Thermal Resistance of Extruded Polystyrene (XPS): Field Data from Western Canada

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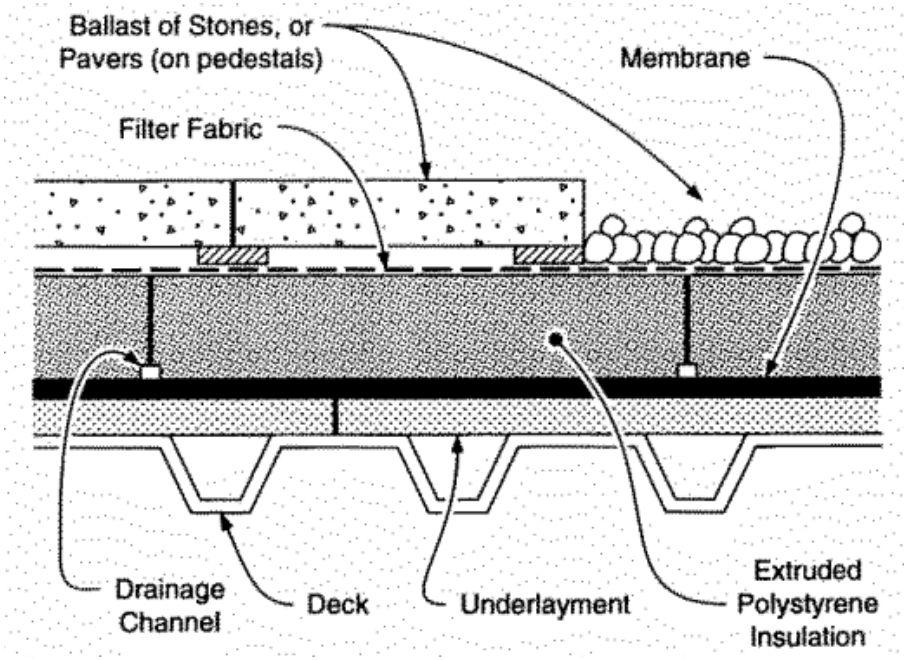
Read Jones Christoffersen Ltd.
Creative Thinking Practical Results

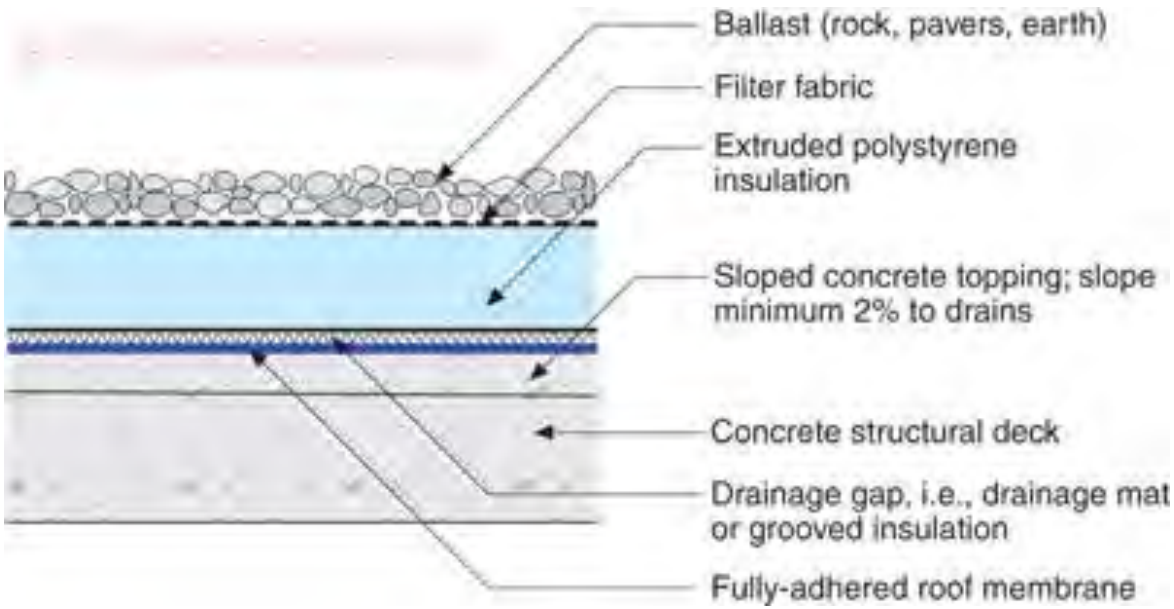
Outline

- **Introduction**
- **Sampling**
- **Sample Analysis**
- **Test Results**
- **Observations**
- **Conclusion**



Introduction
Protected Membrane Roofing

- **A.K.A. Inverted or Upside-down roofing,**
- **Protects the waterproofing membrane,**
- **Moves insulation to exterior of building envelope.**



Introduction

BSCE Water Absorption Experiment

Introduction

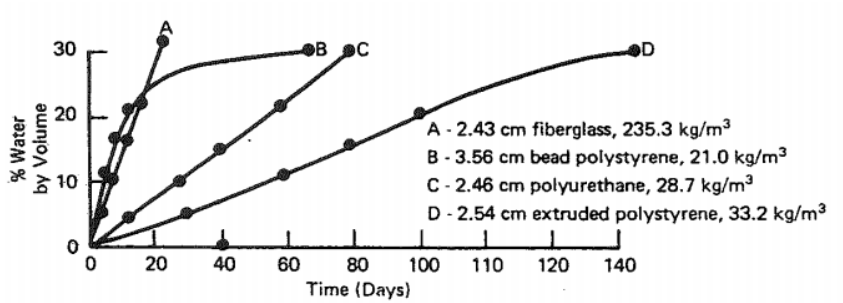
Moisture Absorption by Diffusion

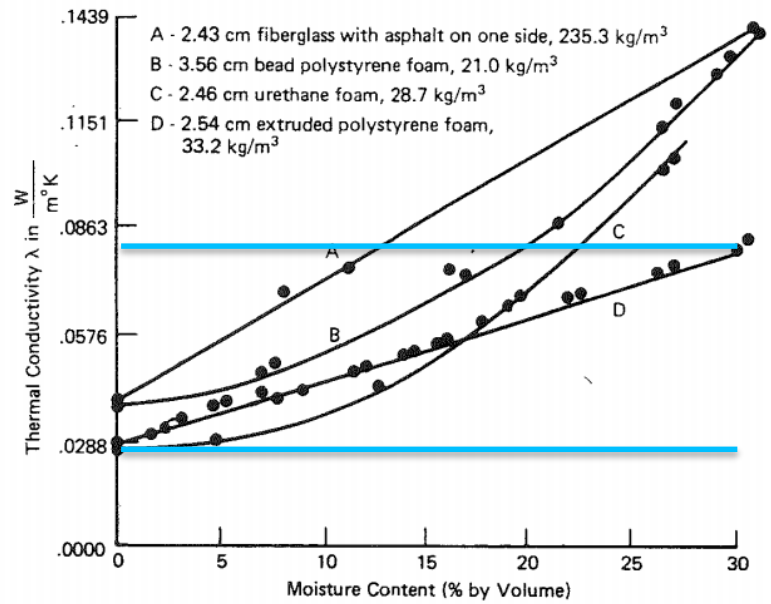
Dow Chemical Co. Experiment

(Dechow & Epstein, 1978)

Boundary Conditions:

- **Saturated (100% RH) and 50°C**
- **Lab Condition 50% RH and 20°C**





Performance reduced to 1/3 of rated R-value at 30% MC by volume.

Introduction

Reroofing the Windiest Place on Earth with a Modified Bitumen Protected Membrane

(Tobiasson and Buska, 1981)

Site Conditions:

- **Wind Speeds up to 103 m/s (231mph)**
- **Snow depths up to 9.8m**

Table 1. Moisture content and insulating ability of insulation specimens taken in June 1991

Location	Moisture content (% of dry weight)	Insulating ability (% of dry value)
Upslope—top board	18	98
Upslope—bottom board	46	94
Midslope—top board	14	98
Midslope—bottom board	158	82
Downslope—top board	21	97
Downslope—bottom board	151	82

Introduction

XPS Types

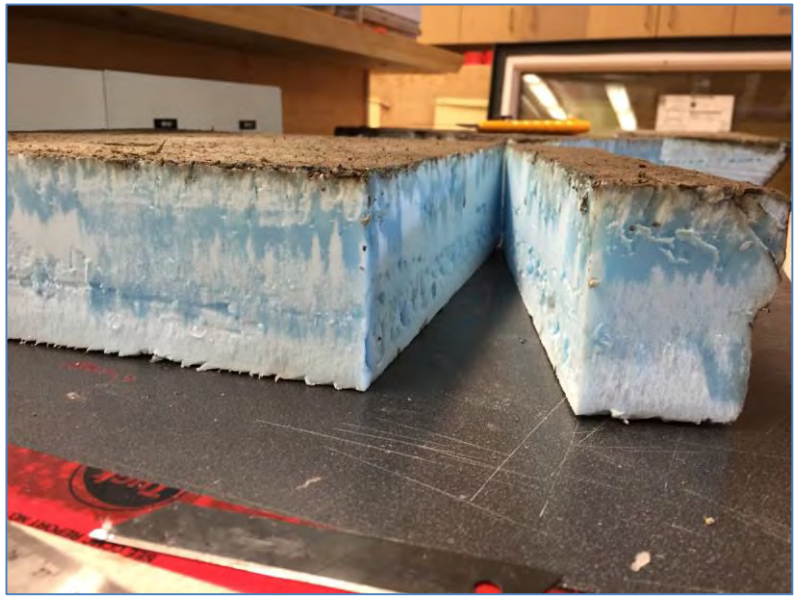
NOTE 7—Types XI, I, VIII, II, IX, XIV and XV are typically EPS insulation. Types XII, X, XIII, IV, VI, VII and V are typically XPS insulation.

Classification	Type XI	Type I	Type VIII	Type II	Type IX	Type XIV	Type XV	Type XII	Type X	Type XIII	Type IV	Type VI	Type VII	Type V
Compressive resistance at yield or 10 % deformation, whichever occurs first (with skins intact), min, psi (kPa)	5.0 (35)	10.0 (69)	13.0 (90)	15.0 (104)	25.0 (173)	40.0 (276)	60.0 (414)	15.0 (104)	15.0 (104)	20.0 (138)	25.0 (173)	40.0 (276)	60.0 (414)	100.0 (690)
Thermal resistance of 1.00-in. (25.4-mm) thickness, min, F·ft^2·h/Btu (K·m^2/W) Mean temperature: 75 ± 2°F (24 ± 1°C)	3.1 (0.55)	3.6 (0.63)	3.8 (0.67)	4.0 (0.70)	4.2 (0.74)	4.2 (0.74)	4.3 (0.76)	4.6 (0.81)	5.0 (0.88)	3.9 (0.68)	5.0 (0.88)	5.0 (0.88)	5.0 (0.88)	5.0 (0.88)
Flexural strength, min, psi (kPa)	10 (70)	25 (173)	30 (208)	35 (240)	50 (345)	60 (414)	75 (517)	40 (276)	40 (276)	45 (310)	50 (345)	60 (414)	75 (517)	100 (690)
Water vapor permeance of 1.00-in. (25.4-mm) thickness (See Note 5.), max, perm (ng/Pa·s·m^2)	5.0 (287)	5.0 (287)	3.5 (201)	3.5 (201)	2.5 (143)	2.5 (143)	2.5 (143)	1.5 (86)	1.5 (86)	2.0 (114)	1.5 (86)	1.1 (63)	1.1 (63)	1.1 (63)
Water absorption by total immersion, max, volume %	4.0	4.0	3.0	3.0	2.0	2.0	2.0	0.3	0.3	1.0	0.3	0.3	0.3	0.3
Dimensional stability (change in dimensions), max,%	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Oxygen index, min, volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Density, min, lb/ft^3 (kg/m^3)	0.70 (12)	0.90 (15)	1.15 (18)	1.35 (22)	1.80 (29)	2.40 (38)	3.00 (48)	1.20 (19)	1.30 (21)	1.60 (26)	1.45 (23)	1.80 (29)	2.20 (35)	3.00 (48)

Introduction

Objective

- **Access existing PMR sites,**
- **Obtain XPS samples from PMR assemblies,**
- **Assess levels of moisture accumulation and associated change in thermal resistance**
- **Obtain site specific information**
  - **years in service,**
  - **assembly details,**
  - **sample locations on roof.**



Sampling

Site Data

Site Location	Installation Date	Years in Service	Assembly details	Roof Area
Calgary	2003	11	50mm pavers, 25mm Sand, 50 mm insulation (XPS), Membrane, concrete 0% slope	N/A
Vancouver	1993	22	70mm precast concrete paver, filter fabric, 38mm insulation (XPS) [*24.8kg/m^3], liquid applied urethane membrane, structural decking with 2% slope	N/A
Vancouver	1988	27	100 mm cast-in-place (CIP) concrete, 38mm insulation (XPS), 1.6mm rubberized asphalt/polyethylene waterproofing membrane, concrete deck with 1.5% slope	50
Burnaby	1985	30	90mm CIP Concrete, 38mm insulation (XPS), EPDM Membrane, concrete deck with 2% slope	25
Vancouver	1980	37	Bricks on bedding sand, filter fabric, 50mm insulation (XPS) [*32kg/m^3], 2-ply SBS Mod. Bit membrane	400
Vancouver	1989	28	Pavers on neoprene pedestals, filter fabric, 50mm insulation (XPS) [*32kg/m^3], rubberized asphalt HDPE membrane	3500

*DENSITY BASED ON XPS LABELING AND PRODUCT DATA SHEETS

Sampling

Site Data

Site Location	Installation Date	Years in Service	Assembly details	Roof Area
Burnaby	1985	32	Concrete Slab, 50mm insulation (XPS), Polyethylene slipsheet, 3-ply built-up roofing membrane with asphalt flood coat, concrete structure	1440
Vancouver	1985	32	Aggregate ballast, filter fabric, 50mm insulation (XPS), rubberized asphalt HDPE membrane	320
Vancouver	1979	3 8	Aggregate ballast, filter fabric, insulation (XPS) [**32kg/m^3], polyethylene slip sheet, rubberized asphalt HDPE membrane	156
Victoria	*???	30+	Aggregate ballast, filter fabric, 50mm insulation (XPS) [**32kg/m^3], waterproofing membrane	312
UBC	*???	30+	Aggregate ballast, 50mm insulation (XPS, built-up roofing (BUR) Membrane	336
UBC	*???	30+	50mm precast concrete pavers on pedestals, 100mm insulation (XPS), 2-ply SBS mod. bit membrane	45
U of C	*???	30+	50mm precast concrete pavers, 75mm insulation (XPS), TPO membrane	750

*INSTALLATION DATES TO BE CONFIRMED WITH ONGOING STUDY
**DENSITY BASED ON XPS LABELING AND PRODUCT DATA SHEETS

Sampling
Site Data

- **Types of Ballast**
  - **Stone aggregate,**
  - **2” concrete pavers on pedestals,**
  - **continuous concrete slab,**
  - **bedding sand and brick pavers,**
- **No waterproofing assemblies with drainage below the XPS,**
- **0.5 – 2% slope existing on 3 of sampled assemblies.**

Sampling
Site Data

Common Site Conditions:

- **Over conditioned space,**
- **No drainage below insulation,**
- **Climates:**
  - **West coast,**
  - **Canadian interior.**

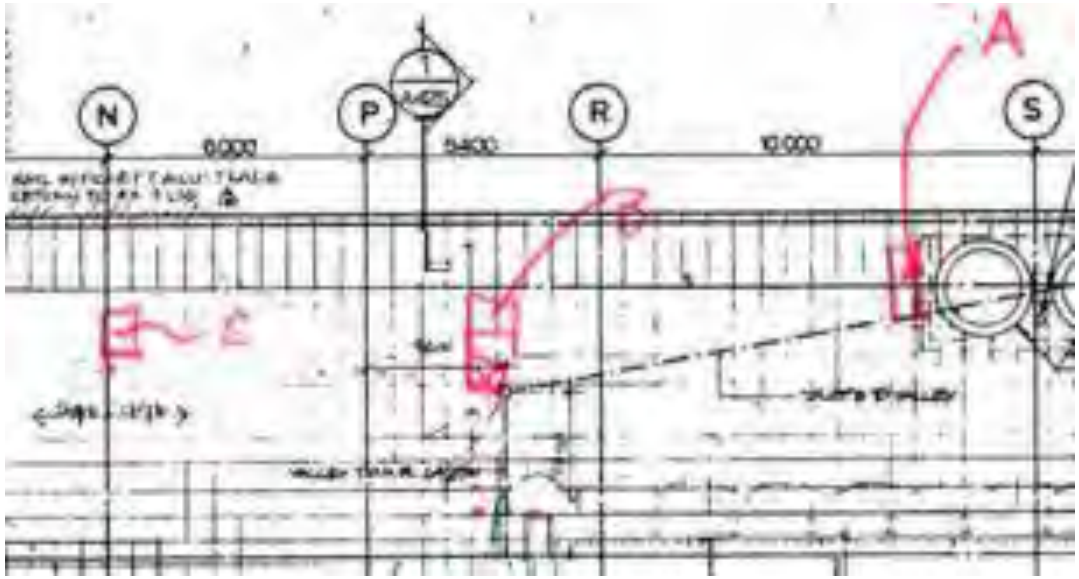
Sampling

Typical Locations

Qty. 3 full 2ft. X 4ft. Boards

3 typical locations:

- **Vertical Upturn (A)**
- **Drain (B)**
- **Field (C)**



Sampling

Procurement

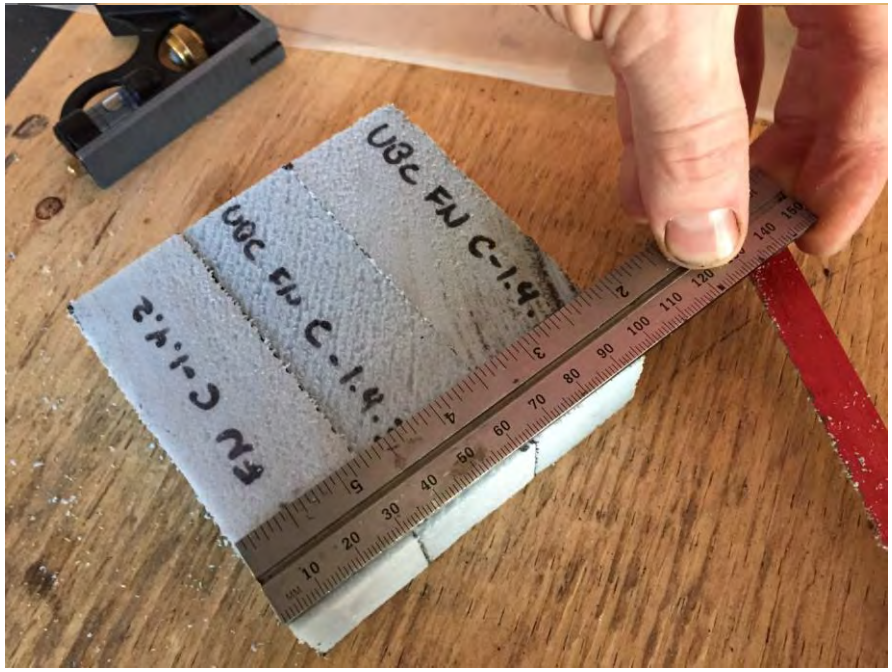
Local: **Wrap samples in 3mil, 42 Gal. bags, seal with poly tape**

Shipped: **Wrapped in aluminum foil and 3mil bags. Sealed with poly tape**

Sample Analysis

Preparation

- **Bulk cuts with table saw,**
- **Precision cuts with utility knife,**
- **From 1 – 2ft x 4ft. Board:**
  - **3 - 12” x 12” HFM,**
  - **9 – 4” x 1” density,**
  - **3 – 4” x 1” moisture.**



Sample Analysis

Moisture Content Measurements

- **Moisture Contents measure via precision balance (+/- 0.1 mg)**
- **Compared to dry mass**
  - **Convective Oven (set to 70°C, measured to ASTM C1498)**

Sample Analysis

Thermal Conductivity Measurement

- **Heat Flow Meter (NETZSCH)**
- **Q-Lab G.U.I.**
- **Settings per ASTM C518**

Mean temperature	24.0°C	75.2°F
Temperature difference	20.0°C	68.0°F
Upper temperature	34.0°C	93.2°F
Lower temperature	14.0°C	57.2°F

Test Results

Moisture Content

Sample Label	Roof Age	Dimensions (mm)			Volume (mm^3)	Weights (g)		Dry Density (kg/m^3)	Moisture Content by Volume	Moisture Content by Volume	Assembly Description
		Length	Width	Thickness		Wet	Oven Dry		(% of dry density)	(% of Vol)	
Samples from 2016 Study											
11-01	11	100	32	38	122770	94.4	3.13	26	30	74	50mm precast concrete pavers
11-02	11	99	29	36	103852	3.32	3.29	32	1	0.03	50mm precast concrete pavers
11-03	11	102	30	35	105839	35.0	3.08	29	11	30	50mm precast concrete pavers
11-04	11	100	29	37	108005	41.2	2.90	27	14	35	50mm precast concrete pavers
22-01	22	103	38	38	148112	57.9	4.73	32	12	36	70mm concrete brick paver, 2% Slope
22-02	22	101	38	37	142660	54.8	4.65	33	12	35	70mm concrete brick paver, 2% Slope
22-03	22	102	38	37	143808	53.7	4.76	33	11	34	70mm concrete brick paver, 2% Slope
27-01	27	102	38	36	140805	39.8	5.81	41	7	24	100 mm CIP concrete, 1.5% slope
27-02	27	102	37	37	139810	40.8	5.73	41	7	25	101 mm CIP concrete, 1.5% slope
27-03	27	101	38	37	140392	16.4	5.80	41	3	8	102 mm CIP concrete, 1.5% slope
30-01	30	102	101	36	369051	137.0	15.5	42	9	33	90mm CIP Concrete, 2% slope
30-02	30	103	104	37	394432	156.9	16.5	42	10	36	90mm CIP Concrete, 2% slope
30-03	30	101	100	37	377024	136.9	16.1	43	9	32	90mm CIP Concrete, 2% slope
30-04	30	101	101	36	366323	162.1	15.5	42	10	0.4	90mm CIP Concrete, 2% slope
30-05	30	101	101	37	383625	177.2	16.6	43	11	0.4	90mm CIP Concrete, 2% slope

Test Results

Moisture Content

Sample Label	Roof Age	Dimensions (mm)			Volume (mm³)	Weights (g)		Dry Density (kg/m³)	Moisture Content by Volume	Moisture Content by Volume	Assembly Description
		Length	Width	Thickness		Wet	Oven Dry		(% of dry density)	(% of Vol)	
Samples from Ongoing Study											
1130WP - Drain	37	299	299	52	4621417	1598	N/A	36	9	31	Interlocking brick pavers on bedding sand
1130WP - Field		297	298	51	4497959	1586	N/A	36	10	32	Interlocking brick pavers on bedding sand
1130WP - Upturn		298	298	52	4616534	752	N/A	36	4	13	Interlocking brick pavers on bedding sand
777D - Drain	28	302	304	51	4672223	285	N/A	36	2	2	Pavers on pedestals, 2% slope
777D - Field		300	302	52	4689241	608	N/A	36	4	9	Pavers on pedestals, 2% slope
777D - Upturn		301	301	51	4598002	452	N/A	36	3	6	Pavers on pedestals, 2% slope
THQ - Drain	32	300	301	50	4477674	160	N/A	36	1	0	Aggregate ballast
THQ - Field		300	301	52	4712513	160	N/A	36	1	0	Aggregate ballast
THQ - Upturn		301	302	52	4676739	1791	N/A	36	11	35	Concrete slab
885WG - Drain	32	301	303	49	4428861	172	N/A	36	1	0	Aggregate ballast
885WG - Field		301	299	49	4443644	178	N/A	36	1	0	Aggregate ballast
885WG - Upturn		304	303	51	4691578	161	N/A	36	1	0	Aggregate ballast
1100M - Drain	38	298	298	51	4549284	285	N/A	36	2	3	Aggregate ballast
1100M - Field		303	302	53	4831844	608	N/A	36	3	9	Aggregate ballast
1100M - Upturn		305	305	52	4849394	452	N/A	36	3	6	Aggregate ballast
WHI - Drain	30+	301	302	53	4772760	127	N/A	36	1	0	Aggregate ballast
WHI - Field		301	302	53	4767772	129	N/A	36	1	0	Aggregate ballast
WHI - Upturn		301	302	52	4728229	390	N/A	36	2	5	Aggregate ballast
RC - Drain	30+	301	301	50	4519427	514	N/A	36	3	8	Aggregate ballast
RC - Field		302	301	51	4630206	582	N/A	36	3	9	Aggregate ballast
RC - Upturn		302	302	51	4683256	617	N/A	36	4	10	Aggregate ballast
FN - Drain	30+	301	302	103	9297746	582	N/A	36	2	3	50mm precast concrete pavers on pedestals
FN - Field		298	299	102	9104617	514	N/A	36	2	2	50mm precast concrete pavers on pedestals
FN - Upturn		305	306	102	9519405	617	N/A	36	2	3	50mm precast concrete pavers on pedestals
ENA - Upturn		301	302	76	6884208	2879	N/A	36	11	38	50mm precast concrete pavers

Test Results

Thermal Conductivity

Sample ID	Roof Age (Years)	Thickness (mm)	Dry density (kg/m3)	Thermal Conductivity (W/(m.K))	Thermal Resistance (m2.K/W)	Thermal Conductivity ratio (K_sample/K_ref)	Thermal Resistance ratio (TRR) (R_sample/R_ref)
Samples from 2016 Study							
11-01	11	39	26	0.1752	0.219	6.07	0.16
11-02	11	37	32	0.0295	1.22	1.02	0.94
11-03	11	37	29	0.056	0.741	1.94	0.57
11-04	11	38	27	0.053	0.732	1.84	0.55
22-01	22	37	32	0.0702	0.528	2.43	0.41
22-02	22	37	33	0.0669	0.447	2.32	0.35
22-03	22	34	33	0.0633	0.536	2.19	0.45
27-01	27	38	41	0.0556	0.68	1.93	0.51
27-02	27	38	41	0.0629	0.605	2.18	0.45
27-03	27	38	41	0.0323	1.177	1.12	0.89
30-01	30	39	42	0.0864	0.446	2.99	0.33
30-02	30	38	42	0.0948	0.402	3.28	0.3
30-03	30	39	43	0.0782	0.492	2.71	0.36

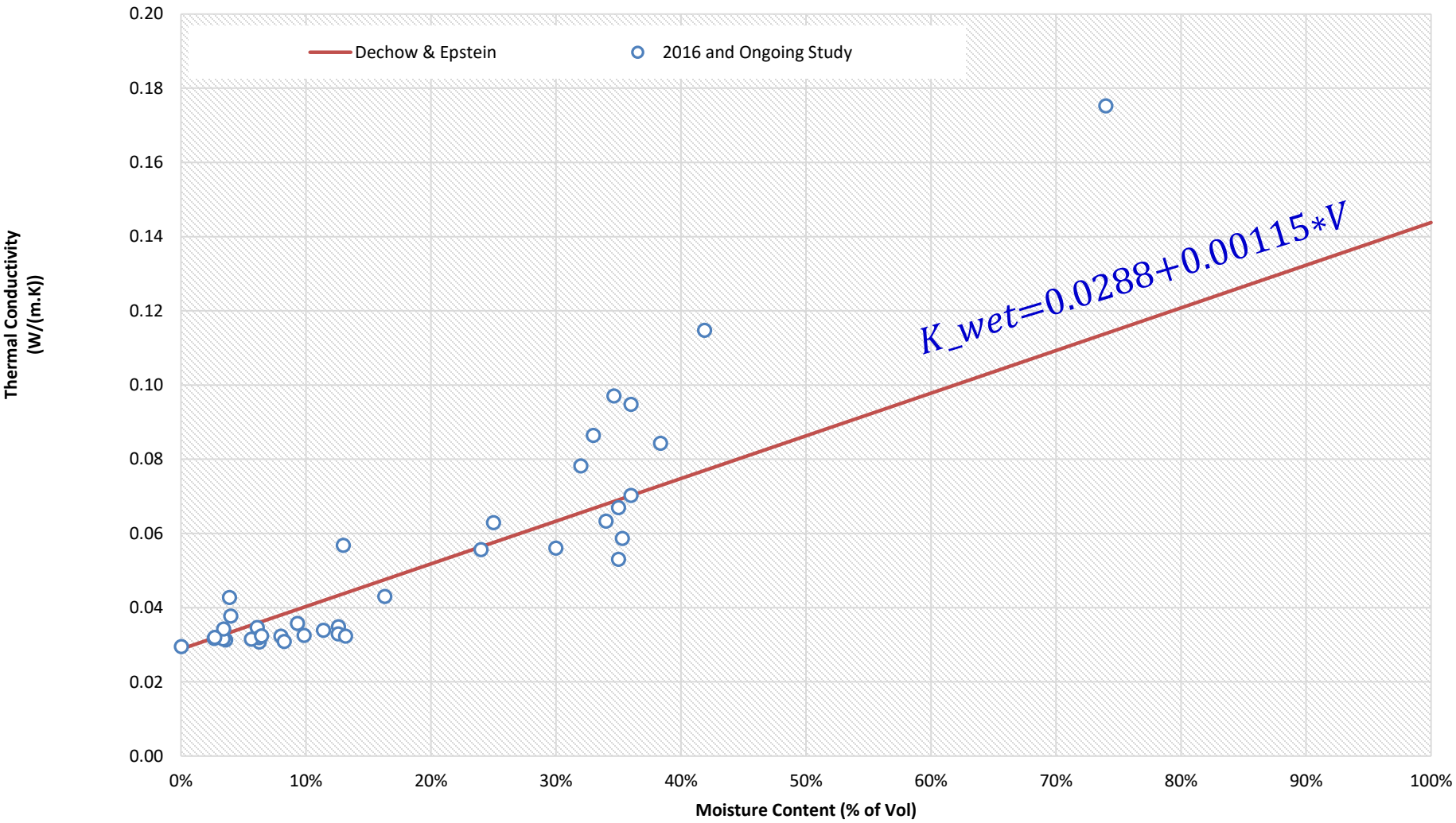
Test Results

Thermal Conducvitiy

Sample ID	Roof Age (Years)	Thickness (mm)	Dry density (kg/m3)	Thermal Conductivity (W/(m.K))	Thermal Resistance (m2.K/W)	Thermal Conductivity ratio (K_sample/K_ref)	Thermal Resistance ratio (TRR) (R_sample/R_ref)
Samples from Ongoing Study							
1130WP - Drain	37	52	32	0.10	0.53	3.37	0.30
1130WP - Field	37	51	32	0.06	0.87	2.04	0.49
1130WP - Upturn	37	52	32	0.04	1.21	1.49	0.67
777D - Drain	28	51	32	0.03	1.47	1.20	0.83
777D - Field	28	52	32	0.06	0.91	1.97	0.51
777D - Upturn	28	51	32	0.03	1.56	1.13	0.89
THQ - Drain	32	50	32	0.03	1.59	1.09	0.92
THQ - Field	32	52	32	0.03	1.66	1.09	0.91
THQ - Upturn	32	52	32	0.08	0.61	2.93	0.34
885WG - Drain	32	49	32	0.04	1.14	1.48	0.67
885WG - Field	32	49	32	0.04	1.31	1.31	0.76
885WG - Upturn	32	51	32	0.03	1.49	1.19	0.84
1100M - Drain	38	51	32	0.03	1.66	1.07	0.94
1100M - Field	38	53	32	0.03	1.51	1.21	0.83
1100M - Upturn	38	52	32	0.04	1.46	1.24	0.81
WHI - Drain	*30+	53	32	0.03	1.66	1.10	0.91
WHI - Field	*30+	53	32	0.03	1.65	1.11	0.90
WHI - Upturn	*30+	52	32	0.03	1.69	1.07	0.93
RC - Drain	*30+	50	32	0.03	1.47	1.18	0.85
RC - Field	*30+	51	32	0.03	1.55	1.14	0.87
RC - Upturn	*30+	51	32	0.03	1.59	1.12	0.89

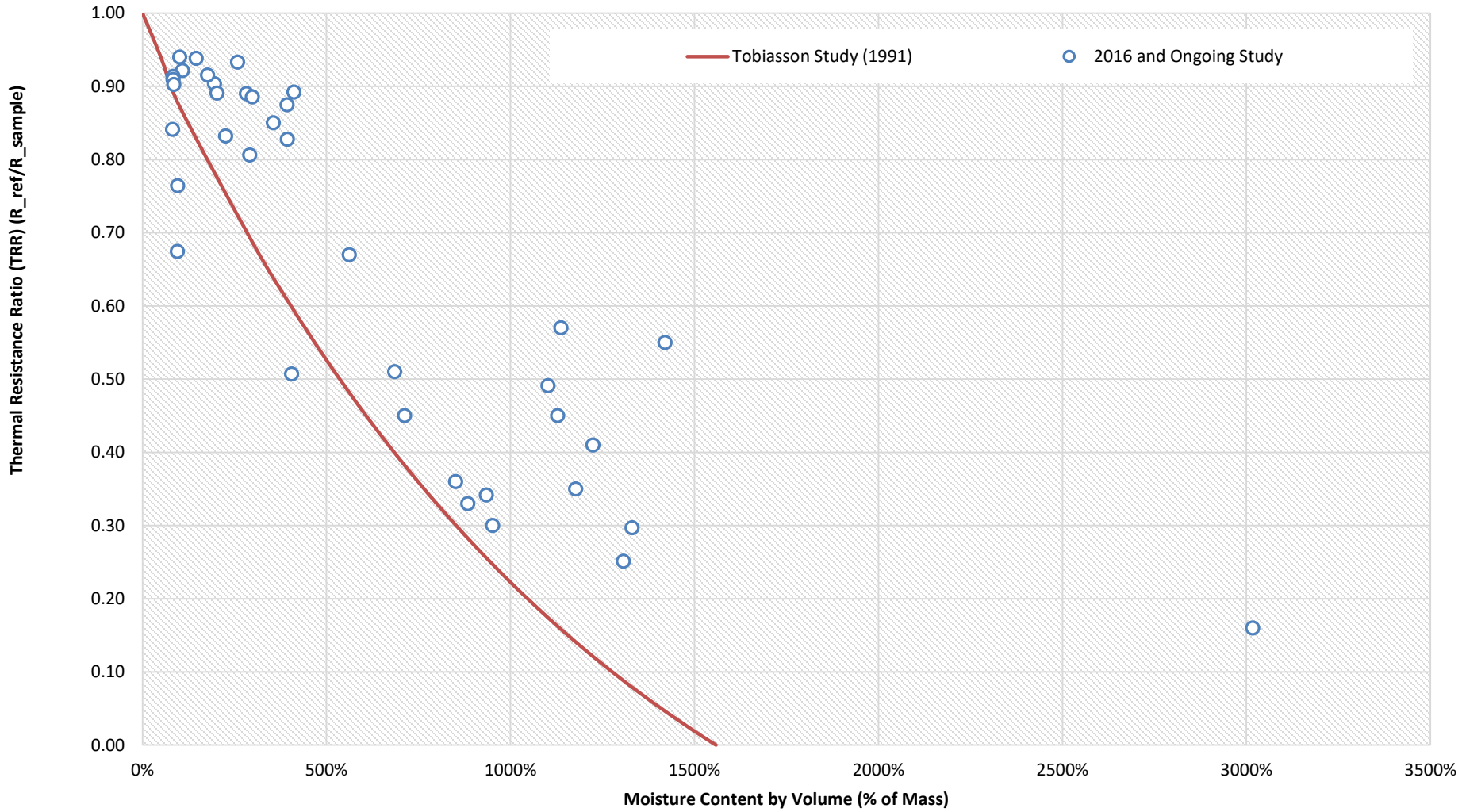
Test Results

Thermal Conductivity vs %MC



Test Results

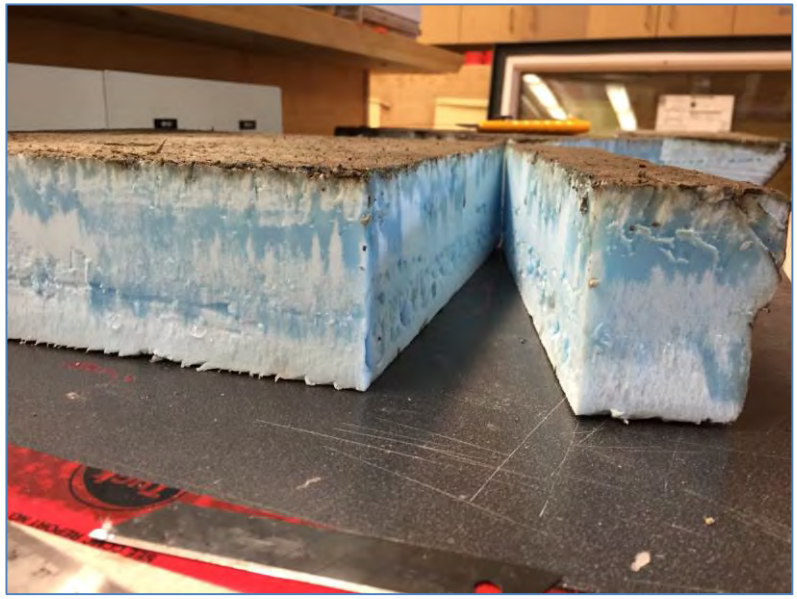
TRR vs %MC



Observations

Sample Prep

- **Water beading from exposed surfaces,**
- **Non-uniform water distribution,**
- **Sponge-like properties**



Observations

Site Sample Variations

Dry:Wet weight ratio of 1:17

Thermal Conductivity Range: 0.0295 - 0.1752 W/(m.K)

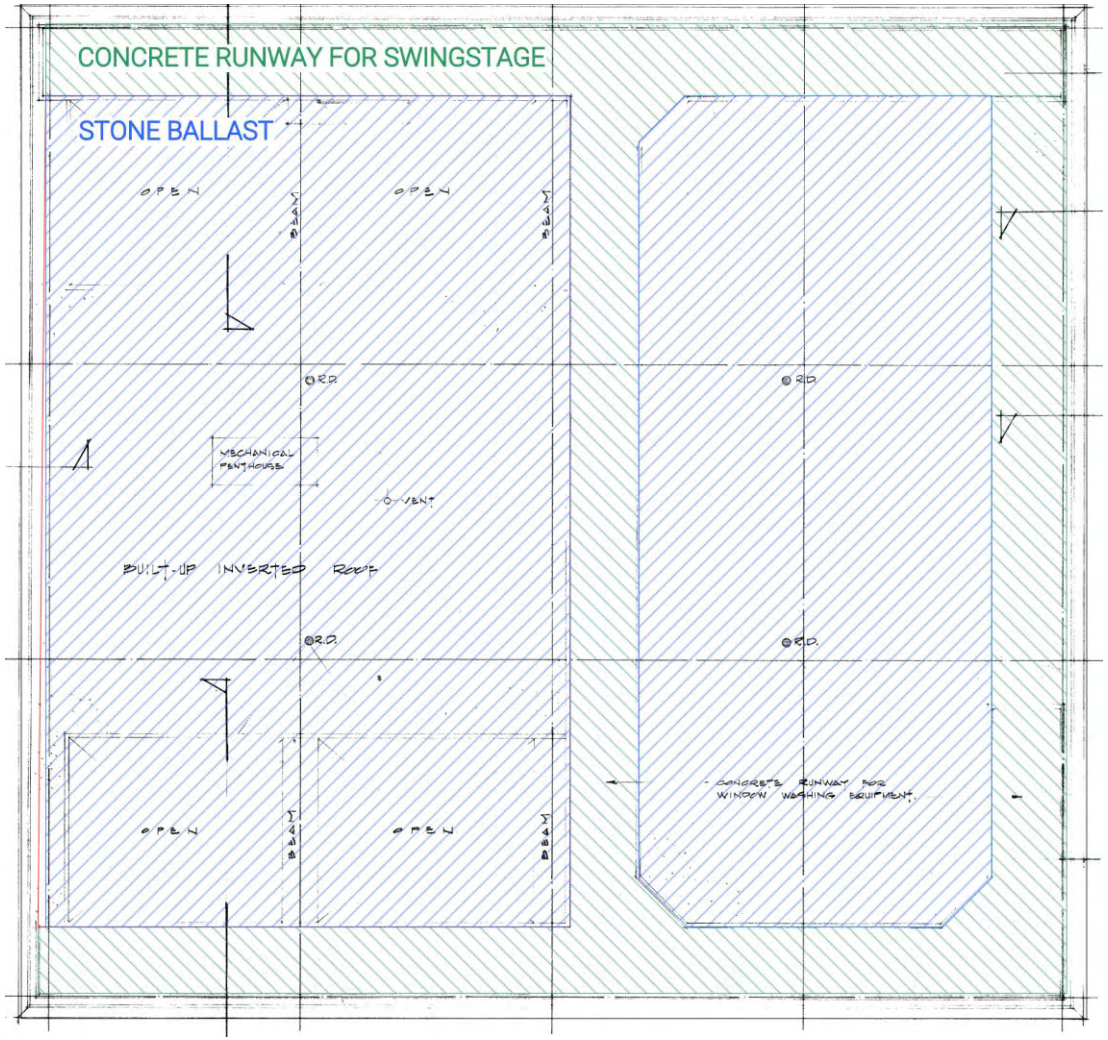
Observations

Ballast

Concrete

vs

Stone Aggregate

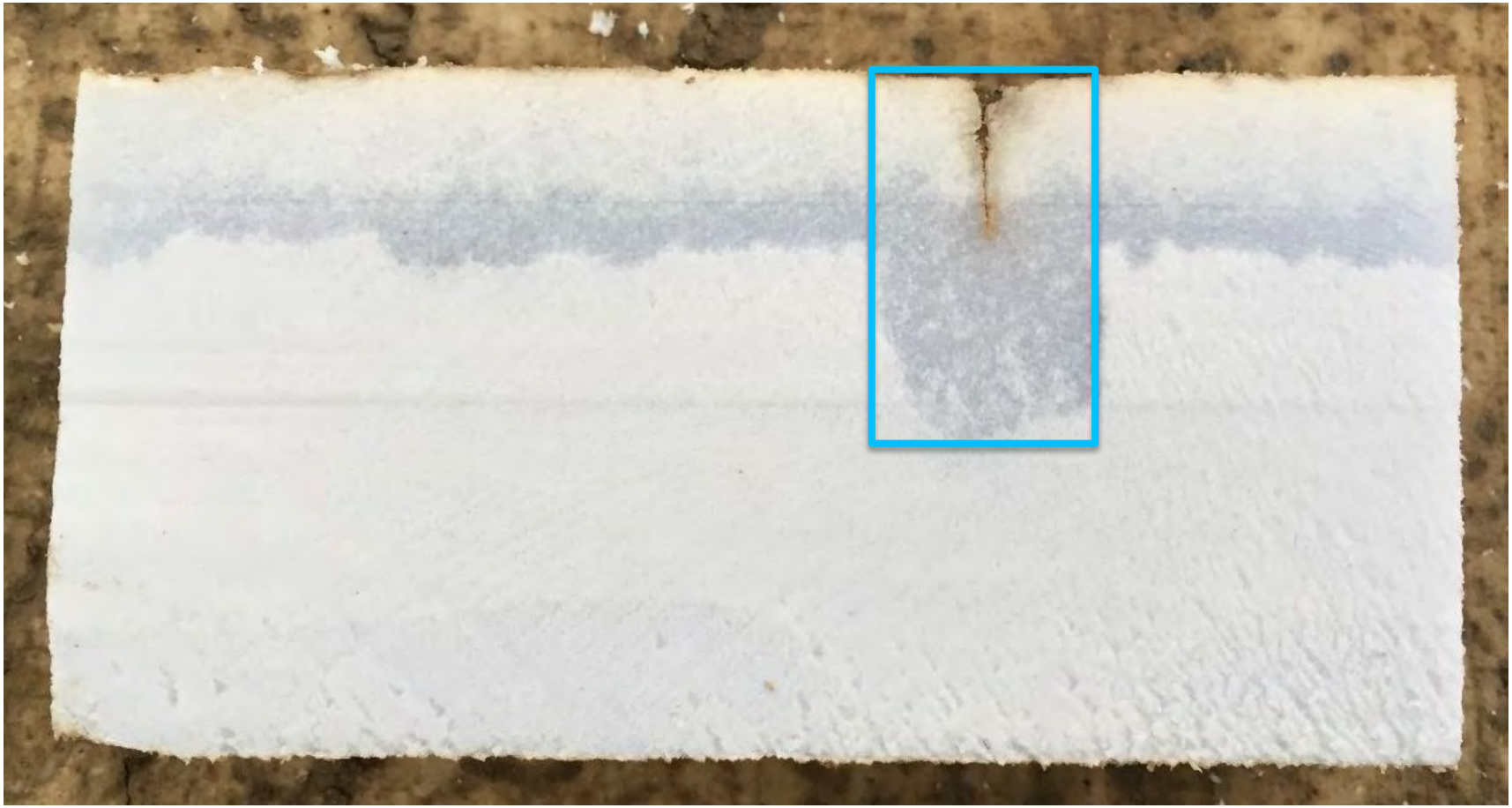


Observations

Surface Damage

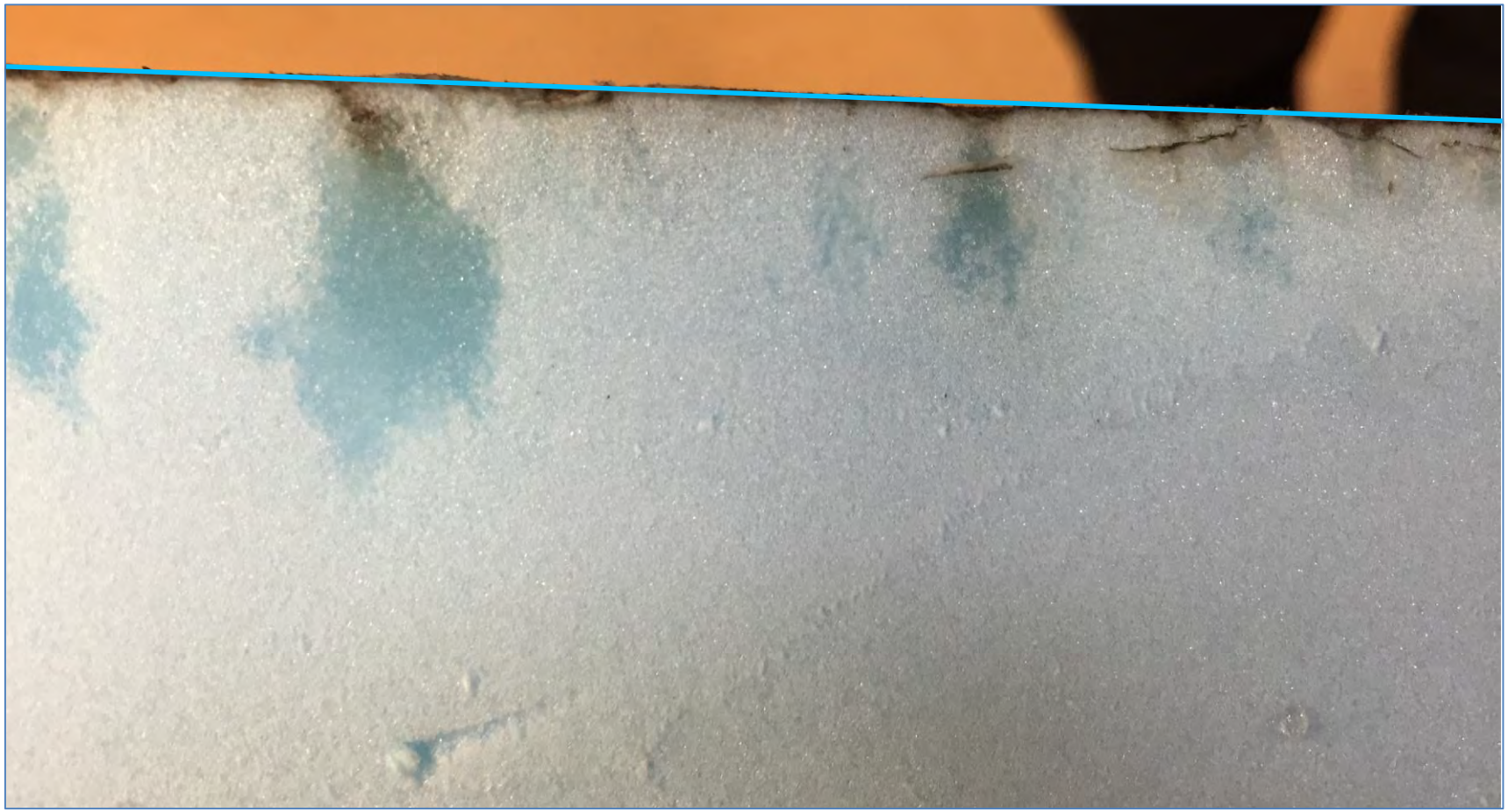
Observations

Surface Damage



Observations

Surface Damage



Conclusion

- **Increase in density due to moisture absorption,**
- **Thermal performance characteristics degraded with moisture,**
- **Variable same-site results,**
- **Highest moisture content from 11 year old sample**
- **Surface damage a factor in moisture absorption.**
- **Higher moisture in assemblies with continuous layers above,**
- **30+ year old samples retained over 80% rated R-value**

Thank you