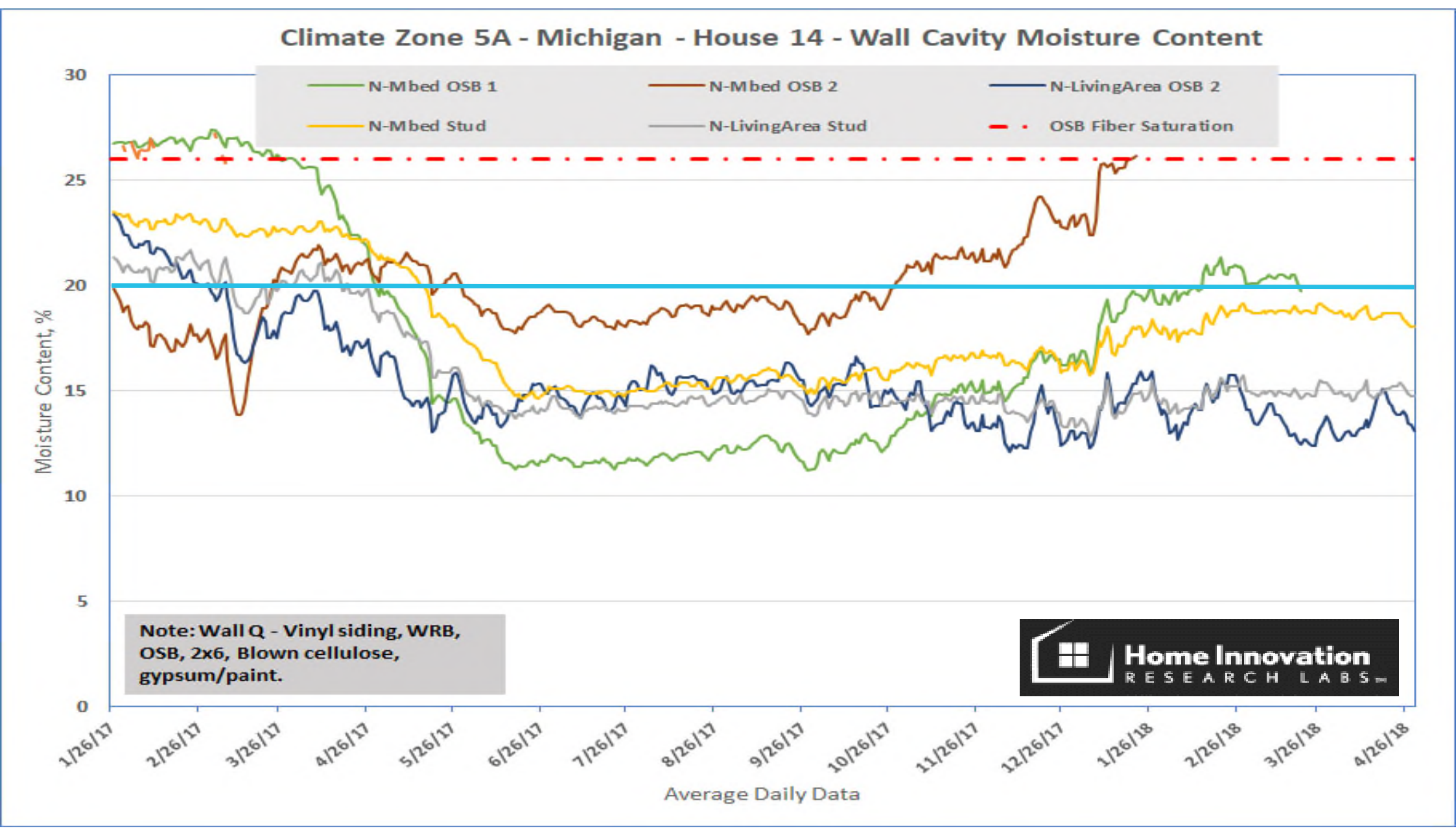
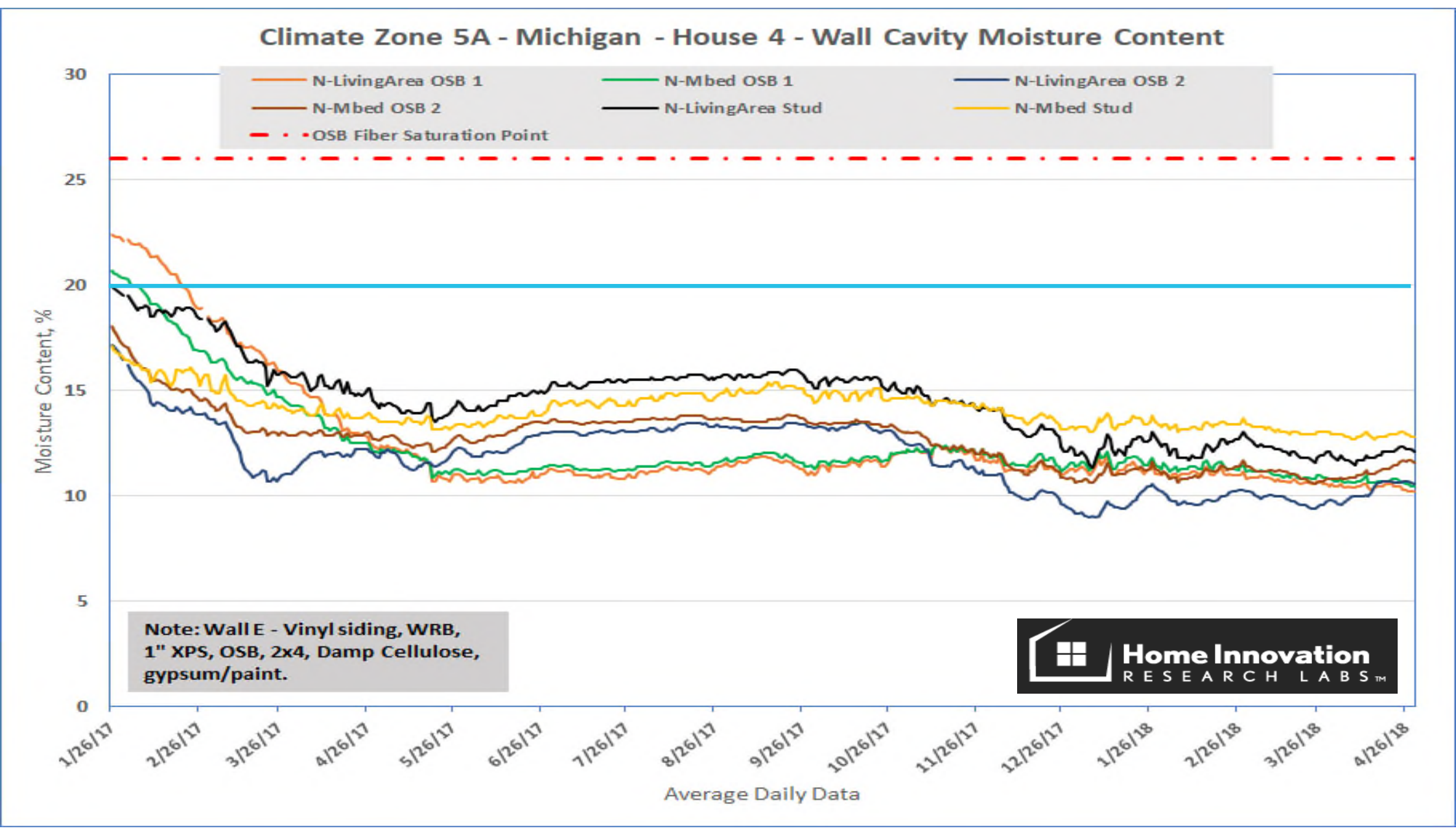
HOME 1
206F01F2


Temperature
2X4 CI and 2X6 Above Grade Walls
Temperature (C)
40
30
20
10
0
-10
-20
-30
11/26/2016 0:00
3/6/2017 0:00
6/14/2017 0:00
9/22/2017 0:00
12/31/2017 0:00
4/10/2018 0:00
7/19/2018 0:00
10/27/2018 0:00
2x4 CI Wall Cavity
2x6 Wall Cavity

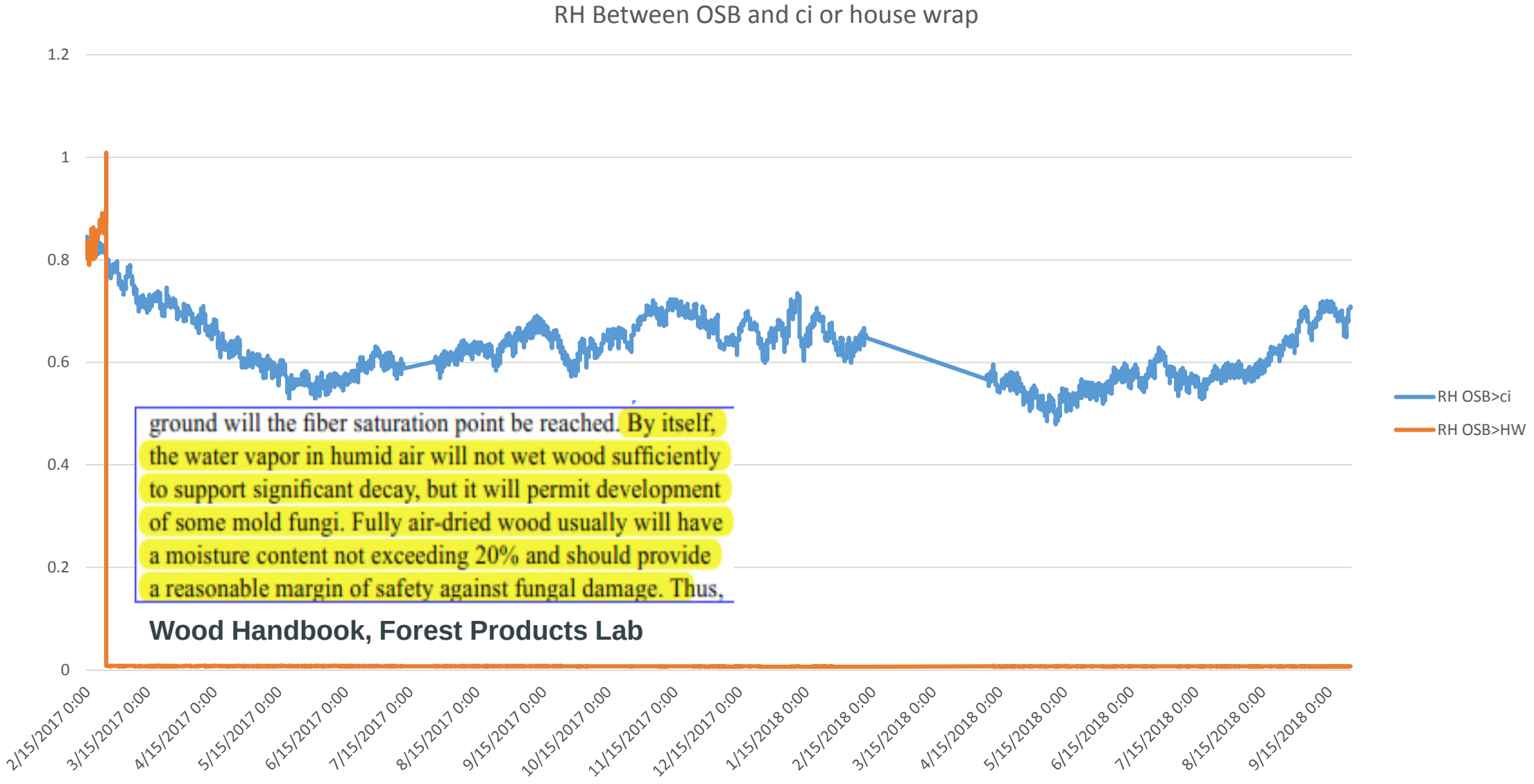

Moisture Fraction Interior Surface of OSB
Moisture Fraction
0.6
0.5
0.4
0.3
0.2
0.1
0
2/6/2017 0:00
3/6/2017 0:00
4/6/2017 0:00
5/6/2017 0:00
6/6/2017 0:00
7/6/2017 0:00
8/6/2017 0:00
9/6/2017 0:00
10/6/2017 0:00
11/6/2017 0:00
12/6/2017 0:00
1/6/2018 0:00
2/6/2018 0:00
3/6/2018 0:00
4/6/2018 0:00
5/6/2018 0:00
6/6/2018 0:00
7/6/2018 0:00
8/6/2018 0:00
9/6/2018 0:00
10/6/2018 0:00
ci OSB
ci Pine
No ci OSB
No ci Pine


Climate Zone 5A - Michigan - House 14 - Wall Cavity Moisture Content
N-Mbed OSB 1
N-Mbed OSB 2
N-LivingArea OSB 2
N-Mbed Stud
N-LivingArea Stud
OSB Fiber Saturation
Moisture Content, %
30
25
20
15
10
5
0
1/26/17
2/26/17
3/26/17
4/26/17
5/26/17
6/26/17
7/26/17
8/26/17
9/26/17
10/26/17
11/26/17
12/26/17
1/26/18
2/26/18
3/26/18
4/26/18
Average Daily Data
Note: Wall Q - Vinyl siding, WRB, OSB, 2x6, Blown cellulose, gypsum/paint.
Home Innovation
RESEARCH LABS


Climate Zone 5A - Michigan - House 14 - Wall Cavity Moisture Content
N-Mbed OSB 1
N-Mbed OSB 2
N-LivingArea OSB 2
N-Mbed Stud
N-LivingArea Stud
OSB Fiber Saturation
Moisture Content, %
30
25
20
15
10
5
0
1/26/17
2/26/17
3/26/17
4/26/17
5/26/17
6/26/17
7/26/17
8/26/17
9/26/17
10/26/17
11/26/17
12/26/17
1/26/18
2/26/18
3/26/18
4/26/18
Average Daily Data
Note: Wall Q - Vinyl siding, WRB, OSB, 2x6, Blown cellulose, gypsum/paint.
Home Innovation
RESEARCH LABS


Climate Zone 5A - Michigan - House 4 - Wall Cavity Moisture Content
N-LivingArea OSB 1
N-Mbed OSB 1
N-LivingArea OSB 2
N-Mbed OSB 2
N-LivingArea Stud
N-Mbed Stud
OSB Fiber Saturation Point
Moisture Content, %
30
25
20
15
10
5
0
1/26/17
2/26/17
3/26/17
4/26/17
5/26/17
6/26/17
7/26/17
8/26/17
9/26/17
10/26/17
11/26/17
12/26/17
1/26/18
2/26/18
3/26/18
4/26/18
Average Daily Data
Note: Wall E - Vinyl siding, WRB, 1" XPS, OSB, 2x4, Damp Cellulose, gypsum/paint.
Home Innovation RESEARCH LABS

www.smtresearch.com



Cost 2x4 ci vs. 2x6 Cavity only

			Building K		Building L	
			2x4 CI		2x6 HW	
	Price	Unit	Q	Cost	Q	Cost
2x4 Bottom Plates	$ 0.57	LFT	628	$ 360.34	0	$ -
2x4 Top Plates	$ 0.31	LFT	1256	$ 389.52	0	$ -
2x6 Bottom Plates	$ 0.75	LFT	0	$ -	628	$ 471.47
2x6 Top Plates	$ 0.50	LFT	0	$ -	1256	$ 624.46
2x4 Studs	$ 2.13	Each	567	$ 1,210.13	0	$ -
2x6 Studs	$ 3.45	Each	0	$ -	567	$ 1,958.11
1" STYROFOAM Sheathing 4x8 material	$ 0.57	SFT	5526	$ 3,174.68	0	$ -
Foam Sheathing Installation	$ 0.10	SFT	5024	$ 502.40		$ -
Foam Sheathing Tape WRB material	$ 17.00	Roll	9	$ 156.30		$ -
Foam Sheathing Tape WRB labor	$ 0.05	LFT	1352	$ 67.60		$ -
Tyvek material	$ 0.13	SFT		$ -	5526	$ 719.45
Tyvek labor	$ 0.11	SFT		$ -	5024	$ 552.64
R-14 Damp spray cellulose (baseline)	$ -	SFT	2999	$ -		$ -
R-21 Damp spray cellulose (premium)	$ 0.23	SFT		$ -	2999	$ 689.77
TOTAL				**$ 5,860.98**		**$ 5,015.90**
		Per Building Premium for 2x4 ci		**$ 845.08**		
		Per unit premium for 2x4 ci		**$ 140.85**		

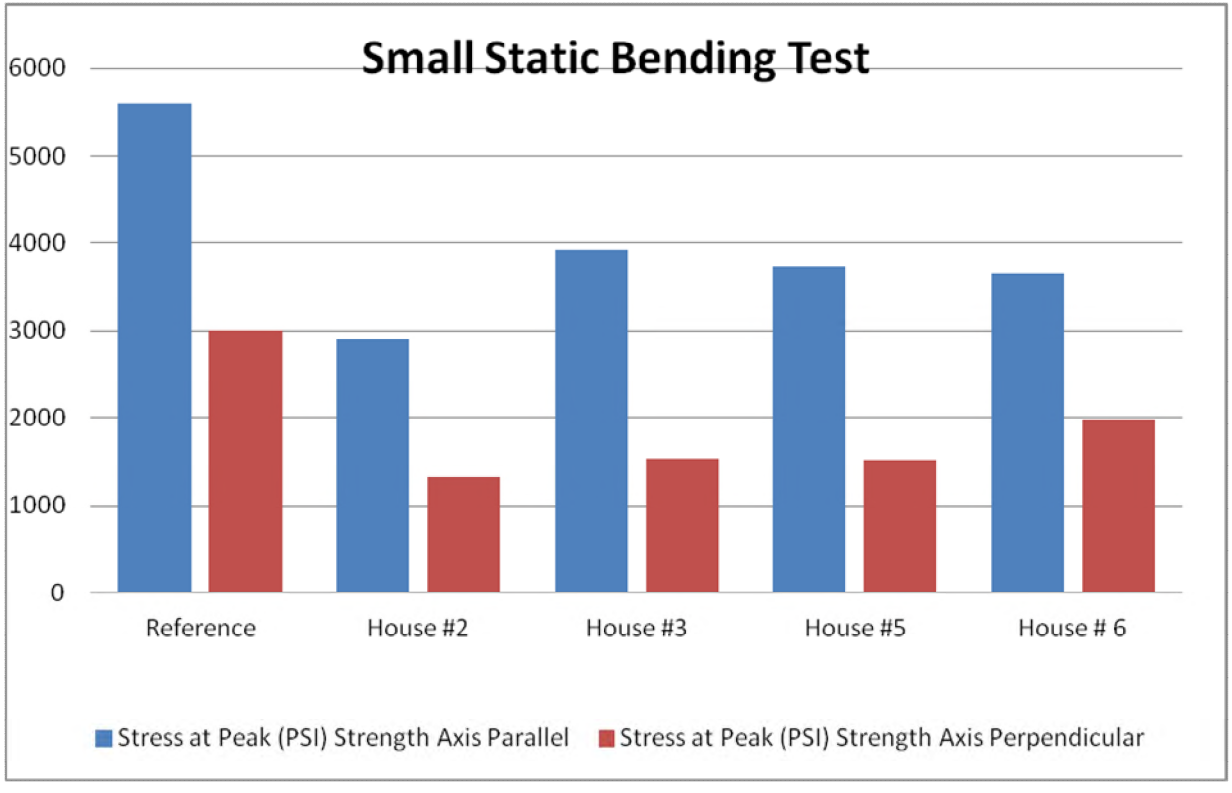
OSB strength loss (TEETH Project)

A piece of OSB is being kept in our conditioned lab for comparison with in situ OSB after 5-years.

2011

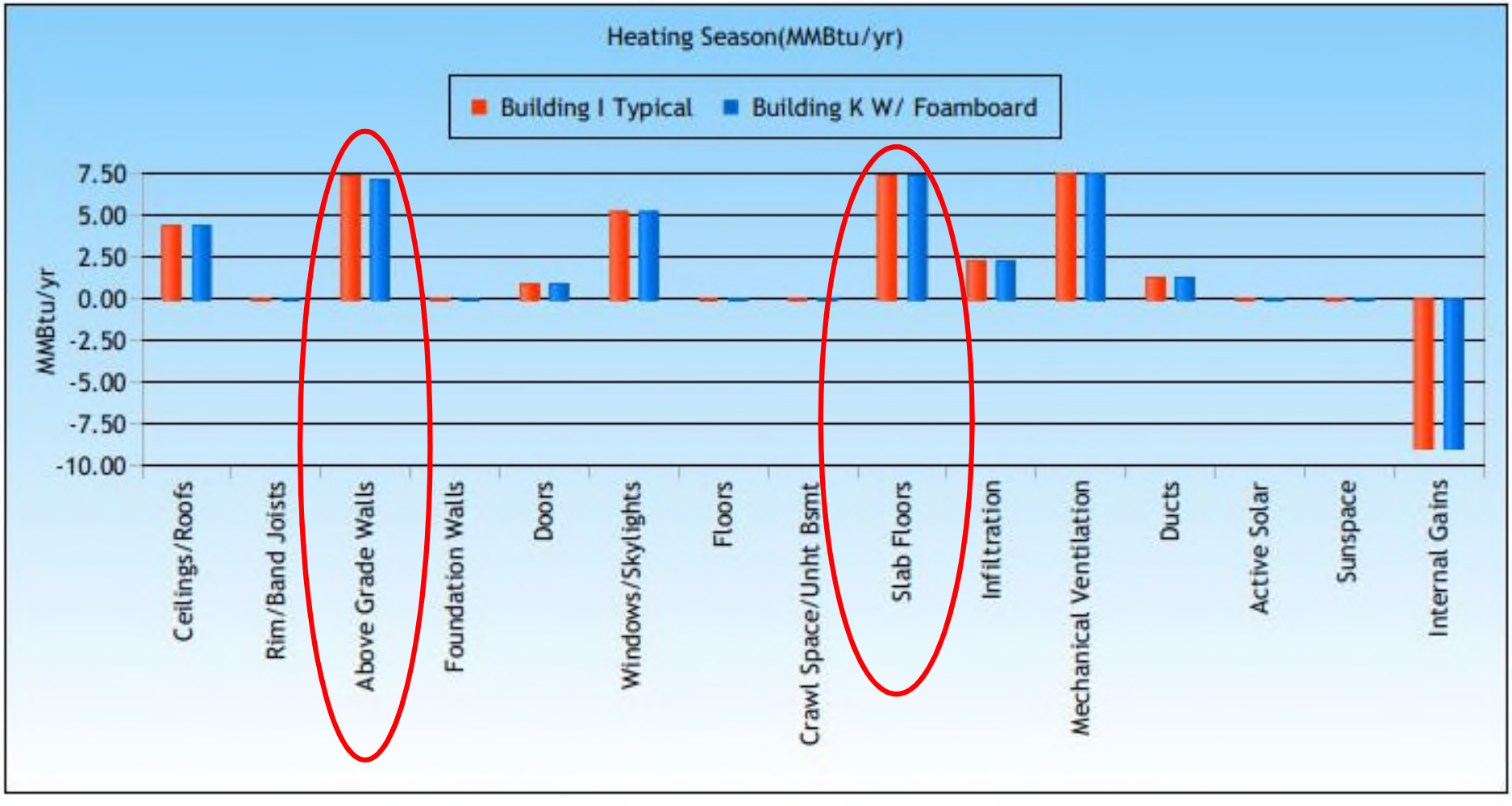
2015

OSB Strength Measurement after 4 years.



PS2 - Performance Standard for Wood-Based Structural Panels

4.5”x 14” ASTM D3043. Method D



REM/Rate - Residential Energy Analysis and Rating Software v15.4.1

This information does not constitute any warranty of energy cost or savings.

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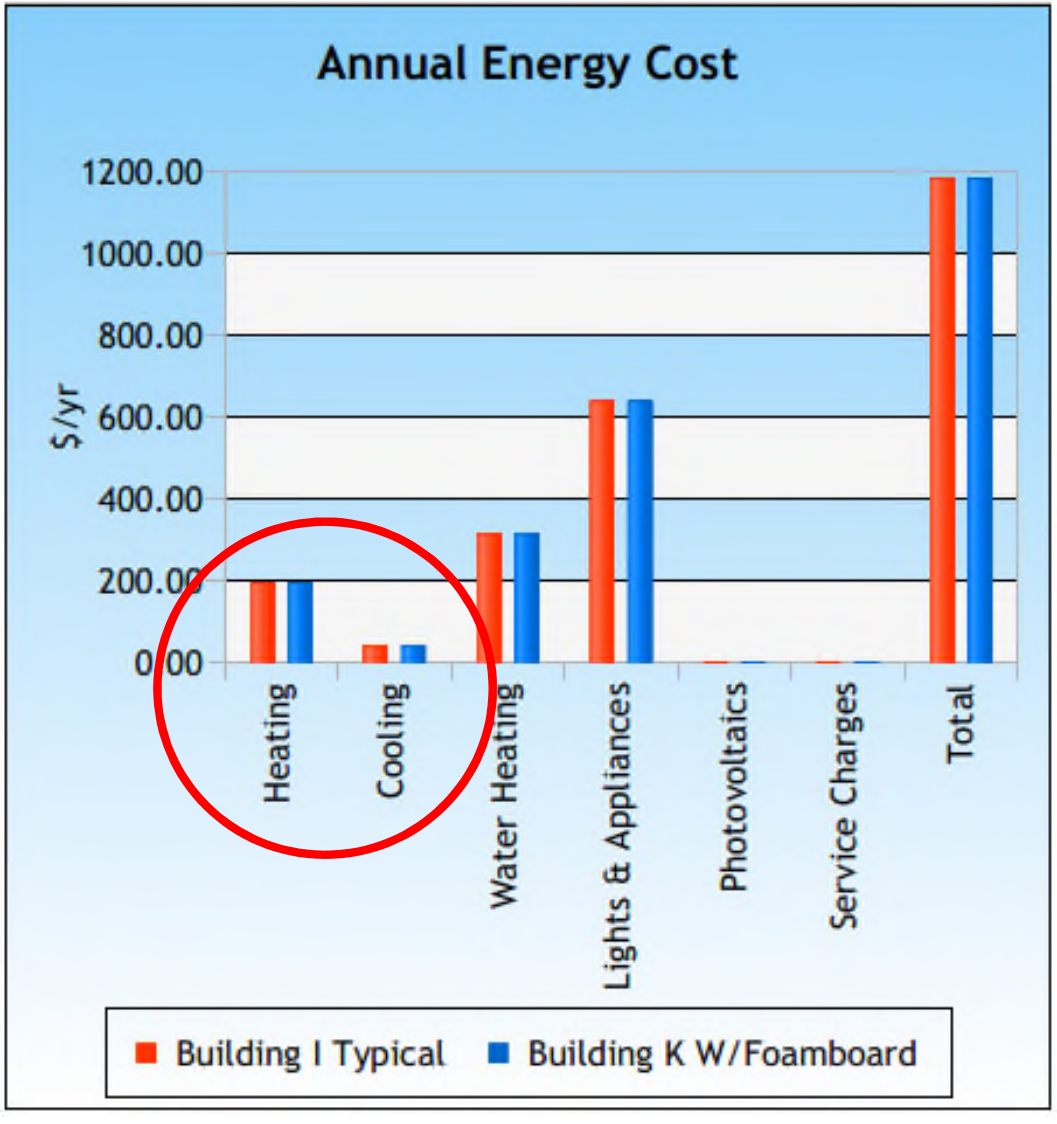

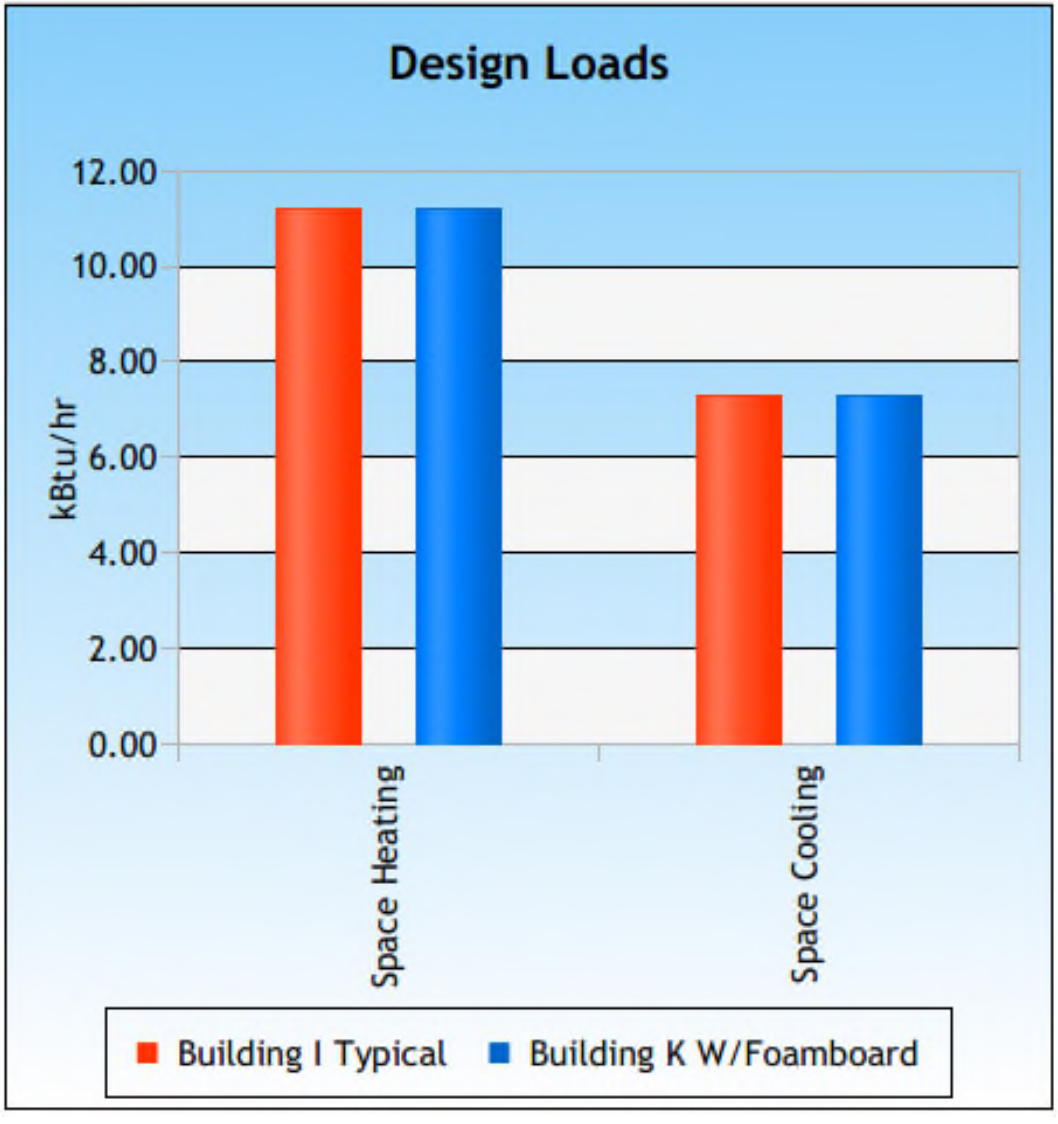

Wall Comparison Summary

Learnings to Date

- The cost of the two strategies are very similar and will vary as prices fluctuate
- Continuous insulation reduces condensation potential
- XPS ci over OSB does not trap moisture

Next Steps

- Began monitoring in 2017
- Plan to continue monitoring through 2022
- Plan to preform forensic investigation in 2022

Thank You