Appendix B

Monitoring of Wall Drying Characteristics in a Temperate Rain Forest Environment

By Marquam George

Introduction

The cool and wet climate of Southeast Alaska is often at odds with the building code. Building codes require that the moisture content of the construction lumber be no greater than 19% at the time of installation in a building. Routinely the moisture content of the framing lumber used to construct buildings in this maritime region exceeds 19%.

Problems from excessive built-in or stored moisture within a building enclosure include twisting and warping of framing materials, nail popping, paint peeling, reduced thermal performance of fibrous insulation, structural deterioration from mold and mildew and concerns with reduced indoor air quality.

Additionally, the building code requires an interior vapor retarder of less than 1.0 permeance to be installed. This combined with an exterior mean relative humidity above 80% raises the question, “How well do the typically constructed walls dry in this environment?”

Methodology

The University of Alaska Southeast Construction Technology program at the Juneau campus undertook this task by conducting an assessment of typically constructed walls for moisture retention, durability and energy efficiency. This project was funded by the Cold Climate Housing Research Center, and supported by a consortium including: the United States Department of Energy-Building America, Alaska State Homebuilding Association, Alaska Housing Finance Corporation, and the Fannie Mae Corporation.

The Cold Climate Housing Research Center (CCHRC) constructed and shipped a mobile test lab to Juneau in March 2003. This mobile test lab has the capability to monitor nine different walls under the same interior conditions. The Southeast Advisory Committee of the CCHRC selected the wall assemblies for assessment. This committee represented regional builders, housing authorities, code officials and the engineering and architectural design community. The wall assemblies were tested concurrently within the test lab attempting to create identical drying potential for all the panels. Walls with similar attributes were installed and oriented within the lab so exterior exposures would be comparable.

Objectives

Evaluate the drying potential and effect of commonly constructed wall assemblies in a controlled environment. Specifically:

1. Identify the variation in drying times of selected wall panels, wetted to 30% moisture content, without re-wetting.

2. Identify wall assemblies that dry faster.

3. Identify if the tested walls dry mold-free.

Mobile Test Lab and Environment

A nine-panel test lab with exterior dimensions of 24' long by 8'-6" wide and 8'-10" high was constructed by Bullet Proof Trailers of North Pole, Alaska for CCHRC. The trailer was constructed similar to a structural insulated panel system using 4-inch polyurethane foam sandwiched between 0.5 inch exterior grade plywood and covered with an acrylic coating. The lab has four test bays on each of the two long sides of the trailer, and one wall alone on the end of the trailer. Each test wall module is 45 inches wide by 89 inches high. The test lab interior was conditioned to simulate a normal living environment. Temperature for the interior of the lab was controlled with electric resistance heaters to achieve 70°F, an intermittent ventilation cycle of 20 minutes per hour was used with a heat recovery ventilator and to simulate occupant moisture release, a room humidifier was installed and set to maintain 50% relative humidity.

To determine the drying effect of the individual wall modules, each wall was periodically opened and the moisture content at the bottom wall plate, common stud and exterior sheathing was recorded. The walls were built and installed in the mobile test lab in April 2003. Moisture measurements and visual inspections were recorded in September 2003, January 2004, and June 2004.
The tested walls were constructed at 16 inch on-center framing with the structural sheathing installed vertical to each panel. The top and sides of each wall assembly were sealed with a cross-laminated vapor retarder, even if the wall did not include a plastic vapor retarder in the test. This was done to ensure that wall drying would be directed through the structural sheathing or the vapor retarder/gypsum side of the wall. If the wall was not to have a plastic vapor retarder, this side and top retarder would be sealed to either the framing or the gypsum board. The bottom plate of each wall was left unsealed and installed in a sheet metal pan flashing over the plywood floor. Each test bay was thermally isolated from adjoining test bays with 1" of extruded polystyrene insulation around each opening.

All walls had one non-airtight 2" x 4" outlet box installed in the center stud bay 16 inches up from the bottom of the wall. Additionally each wall had a 1/2" hole for the remote sensor cable of the data logger.

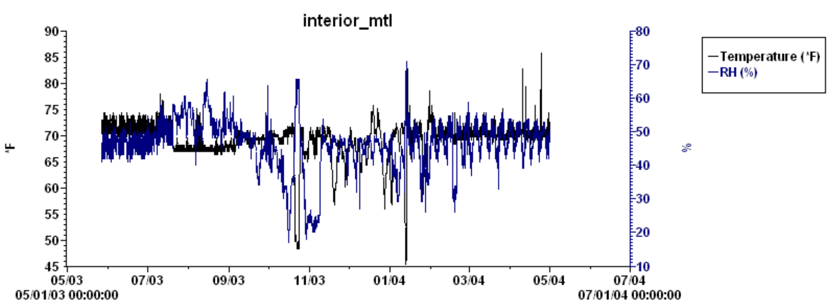
Each test wall had one HOBO® LCD Temperature/Relative Humidity data logger (Model # H14-001) installed in the center stud bay, secured to the inside of the structural sheathing 18 inches below the top plate. Moisture measurements were taken using a GE Protimeter Survey Master moisture meter.

Framing lumber was hem-fir supplied as a normal yard order from a local supplier. Prior to constructing the walls a container was fabricated to submerge all stud framing materials to reach fiber saturation.

The initial moisture content for all common framing materials was 30% and the structural sheathing was 10%.

Exterior Environment
May 2003 – May 2004

Month	Average Temp	Rainfall	Snowfall
05_2003	49.6	3.84	0
06_2003	54.6	5.5	0
07_2003	59.1	5.2	0
08_2003	56.8	6.87	0
09_2003	50.06	17.57	0
10_2003	46.1	7.53	0
11_2003	33.6	9.09	10.3
12_2003	34	11.73	20.3
01_2004	28.1	7.56	11.8
02_2004	36.5	5.58	4.4
03_2004	36.7	10.04	10.8
04_2004	43	7.39	0
05_2004	54.1	0.69	0



Average Interior Environment
May 2003 – May 2004
Temperature – 69.31°F
Relative Humidity – 46.22%

Test Panels

Wall 1

vinyl siding
Tyvek
OSB
2X6 framing
R-21 batt insulation
vapor retarder
gypsum
latex paint

Wall 2

bevel cedar siding
Tyvek
OSB
2X6 framing
R-21 batt insulation
vapor retarder
gypsum
latex paint

Wall 3

bevel cedar siding
0.5” vented furring strips
30 lb. asphalt felt
plywood
2X6 framing
R-21 batt insulation
vapor retarder
gypsum & latex paint

Wall 4

concrete board lap siding
#15 asphalt felt
plywood
2X6
R-21 batt insulation
vapor retarder
gypsum
latex paint

Wall 5

vinyl siding
3” EPS
bituthane
OSB
2X4
gypsum

Wall 6

vinyl siding
Tyvek
OSB
2X6
caulk & seal airtight drywall approach
gypsum
vapor barrier primer

Wall 7

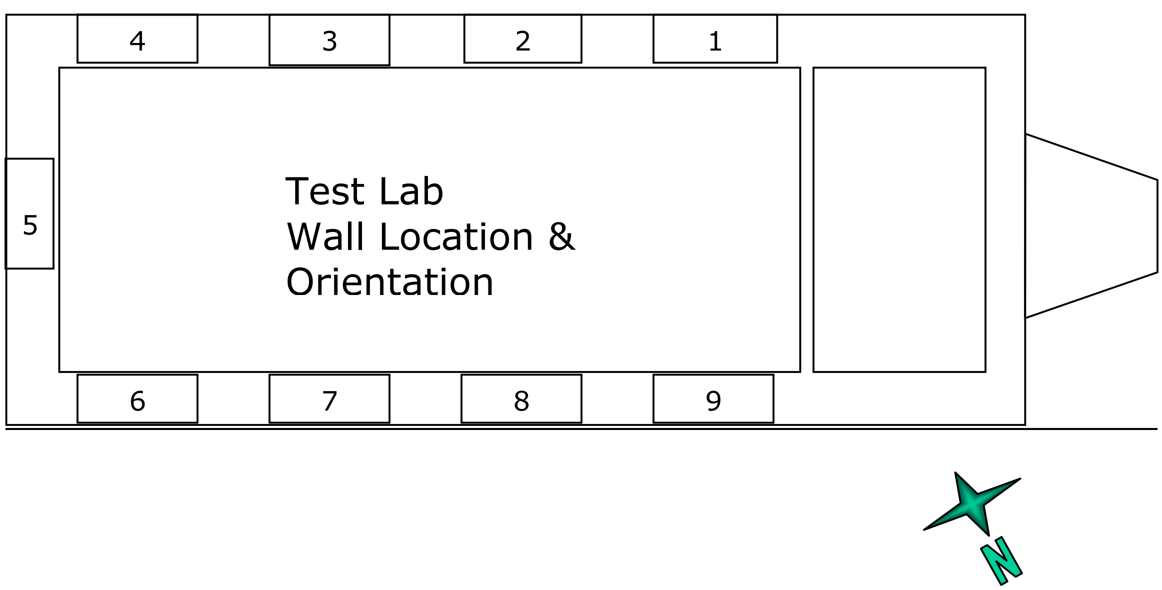
T1-11 siding
Tyvek
2X6
R-21 batt insulation
vapor retarder
gypsum
latex paint

Wall 8

Vinyl siding
Tyvek
OSB
2X6
3” spray - polyurethane foam
gypsum
vapor barrier primer

Wall 9

Bevel cedar siding
2-layers #15 asphalt felt
plywood
2X6
R-21 fiberglass batt
vapor retarder
gypsum



Wall Assembly Components and Materials

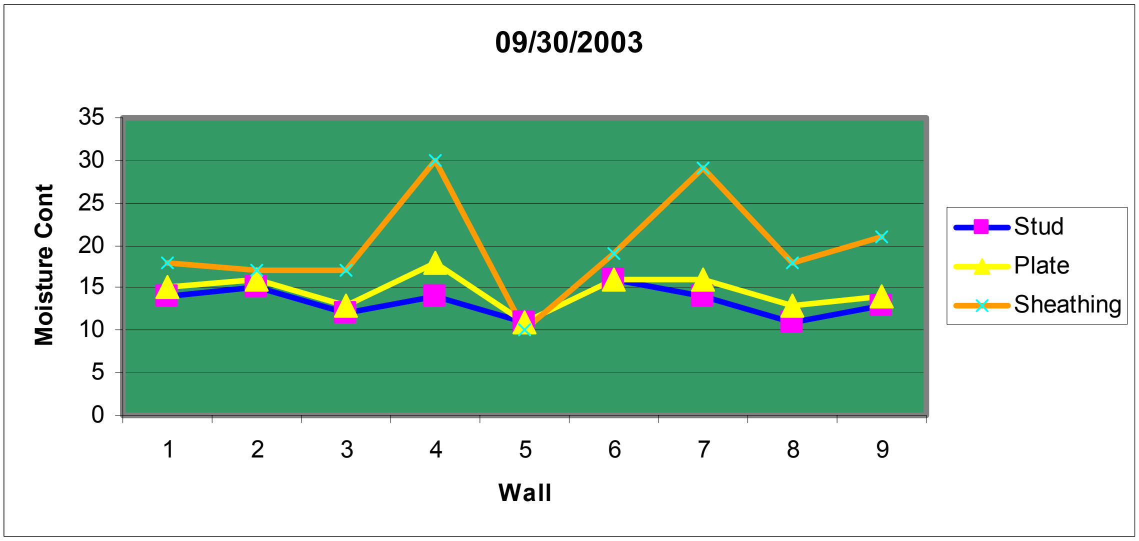
Component	Wall 1	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Wall 9
2 x 4 Framing					X				
2 x 6 Framing	X	X	X	X		X	X	X	X
Plywood Sheathing			X	X					X
OSB Sheathing	X	X			X	X		X	
Vinyl Siding	X				X	X		X	
Cedar Lap Siding		X							X
Concrete Lap Siding				X					
T-1-11 Siding/Sheathing							X		
Tyvek	X	X				X	X	X	
#15 Asphalt Felt				X					X*
30 lb. Asphalt Felt			X						
Furred, 1/2” Vent Space			X						
R-21 Batt Insulation	X	X	X	X		X	X		X
Spray Foam Insulation								X	
EPS Foam					X*				
Bituthane Membrane					X				
Plastic Vapor Retarder	X	X	X	X			X		X
Gypsum Board	X			X	X	X	X	X	X
Caulked Drywall (Airtight Drywall Approach)						X			
Vapor Barrier Primer						X		X	
Interior Latex Paint	X	X	X	X	X		X		

Wall 5 tested using 2-layers of 1 ½ inch EPS sheathing.
Wall 8 insulated with an average lift of 3 ½ inches of spray polyurethane foam.
Wall 9 tested using 2-layers of #15 asphalt felt.

Results

The moisture content of the common wall studs and bottom plates in every assembly except wall #7 reached a moisture content of 19% or less by the end of the test period. It appears there was initially a speedy release of the stored moisture within the test panels from the measurements taken after four months of testing (09/30/2003). This liberation of stored moisture was transferred to the structural sheathing in every wall with a vapor retarder installed in the traditional manner behind the gypsum board.

The installation of the structural sheathing parallel to the wall framing members might have created a handicap of the built-in moisture being removed from the wall assemblies. Canada Housing and Mortgage Corporation have evaluated the effectiveness of drying ports for enhanced vapor diffusion in wall assemblies. Their studies showed that OSB sheathed walls with holes or drying ports had lower moisture content and increased drying, while plywood sheathed walls with holes or drying ports showed little difference.



Moisture Content Measurements of 09/30/2003

Wall	Stud	Plate	Sheathing
1	14	15	18
2	15	16	17
3	12	13	17
4	14	18	30
5	11	11	10
6	16	16	19
7	14	16	29
8	11	13	18
9	13	14	21

The drying trend of the framing members and the increased moisture content of the sheathing amplified as the test continued into the winter season. The moisture content of the sheathing reached its highest measured moisture levels during the January moisture recording. Comparison of the absolute humidity levels between the interior of the test lab, the interior of the wall cavities, and the exterior environment indicated that a significant outward vapor drive was occurring during that time.

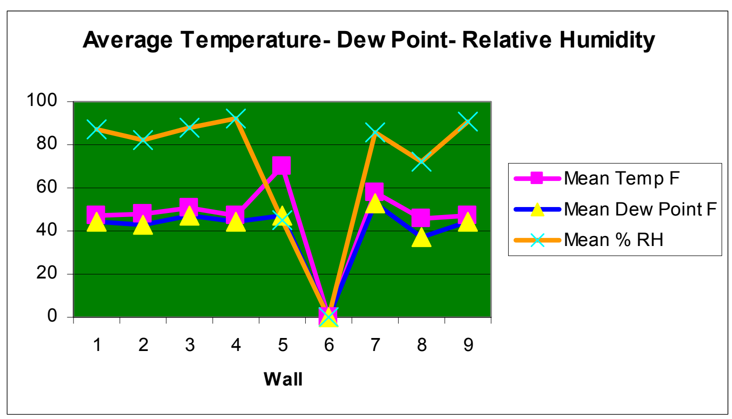
Absolute Humidity g/m³ Comparisons of 12/21/2003

MTL Interior	Wall 1	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Wall 9	MTL Exterior
8.77	6.14	6.11	7.25	6.37	7.51	7.02	6.24	5.21	6.27	5.44
8.77	6.48	6.45	7.64	6.73	7.67	7.41	6.41	5.36	6.62	5.55
8.97	6.66	6.37	7.64	6.73	7.84	7.41	6.41	5.51	6.62	5.53
8.97	6.48	6.37	7.74	6.73	7.67	7.21	6.41	5.36	6.62	5.6
8.96	6.48	6.37	8.03	6.55	7.67	7.21	6.41	5.36	6.62	5.69
8.97	6.66	6.55	8.03	6.73	7.67	7.41	6.59	5.66	6.81	5.94
8.96	7.03	6.91	8.88	7.17	7.51	7.81	6.95	6.05	7.18	6.31
8.96	7.41	7.09	9.33	7.55	7.63	8.01	7.14	6.37	7.29	6.39
9.16	7.41	7.28	9.33	7.55	7.63	8.22	7.33	6.37	7.49	6.52

While measurements showed drying, the drying tolerance of commonly constructed assemblies appears to be less than forgiving. The temperature and relative humidity swing within the wall cavities could pose a question of long term durability of a chosen wall. Nearly half of the walls were nearing condensation conditions at the sheathing. While this study did not incorporate any window or door openings, these penetrations should only increase the likelihood of wetter conditions at the sheathing.

Average Wall Cavity Dew Point Temperature and Relative Humidity
05/01/2003 – 06/01/2004

Wall	Ave Temp F	Ave DP Temp F	Ave RH
1	47	44	87
2	48	43	82
3	51	47	88
4	47	44	92
5	70	47	45
6	0	0	0
7	58	53	86
8	46	37	72
9	47	44	91



*Wall #6 data removed due to logger failure from excessive condensation. Data logger failed 01/16/2004.

Fundamentals of moisture and structural failures have been studied and discussed for years. Structural failures due to decay of wood, while rare, have occurred. Ideally the monthly surface relative humidity of wood shouldn't stay above 80% for long periods. Perhaps the typical cavity temperature of below 50°F is just enough to balance the high relative humidity in the walls. The coldest surfaces within a wall might well be a metal fastener, nail plates or a building component. Depending on the steel, corrosion can occur from high relative humidity and most certainly be increased with liquid water from elsewhere.

Of the nine walls tested, both foam insulated wall systems out performed walls filled with fiberglass batt insulation. To go from near condensing sheathing temperatures to greater fault forgiving was measurable.

During the winter measurement and inspection, it was noted that the fiberglass batts in the stud cavities ranged from slightly damp to wet on the sheathing side of the insulation. This dampness or wetness was not evident during the final inspection, all batt insulation felt dry to the touch.

Measured moisture content of both the framing members and the sheathing was consistently greater at the bottom of the walls. This was perhaps the result of the bottom plate wicking moisture from the pan flashing and becoming a more prevailing force than convection in a small cavity. Despite the moisture measurements, the mold growth in the affected cavities was more extensive at the upper portion of the wall. Mold growth was obvious in walls, 3, 4, 7, and 9.

Some fungal growth should be expected. Depending on the environment conditions and wood species, surface mold is possible at 16% moisture content. The value of the equilibrium moisture content varies with both humidity and temperature; it is affected most by humidity. The equilibrium moisture content (EMC) of wood exposed to the average outdoor atmosphere in Juneau should be 16.31%. Based on tables from the United States Department of Agriculture, Forest Products Laboratory, Southeast Alaska would experience the lowest EMC during April, May and June, while the highest would be from September through December historically. The EMC for Anchorage would be 13.12% and for Fairbanks 11.78% for comparison.

The struggle of complying with the building code and ensuring durability was most difficult with walls 4 and 9. Both of these assemblies averaged above 90% RH and 47°F during the test period. At 90% RH and an ambient temperature of 50 degrees or less, the equilibrium moisture content would exceed 20%.

Table 1—Dependence of equilibrium moisture content (EMC) of wood on relative humidity (RH) and temperature

Temperature (°F (°C))	5% RH	10% RH	15% RH	20% RH	25% RH	30% RH	35% RH	40% RH	45% RH	50% RH	55% RH	60% RH	65% RH	70% RH	75% RH	80% RH	85% RH	90% RH	95% RH
	EMC (%)																		
30 (−1.1)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
50 (10.0)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
70 (21.1)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
90 (32.2)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
110 (43.3)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
130 (54.4)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
150 (65.6)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4

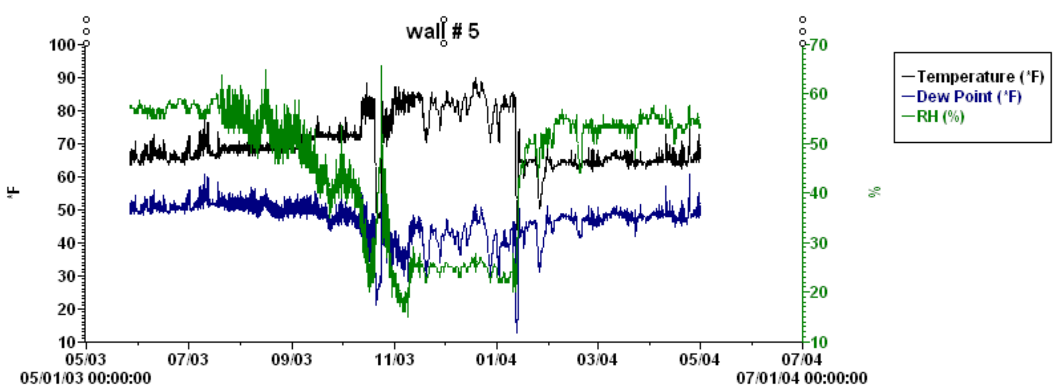
Courtesy: USDA Forest Products Laboratory
Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide

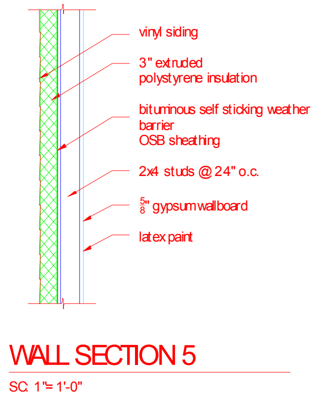
Averaging relative humidity in the fiberglass insulated walls over the year of study does not offer much improvement with the EMC. The average relative humidity and temperature of walls 1, 2, 3, 4, 7, and 9 would represent moisture content near 19%, again limited forgiveness.

Of the nine walls, the standout was most certainly wall #5. Without uncertainty it offered the most reliable approach to drying of built-in moisture.

Wall #5 is an adaptation CCHRC has been working on of the Pressure Equalized Rain Screen Insulated Structure Technique (PERSIST) from Canada. Clearly it makes sense that keeping a building warm and dry is a sensible technique.

Test Lab Wall #5





Wall #5

All insulation on the exterior on the structure.

Structural components stayed the same temperature and humidity as the ambient interior living conditions.

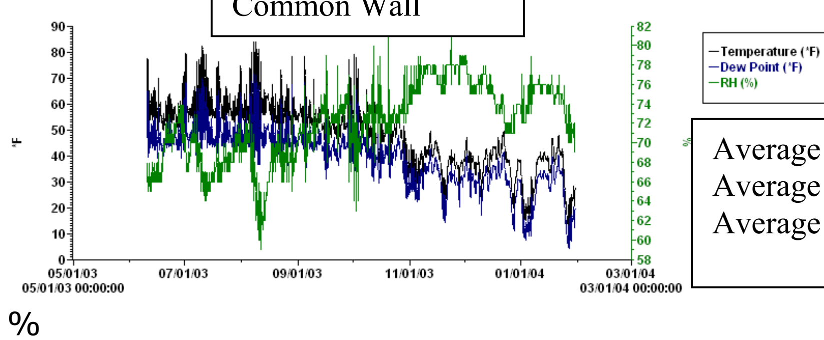
Average moisture content of framing and sheathing components : < 8%

Outside of the test lab monitoring occurred on two production houses in a Juneau subdivision during the test period. Situated on the same street with identical floor plans, orientation, and construction crew houses were constructed similar to test walls 1 and 5.

Common wall house: vinyl siding, Tyvek, plywood sheathing, 2X6 framing @ 24" o.c., R-21 fiberglass batt, 6 mil vapor retarder, gypsum, latex paint

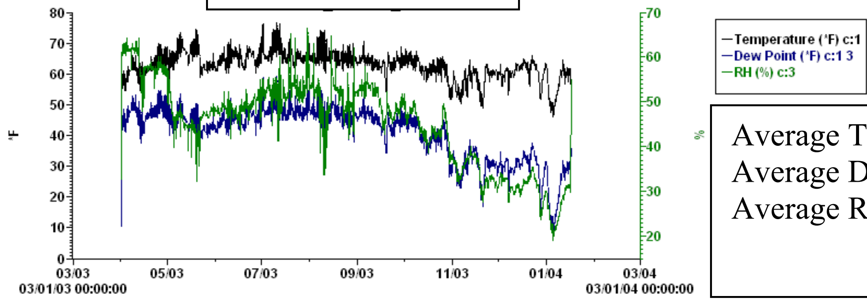
Outside insulation house: vinyl siding, Tyvek, 3" EPS foam sheathing, bituthane, plywood sheathing, 2x6 framing @ 24" o.c., gypsum, latex paint

Common Wall



Average Temp 48°F
Average Dew Point Temp 39°F
Average Relative Humidity 72%

Outside Insulation



Average Temp   64°F
Average Dew Point Temp   41°F
Average Relative Humidity   45%

Discussion

Over the course of the assessment, four walls experienced mold growth in their wall cavities. The pan flashing installed to keep water out of the trailer in turn trapped water under some of the test walls. Sill and threshold pan flashings should be sloped to the exterior to drain the moisture. Projecting the cladding past the deck or flashing is important. Some walls shed the rain onto the flashing which affected their continued moisture loading.

The placement of space heating elements in a small space is significant to ensure uniform surface conditions. This proved difficult in keeping a stable interior temperature without getting hot and cold areas during the testing. Risk of fire from heating elements should be scrutinized carefully.

High relative humidity and liquid water protection is crucial for survival and reliability of the data loggers. Testing protocols should plan for protection of the logger or sensor from failing in a hidden space.

Conclusions

Objective 1:
Moisture stored within the framing components of the tested walls decreased from the worst-case start up in all of the wall assemblies.

Moisture content in the structural sheathing increased in every wall except wall #5.

The measurements of the dimensional wood products taken over this study reflect a comparable drying trend in all of the normally constructed walls.

	Moisture Content 04/.2003		Moisture Content 06/2004	
	Framing	Sheathing	Framing	Sheathing
Wall 1	30	10	13	18
Wall 2	30	10	14	22
Wall 3	30	10	13	17
Wall 4	30	10	16	22
Wall 5	30	10	8	9
Wall 6	30	10	12	19
Wall 7	30	10	20	21
Wall 8	30	10	14	16
Wall 9	30	10	14	21

<u>Objective 2:</u>
Walls with fiberglass batt insulation dry slower than walls insulated with foam, either inside a stud cavity or completely on the exterior side of the enclosure. No wall performed better than the assembly which was insulated, air and vapor sealed on the exterior of the structure.

<u>Objective 3:</u>
The issue with wicking moisture from the pan flashing clouds this objective of mold growth. Four of the 9 walls showed mold growth after one year of service. It would be an unfair assessment because of this continued wetting from the wall placement and non-sloped pan flashing to label the affected walls more prone to conditions of mold growth than the unaffected assemblies.

Managing built-in moisture is dependent on the installed moisture content and ability of a material to safely store bound moisture until vapor transfer through air movement, and or diffusion can occur before the potential for condensation takes place.

The weather barrier and requisite flashing elements must provide surface draining, protection of capillary moisture and permeability of interior moisture.

Appendix C- DVD of BAA and REMOTE

Appendix D- CD of 4-hour Building America in Alaska