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Vancouver Field Exposure Facility: Phase III Exterior Insulation Analysis

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Abstract:

This report compares the moisture related performance of an exterior insulated wall to the performance of two other common construction methods, side-by-side. The data presented is a subset of experimental data from a multi-phase, multi-year research project at the Vancouver Field Exposure Test Facility led by Building Science Corporation (BSC) and Gauvin 2000 Construction Limited. The analysis includes results from normal operating conditions in a high stress exterior moisture environment (typical of the Pacific Northwest climate) and under intentional controlled wettings to the interior and exterior of the sheathing. There were no measured or observed moisture related durability concerns of the wood structural sheathing when 1.5" of exterior insulation was installed.

VANCOUVER FIELD EXPOSURE FACILITY

Phase III Exterior Insulation Analysis

February 17th, 2012

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1. Introduction

A multi-phase, multi-year research project at the Vancouver Field Exposure Test Facility near Vancouver, British Columbia project is being led by Building Science Corporation (BSC) and Gauvin 2000 Construction Limited.

A test hut was constructed in the fall of 2005, in Coquitlam, British Columbia that permits the side-by-side construction and comparison of seven 1.0m x 2.4m (38" x 96") test wall panels on each cardinal orientation (for a total of 28 wall test panels) and three 3.6m x 7.2m (12' x 24') roof panels on the north and south facing roof slopes (for a total of 6 roof test panels). All of the test panels are exposed to the same indoor conditions. The objective of the test hut was to determine the performance of historical, current and possible future wall assembly configurations under field conditions. Each wall or roof assembly is instrumented with different types of sensors to collect the desired assembly data (e.g. moisture content, temperature relative humidity, etc.) and is stored on a central data logger. Exterior weather data is also collected with a small meteorological tower mounted on the roof.

The third phase of testing started December 17, 2009 and was completed on November 3, 2011. The primary focus of this phase was to simulate wetting events directly against the exterior surface of the wood sheathing instead of the interior of the enclosure as previously tested, while simulating representative interior wintertime relative humidity levels. These test conditions are described in more detail below.

This report is divided into five main sections

- Section 1 explains the background of the research, the objective of the report, and how the analysis will be conducted
- Section 2 describes the experimental plan including the test facility, monitoring instrumentation and wetting systems.
- Section 3 is the data analysis from the moisture monitoring instrumentation system. The measured sheathing moisture contents are compared following intentional wetting events, and under normal operating conditions. Dew point analysis is always conducted to determine the moisture durability risk to the walls from potential air leakage condensation.
- Section 4 includes the visual observations from the test wall deconstruction conducted in November, 2011
- Section 5 is the conclusions based on the data analysis and observations.

Objective

This report will analyze the performance of a test wall on all four cardinal orientations constructed with 38mm (1.5") of exterior insulation installed over OSB, in particular, when there is liquid water trapped directly against the sheathing between the sheathing and the exterior XPS insulation. There are reported perceptions that installing low vapor permeance exterior insulation over wood sheathing will result in moisture related durability issues of the wood based structural sheathing. This perception is important to address because installing exterior insulation will become more prevalent with the changing building codes, and requirements for continuous insulation.

The performance results of the exterior insulated wall will be compared to the performance of two other common construction methods, side-by-side. The analysis will include the results from normal operating conditions (i.e. without intentionally adding water) in a high stress moisture environment (on the exterior that is typical of the Pacific Northwest climate), and under intentional controlled wettings to the interior and exterior of the sheathing.

Scope

This analysis will focus on the performance of an exterior insulated wood framed residential wall on all four cardinal orientations. The performance results of the exterior insulated wall will be compared to the performance of two other wall systems. The comparison wall systems are as follows:

1. Direct applied stucco with an interior 6 mil polyethylene vapor control layer
2. Ventilated stucco with an interior 6 mil polyethylene vapor control layer

This analysis is a small subset of all test hut data. Analyzing all of the test hut data and comparisons in one report would make the report too cumbersome to both write and read. There are further analysis reports expected similar to this one to analyze various performance differences based on other comparison criteria such as vapor control, cladding type, ventilation, sheathing membrane and interior conditions.

Approach

The analysis of these walls will be done by comparing several criteria. These criteria include:

- Sheathing wood moisture content measurements under normal operating conditions
- Sheathing wood moisture content measurements during the wetting and drying from an interior wetting event
- Sheathing wood moisture content measurements during the wetting and drying from an exterior wetting event
- Qualitative visual observations during deconstruction

2. Experimental Plan

The Test Facility

A 957 sq. ft. (29’x33’) field exposure test facility was designed and constructed in the Coquitlam suburb of lower mainland BC.

Figure 1 : Test hut location in Coquitlam, British Columbia

The facility permits the side-by-side construction and comparison of seven 1.0m x 2.4m (38" x 96") test wall panels on each cardinal orientation for a total of 28 wall test panels. This building permits all of the test panels to be exposed to the same interior conditions. The test panels were also exposed to the same exterior conditions relative to their orientation (i.e. all North walls can be expected to have the same exterior conditions).

The test facility was constructed on the roof of a low rise office building which is owned by Gauvin 2000 Construction. This location eliminated the need to buy or rent a large empty site (with free wind and solar approach) in the expensive real estate market of greater Vancouver. It also affords the test facility some protection from vandalism.

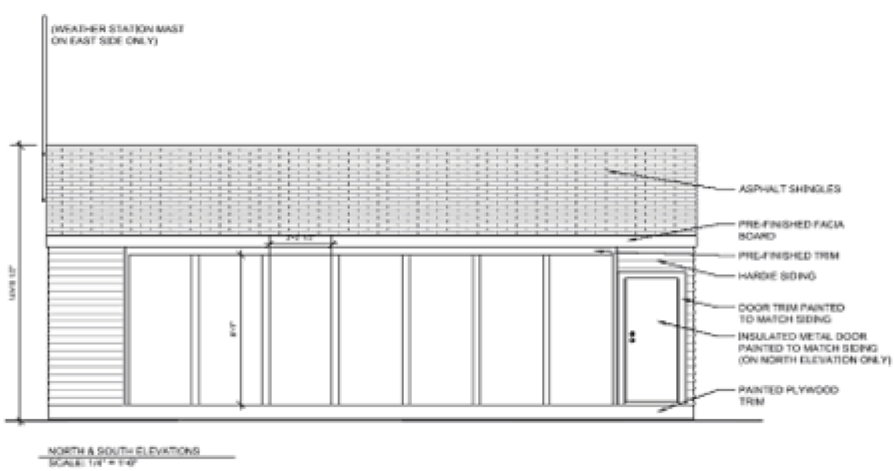


Figure 2 : Elevation drawing of Coquitlam test hut

Instrumentation

Each of the test walls was outfitted with a series of temperature, relative humidity (RH) and wood moisture content (MC) sensors. These sensors were continuously monitored and recorded throughout the testing period using a data acquisition system. Variations on a "typical" sensor package (illustrated Figure 5) were used for each test panel. Photographs of the individual sensors are shown below.

Moisture content pins were installed in the framing lumber and the sheathing (from the interior) in all wall systems (Figure 3). Wood moisture contents can be determined from electrical resistance of wood based on the Garrahan equation[1, 2]. These pins can be used to measure moisture content at any depth chosen because the pins are electrically insulated except for the tips. Measurements are most commonly taken at ¼" (6mm) tip depth. In this study, moisture contents were taken at two depths on the lower OSB near the wetting system. The wood moisture content pins were installed in combination with a temperature sensor in all locations. To correct the moisture content readings for temperature effects, a hole was drilled to the same depth as the moisture content pins and a temperature sensor was installed inside.

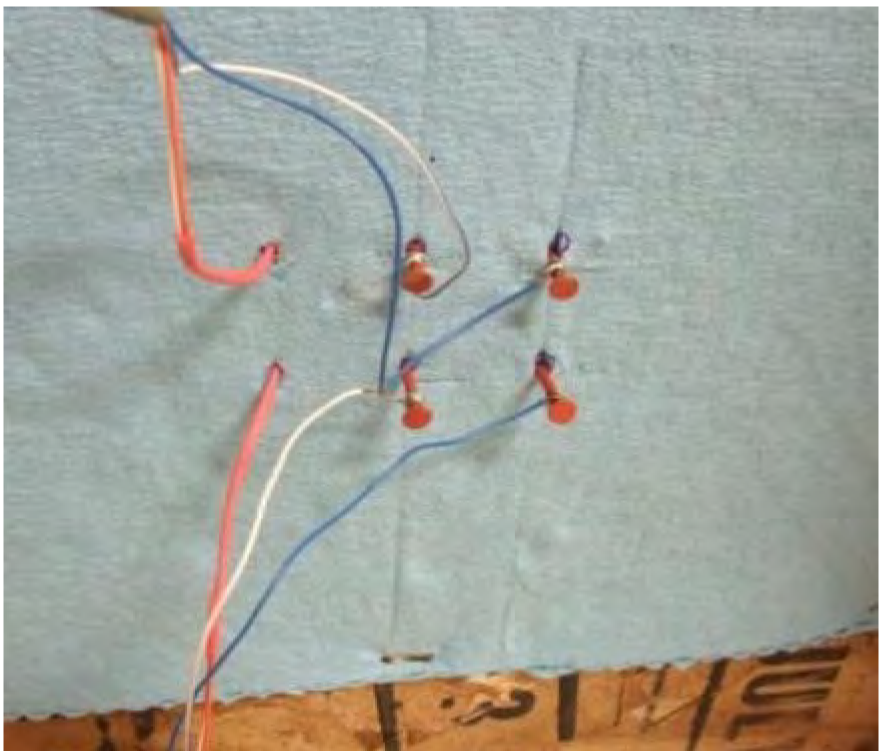


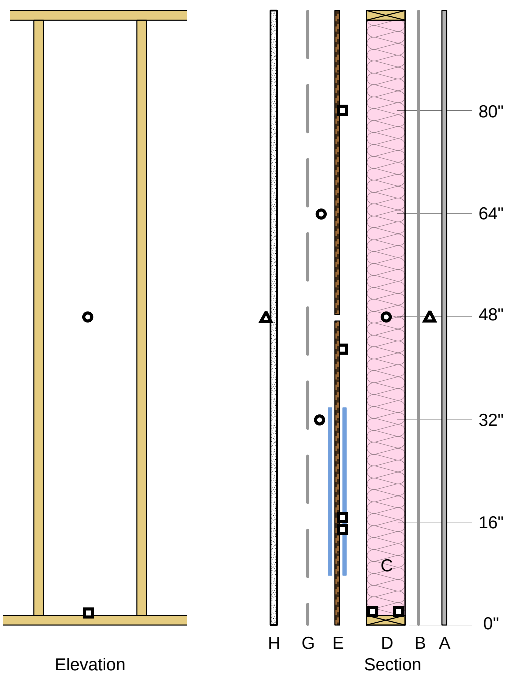
Figure 3 : Moisture content pins installed in plywood sheathing through the wetting system

Relative humidity sensors were installed in the middle of each stud cavity, and in the drainage space of each wall. The relative humidity sensor was always installed in combination with a temperature sensor, both of which are protected by a vapor permeable, water resistant cover (see Figure 4). Relative humidity and temperature sensors were installed at the midpoint of the stud space, between the drywall and the sheathing, as well as some drainage cavities.

[1] Garrahan, P. *Moisture meter correction factors.* Ottawa, Canada: Forintek Canada Corp. 1988

[2] Onysko, D. et al. *Field Measurements of Moisture in Building Materials and Assemblies: Pitfalls and Error Assessment*, Building Enclosure Science and Technology (BEST2) Conference. 2010

Figure 4 : Relative Humidity and temperature sensor installed in a stud bay (with moisture content pins installed below).



Assembly

Layer	Function	Description
A	Interior Finish	gypsum wall board
B	Vapor Control	poly
C	Studspace	fiberglass batt
D	Framing	2x6
E	Sheathing	½" OSB
F	Sheathing Membrane	#15 felt
G	Drainage Gap	none
H	Cladding	stucco

Sensor Package

Layer	Code	Location
A	taem	Interior finish, exterior face, 48"
C	r/tcnm	Studspace, interstitial, 48"
D	m/tdeb	Framing, exterior edge, bottom plate
D	m/tdib	Framing, interior edge, bottom plate
E	m/teem	Sheathing, exterior, 16"
E	m/teim	Sheathing, interior, 16"
E	m/tenm	Sheathing, interstitial, 48"
E	m/tenm	Sheathing, interstitial, 80"
G	r/tgnw	Drainage space, interstitial, 32"
G	r/tgne	Drainage space, interstitial, 64"
H	them	Cladding, exterior surface, 48"

○ Relative Humidity and Temperature Sensor Package
□ Moisture Content Pins and Temperature Sensor Package
△ Temperature Sensor
Moisture Content Wafer and Temperature Sensor Package
= Moisture Content Pins

Figure 5 : Typical Wall Construction and Sensor Configuration

One of the most significant advantages to using a test hut for analysis compared to instrumenting walls in existing buildings is that the experimenter can deliberately and easily stress the walls with high moisture loads, either in terms of vapor (eg. >=50% interior RH) or liquid water (e.g. intentional wetting systems) in test huts with removable/replaceable walls. In most cases, building owners are not interested in participating in research conducted on their enclosure walls by adding moisture. In addition, it is often difficult to determine the performance of a wall system without stressing the moisture tolerances of a wall to determine the comparative risk of certain construction techniques.

Enclosure Wetting Systems

A wetting apparatus was installed on both the interior and exterior of each of the test walls to allow a known amount of water to be injected at a controlled time and location. The wetting apparatus consisted of a storage media installed directly against the interior and exterior surface of the sheathing (Figure 6), with a perforated tube connecting each of the storage media to the interior of the test hut for access for water injections. This enables wetting to either the interior or exterior independently without opening and disturbing the wall system. The wetting system is designed to simulate a window leak, and can be used to help determine the drying potential of a wall system. A photograph of an exterior installed wetting apparatus is shown in Figure 6. On the analysis graphs the exterior wetting events are indicated by red vertical dashed lines and the interior wetting events are indicated by blue vertical dashed lines. When an intentional wetting event occurred repeatedly over multiple days, only one line is shown indicating the first wetting. There were five intentional wetting events as shown in Table 1. For each wetting event, 1.5 oz (45 mL) was injected twice a day for five days. This is a total of 15oz (~450mL) into the wetting apparatus directly against the sheathing. For the entire test period 60 oz (~1.8L) was injected against the exterior of the sheathing, and 15oz (~450mL) was injected against the interior surface of the sheathing.

Figure 6 : Exterior wetting apparatus

Table 1 : Intentional wetting event schedule and location for Phase III

	Location	Start Date	Amount
Wetting Event 1	Exterior	July 5, 2010	15oz (450 mL)
Wetting Event 2	Exterior	August 30, 2010	15oz (450 mL)
Wetting Event 3	Interior	Jan 19, 2011	15oz (450 mL)
Wetting Event 4	Exterior	May 9, 2011	15oz (450 mL)
Wetting Event 5	Exterior	August 9, 2011	15oz (450 mL)

Climate

To monitor the exterior weather conditions, a steel mast on the roof of the test facility supports a weather station at a height of 22 ft above the roof of the office building and 50 ft above ground level. The monitoring system continuously collects weather data including: temperature, relative humidity, wind speed and direction, rainfall, and solar energy. A photograph of the installed weather station is shown in Figure 7. It is important to have on-site weather information for comparison and correlation purposes with the data.

Figure 7 : Weather station on the roof of the Coquitlam Test Hut

The measured exterior temperature and relative humidity for the analysis period are shown in Figure 30 and Figure 31 respectively, further in the report.

Figure 8 shows the temperature and RH distribution in Vancouver based on the Environment Canada Canadian Climate Normals from 1971-2000. This distribution shows a relatively moderate climate with a significant portion of the year at high RH, especially at temperatures between zero and 12°C.

To add context to Figure 8, two other temperature and RH distributions are shown in Figure 9 and Figure 10 for Seattle, WA and Toronto, ON. Seattle has a very similar temperature and RH distribution to Vancouver, while Toronto is more evenly distributed through the temperature ranges with significantly less hours at high relative humidities.

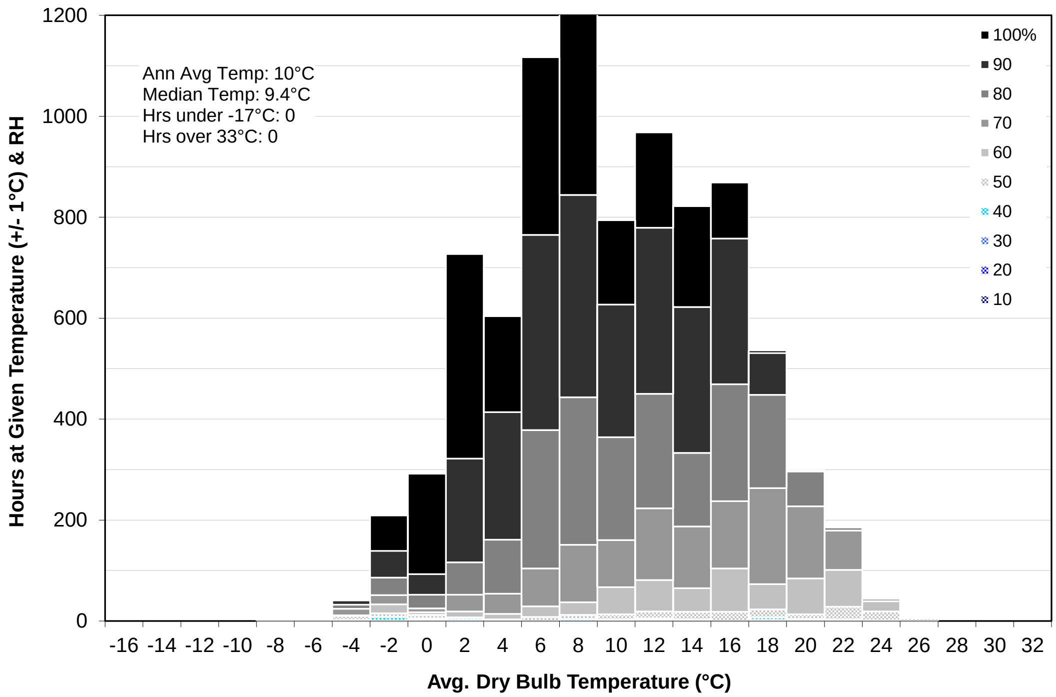


Figure 8 : Vancouver temperature and RH distribution (reproduced with permission by Balanced Solutions Inc 2005)

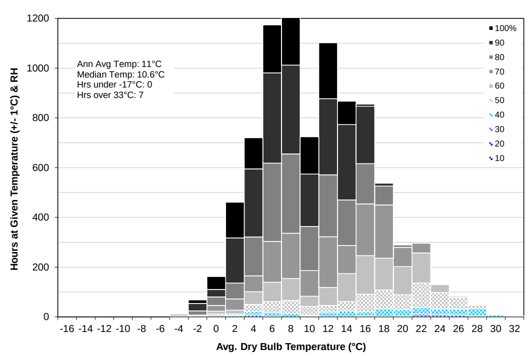


Figure 9 : Seattle, WA temperature and RH (Balanced Solutions Inc. 2005)

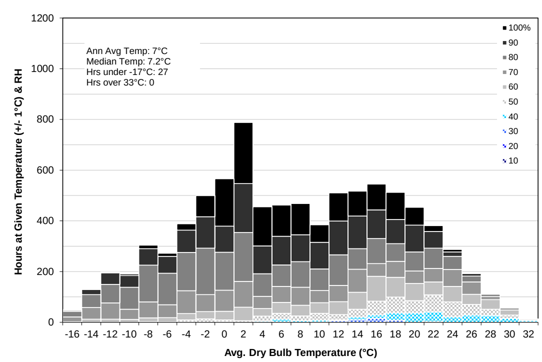


Figure 10 : Toronto, ON temperature and RH (Balanced Solutions Inc. 2005)

The driving rain rose in Figure 11 for Vancouver shows the amount of rain in mm/yr, and the direction of rainfall during the year. The driving rain is predominantly from the east in Vancouver, but this may vary slightly depending on the exact location. Total rainfall in Vancouver based on the 30 year average is 1155mm (46”). Again, to add context, the driving rain roses for Seattle, WA and Toronto, ON, are also included using the same scale. The driving rain for Seattle is similar to Vancouver both in shape and volume, but oriented from the south instead of the east. The driving rain rose for Toronto is significantly smaller, indicating much less total rain over the year. Seattle receives approximately 945mm (37”) and Toronto receives approximately 685mm (27”).

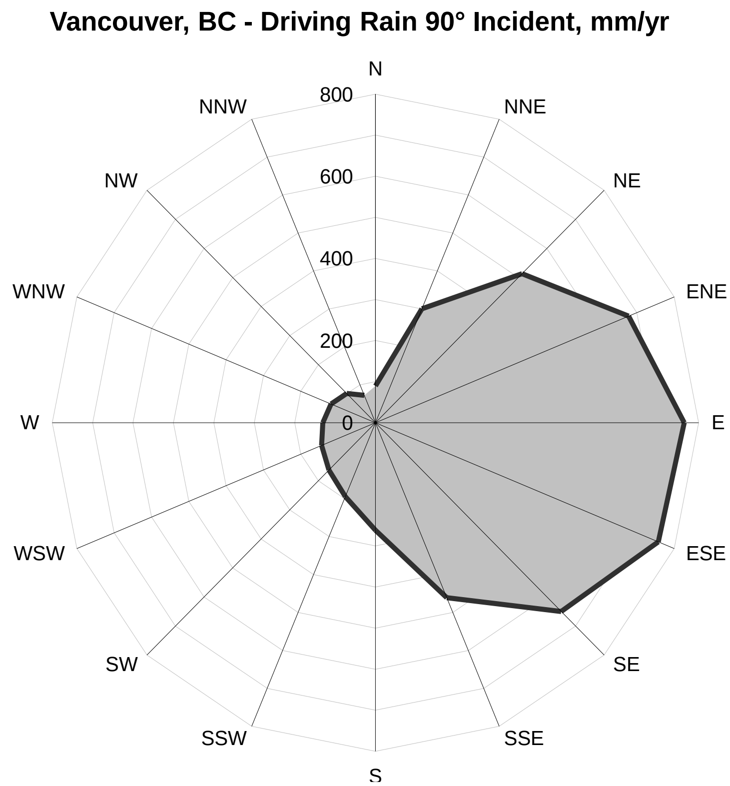


Figure 11 : Vancouver, BC driving rain rose

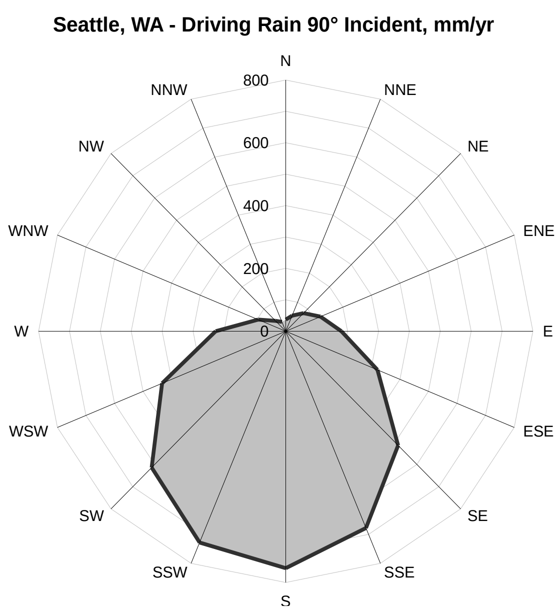


Figure 12 : Seattle, WA driving rain rose

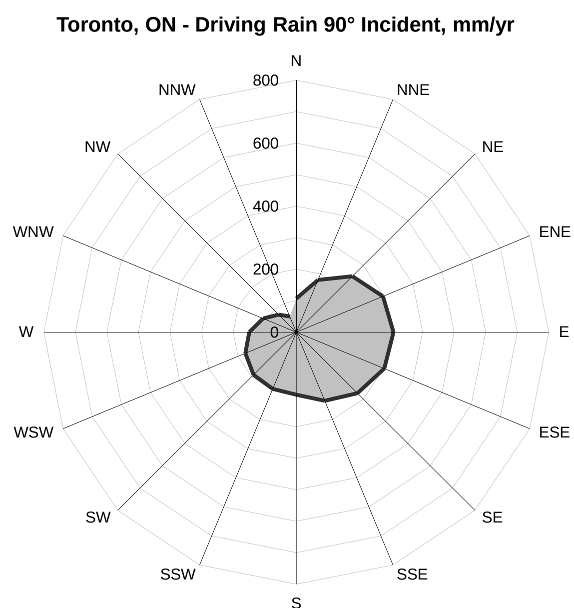


Figure 13 : Toronto, ON driving rain rose

3. Observations and Data Analysis

This report and the analysis contained herein is limited to observations and data collected during the monitoring period (December 17, 2009 to November 3, 2011) for the exterior insulated Wall 7 (Figure 14), traditional stucco Wall 2 (directly applied to building paper over wood sheathing) (Figure 16), as well as the ventilated stucco cladding Wall 5 East and West (Figure 15).

The original wall numbers (Wall 2, 5 and 7) were used in this report even though this is only an analysis subset of all of the test wall data, so that it will be less confusing to the reader when subsequent reports are written that may also have comparisons with the test walls included in this analysis.

As mentioned in the approach, there are several analysis criteria that will be used for comparing the performance of the test walls. These criteria include:

- Sheathing wood moisture content measurements under normal operating conditions
- Sheathing wood moisture content measurements during the wetting and drying from an interior wetting event
- Sheathing wood moisture content measurements during the wetting and drying from an exterior wetting event
- Qualitative visual observations during deconstruction

For this report, we will focus on the measured moisture content of the sheathing at the four measurement locations, the measured temperature at the interior of the sheathing, and the measured interior dew point.

The four sheathing moisture measurements are:

- 16" from the bottom of the bottom plate at the interior edge of the sheathing (MEIL)
- 16" from the bottom of the bottom plate at the exterior edge of the sheathing (MEEL)
- 48" from the bottom of the bottom plate at the centre of the sheathing (MENM)
- 80" from the bottom of the bottom plate at the centre of the sheathing (MENU)

The two moisture content sensors at 16" will be used to evaluate the performance following wetting events as they are installed in the sheathing in direct contact with the wetting system (Figure 3). The moisture content sensors at 48" and 80" from the bottom plate generally speaking are not affected by either the interior or exterior wetting events, and are a good indication of how the sheathing moisture content is affected by the construction assembly under normal operating conditions.

Sheathing moisture is used as the performance criteria because this is the first location where vapor diffusion condensation would occur in a cold climate during the heating season. In the case of these test walls, the most significant moisture risks were at the locations of the wetting systems, to compare the sheathing moisture performance under significant moisture stresses. Moisture contents of the sheathing will be used as a comparison rather than pass/fail criteria for the wall assembly. Generally, under normal conditions, the following criteria are used to assess the risk of various test wall assemblies.

1. Peak sheathing moisture content less than 20% - no mold growth, very little risk
2. Peak sheathing moisture content between 20% and 28% - potential for mold growth eventually, depending on frequency and length of wetting, and temperatures during wetting. This design can be successful but conservative assessments usually require corrective action be taken.
3. Peak sheathing moisture content >28% - moisture related problems are expected and this design is not recommended.

Predicted wood moisture contents of wood based sheathing are generally assessed with respect to relative risk as opposed to judged on a pass/fail criteria. The predicted moisture content should be kept in context and good scientific judgment is required to determine the moisture risk to the sheathing. For example, elevated wood moisture contents in the cold winter months when the wood substrate is on the cold side of the assembly are much safer from a mold growth perspective than similar moisture contents in the summer, when the temperatures are in the correct range for optimal mold growth. Also, high moisture content for a short period followed by drying is not necessarily risky, as wood framed structures are able to manage high moisture contents for short periods without exceeding the safe storage capacity of the assembly.

The safe storage capacity is the amount of moisture an assembly is able to manage without suffering any moisture related issues. The baseline wood moisture content is a factor in the safe storage capacity since the lower the wood moisture content is during normal operation (without wetting events), the more moisture the wood can handle before reaching any durability risks. If the measured wood moisture content is consistently higher, even if there are no moisture durability risks, there is less moisture buffering capacity in the wood before reaching moisture related durability risk levels.

The wall system performance will also be evaluated qualitatively based on the photos and observations from the test wall deconstruction on November 2 and 3, 2011.

Wall Assemblies

Wall 7 was installed at all four orientations. The construction of Wall 7 is shown in Figure 14. The performance of the exterior insulated wall is compared to two other walls for the purposes of this analysis. In this analysis, comparisons were only made between walls on the same orientation since they are typically subjected to the same exterior boundary conditions simultaneously. It is possible to conduct comparisons between walls on different orientations to see what effect the orientation has on the performance, but that was outside the scope of this report.

The first wall (East/West 5) is representative of a well-ventilated and drained stucco cladding typical of code approved current construction practices in Vancouver (Figure 15). This comparison was made to determine what performance differences exist between the code approved ventilated cladding, and the non-code approved, more energy efficient exterior insulated wall assembly.

The second wall for comparison (Wall 2) is a more commonly constructed wall (though no longer code approved in Vancouver) with direct applied ¾” stucco on one layer of 30 min building paper (Figure 16). This comparison was conducted to demonstrate any potential improvements in performance by including exterior insulation to the direct applied stucco wall assemblies.

Wall 2 was implicated in many “Leaky Condo” failures in the Vancouver area, and has been replaced by the rainscreen wall, Wall 5 in the Vancouver/Lower Mainland area. A wall comparison summary table is shown in Table 2.

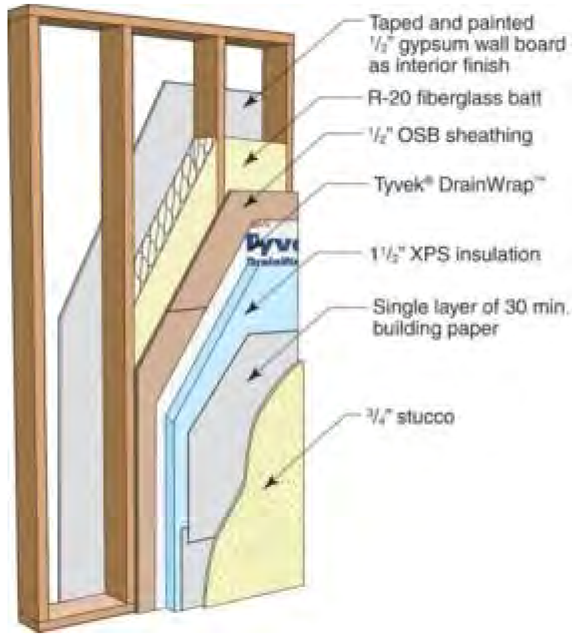


Figure 14 : Construction of Wall 7 on all four orientations

Wall 7, with exterior insulation has a Class III interior vapor control layer (latex paint on the drywall) as is allowed in the International Residential Code (IRC) Table R601.3.1 for climate zone 4C. The comparison walls use a polyethylene Class I vapor control layer on the interior of the framing as is required by code.

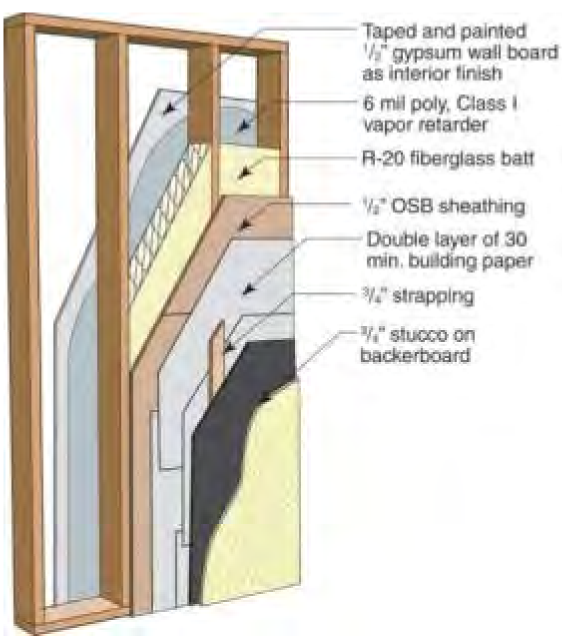


Figure 15 : Wall 5 on the East and West orientation

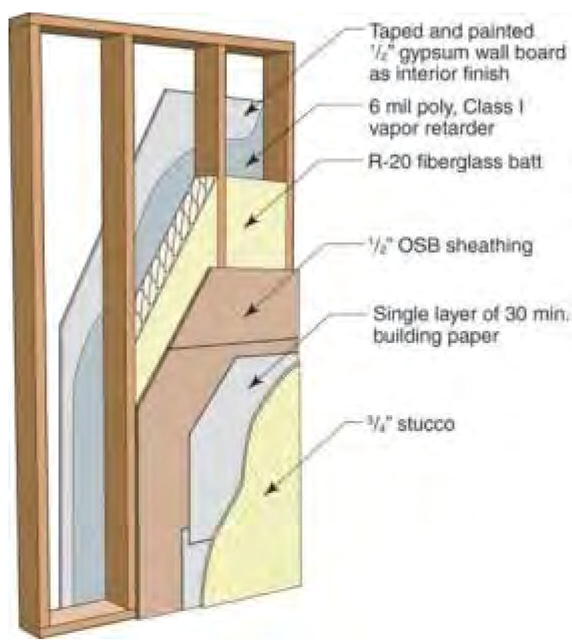


Figure 16 : Wall 2 on all four orientations

Table 2 : Walls for the comparison of exterior insulation

Wall	Interior Finish	Vapor Control	Insulation	Framing	Sheathing	Shtg membrane	Drain/vent gap	Cladding
NESW 7	latex paint	latex paint	R-20 batt	2x6	1/2" OSB	Tyvek DW on OSB, 1.5" XPS	DrainWrap	3/4" stucco
EW 5	latex paint	6 mil poly	R-20 batt	2x6	1/2" OSB	2 x 30 minute paper	3/4" strapping	3/4" stucco on backer board
NESW 2	latex paint	6 mil poly	R-20 batt	2x6	1/2" OSB	1 x 30 min paper	none	3/4" stucco

Comparison of Walls 5 and 7 on the East and West Orientation

The sheathing moisture content comparisons for Walls 5 and 7 on the East and West orientation are shown in Figure 17 and Figure 18. Wall 5 on the North and South orientation was constructed with fiber cement cladding, and is not compared to Wall 7 because of the multiple construction variables between the walls.

Comparison on the west orientation (Figure 17) and the east orientation (Figure 19) shows the measured moisture content at the interior and exterior edge of the lower OSB sheathing for walls 5 and 7. These comparisons demonstrate the moisture performance during both interior and exterior wettings, since both of these sensors are adjacent to the wetting system as indicated in Figure 5. Following each of the exterior wetting events on both orientations, Wall 5 with a ¾" ventilation cavity dries more quickly than Wall 7 likely because of Wall 5's ventilation drying capability.

Following the interior wetting event (blue vertical line, Jan 19, 2011) both walls perform very similarly, reaching the same MC and drying at similar rates. At the start of testing, under normal operating conditions without any wetting (prior to July 5, 2010), the walls have very similar moisture content measurements with no measured risk of moisture related durability problems (see criteria above). The interior and exterior boundary conditions are shown later in Figure 31 and Figure 34.

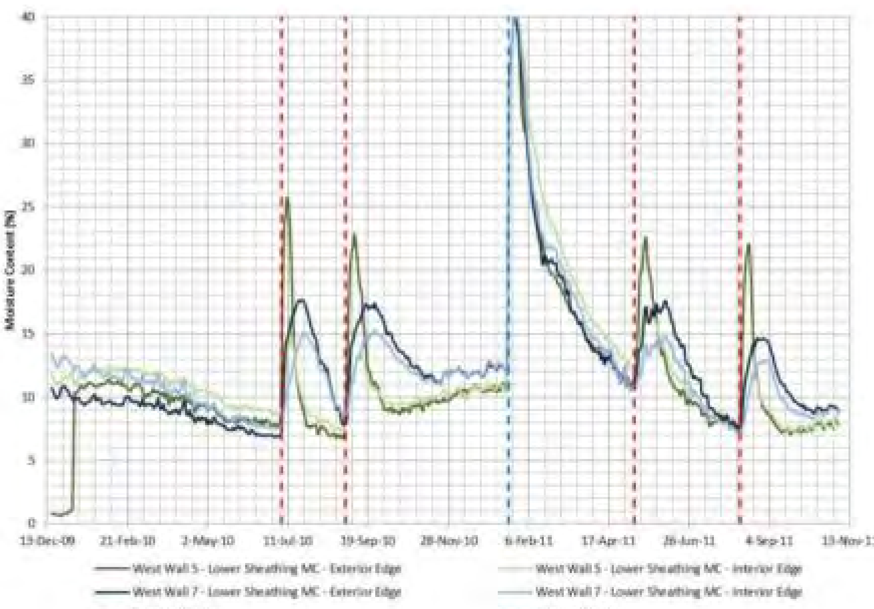


Figure 17 : Lower OSB sheathing measured moisture content comparison between West Wall 5 (ventilated stucco) and West Wall 7 (exterior insulation)

The middle and upper sheathing moisture content measurements (Figure 5) were largely unaffected by the intentional wetting events because of the distance from the wetting system and are used as a comparison of sheathing moisture conditions without the influence of “water leaks”. Figure 18 shows the comparison between the mid-height and upper sheathing moisture content sensors in Walls 5 and 7 on the west orientation. Figure 20 shows the same sensors on the east orientation. The measured sheathing moisture content was dry and very similar in both Wall 5 and Wall 7 on both orientations at the mid-height and upper sheathing moisture content sensors.

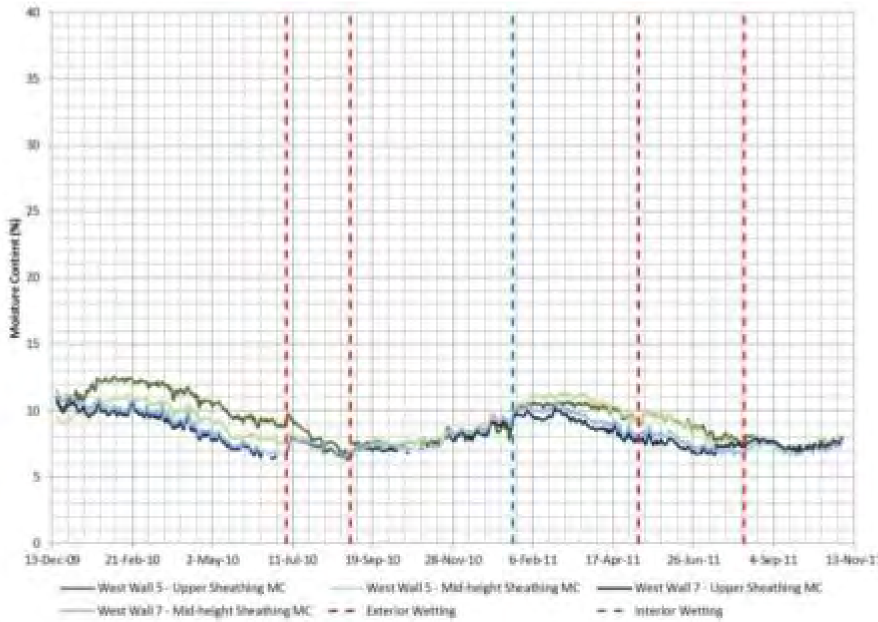


Figure 18 : Middle and upper OSB sheathing measured moisture content comparison between West Wall 5 (ventilated stucco), and West Wall 7 (exterior insulation)

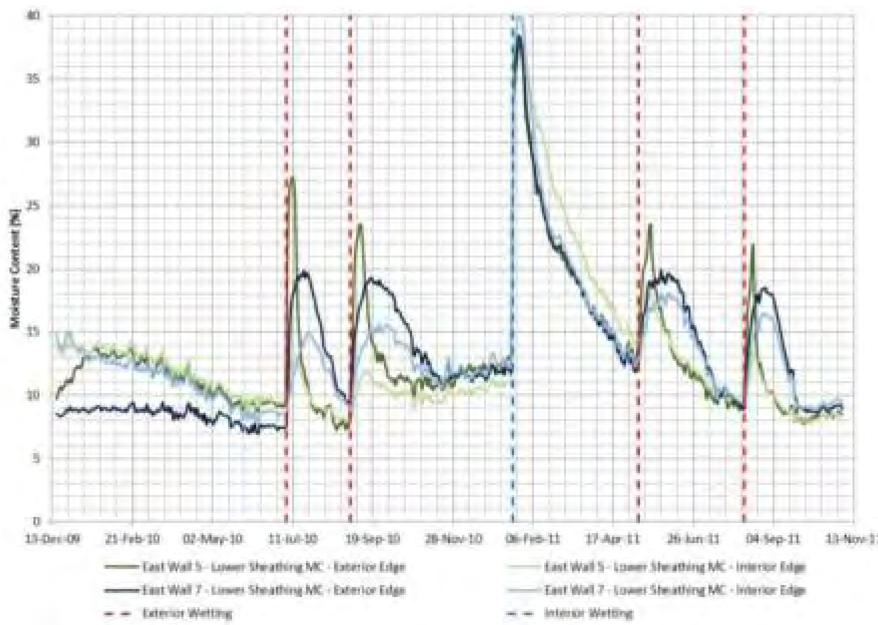


Figure 19 : Lower OSB sheathing measured moisture content comparison between East Wall 5 (ventilated stucco) and East Wall 7 (exterior insulation)

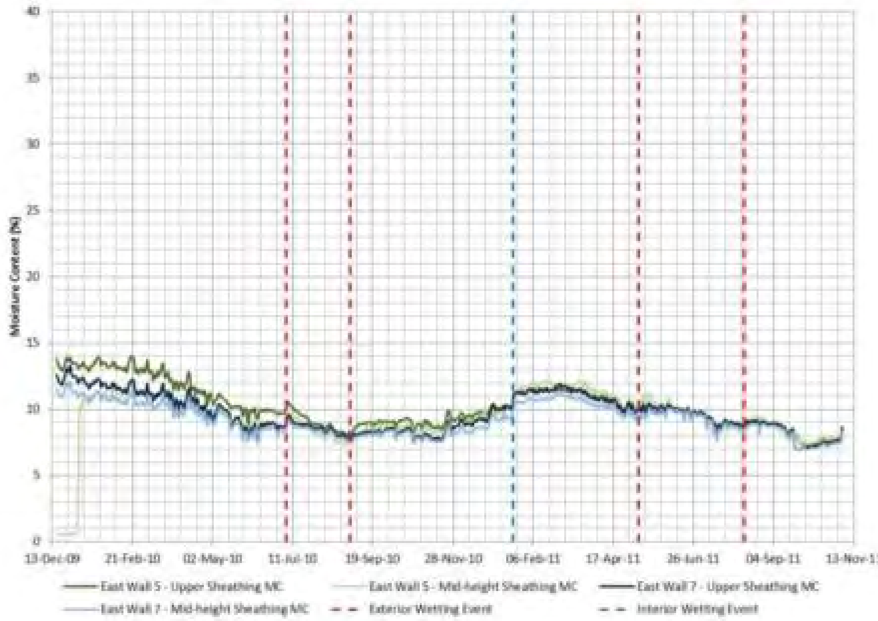


Figure 20 : Middle and upper OSB sheathing measured moisture content comparison between East Wall 5 (ventilated stucco) and East Wall 7 (exterior insulation)

Comparison of Walls 2 and 7

Comparing the overall moisture content measurements at the lower measurement location (both interior and exterior) indicates the moisture content was higher on Wall 2 relative to Wall 7 for the same sensor (interior edge compared to interior edge, and exterior edge compared to exterior edge) for the entire monitoring period. The only exception is on North Wall 2, when the interior edge moisture content sensor does not appear to respond to the first two wetting events. The reason for this is unknown.

Following the intentional interior wetting event (January 2011), Wall 7 dried more quickly in all cases than Wall 2. This is because there is very little drying potential to the exterior in both Wall 2 and Wall 7. Wall 2 is constructed with Class I polyethylene vapor control on the interior, so drying to the interior is not possible, whereas Wall 7 has a Class III interior vapor control layer (latex paint on the drywall) and is thus able to dry to the interior. Table 3 shows the amount of time, in days, following the interior wetting event until the measured moisture content was less than 20%. The next wetting event was May 5, 2011, so if the measured sheathing moisture content was still above 20% MC at that time, then a value of >106 days was used.

Table 3: Comparison of drying rates for Wall 2 and Wall 7 following interior wetting event in January 2011

	Wall 2 (direct applied stucco)	Wall 7 (XPS ext. ins.)
North	>106 days	68 days
East	>106 days	53 days
South	68 days	29 days
West	95 days	47 days

At the mid-height and upper moisture content measurement locations (Figure 22 and Figure 26), which is largely unaffected by the intentional wetting events, the moisture content measurements on Wall 7 on all orientations do not exceed 11%, and are always less than Wall 2. Wall 2 measurements do not exceed 17%, which is also considered a safe level of moisture in the OSB sheathing.

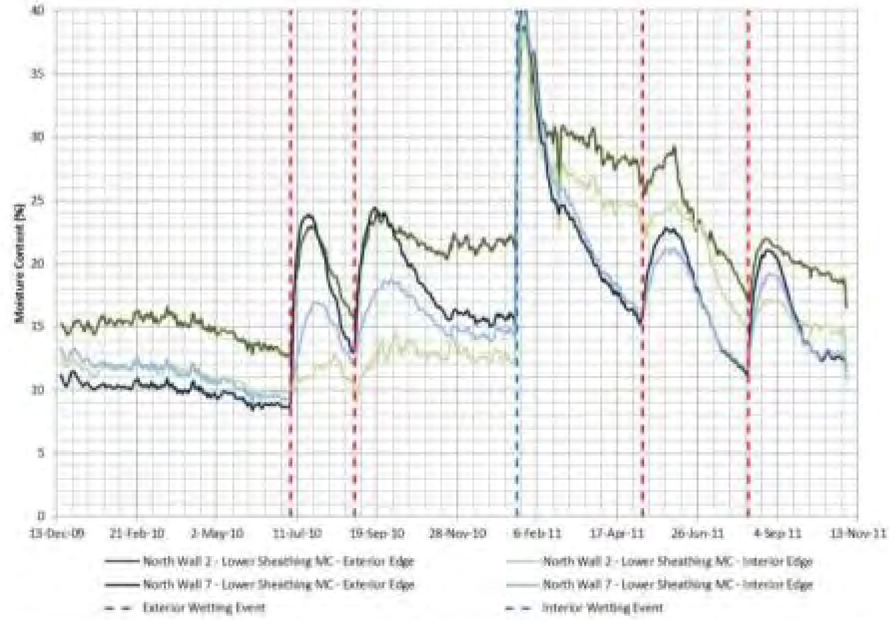


Figure 21 : Lower OSB sheathing measured moisture content comparison between North Wall 2 (direct applied stucco) and North Wall 7 (exterior insulation)

Figure 22 : Middle and upper OSB sheathing measured moisture content comparison between North Wall 2 (direct applied stucco), and North Wall 7 (exterior insulation)

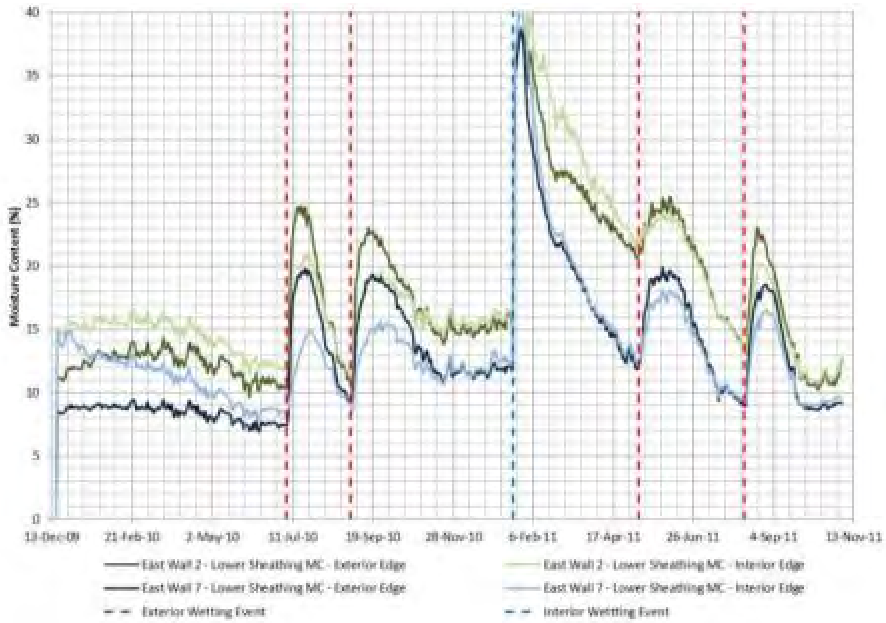


Figure 23 : East Wall 2 (direct applied stucco) and East Wall 7 (insulating sheathing) lower OSB sheathing measured moisture content

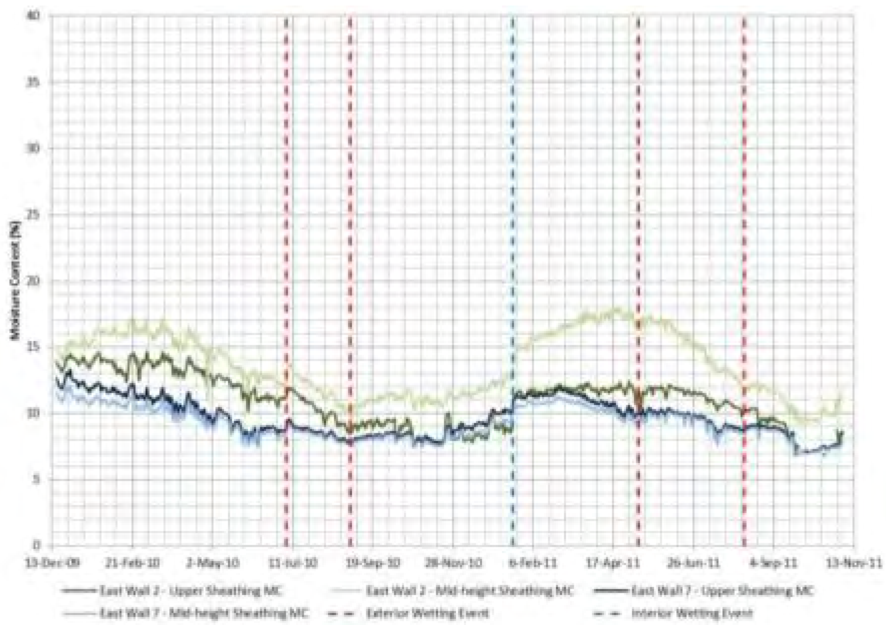


Figure 24 : East Wall 2 (direct applied stucco), and East Wall 7 (insulating sheathing) middle and upper OSB sheathing measured moisture content

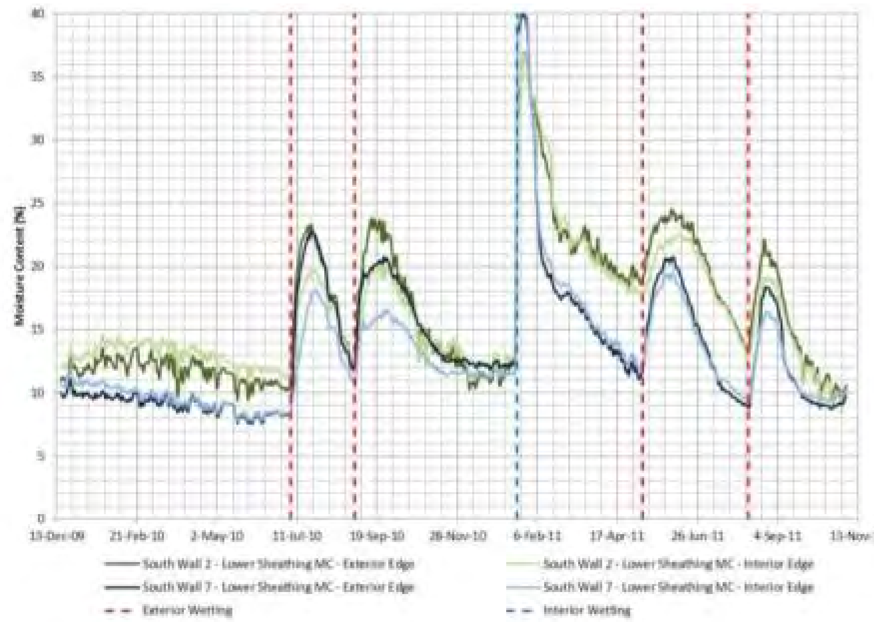


Figure 25 : South Wall 2 (direct applied stucco) and South Wall 7 (exterior insulation) lower OSB sheathing measured moisture content

Figure 26 : South Wall 2 (direct applied stucco), and South Wall 7 (exterior insulation) middle and upper OSB sheathing measured moisture content

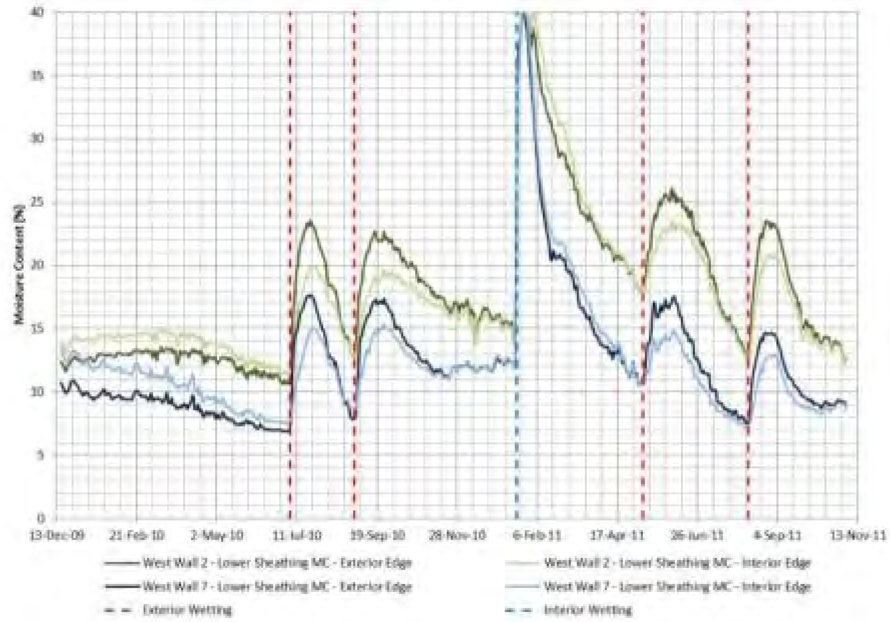


Figure 27 : West Wall 2 and West Wall 7 Lower OSB sheathing measured moisture content comparing exterior insulation

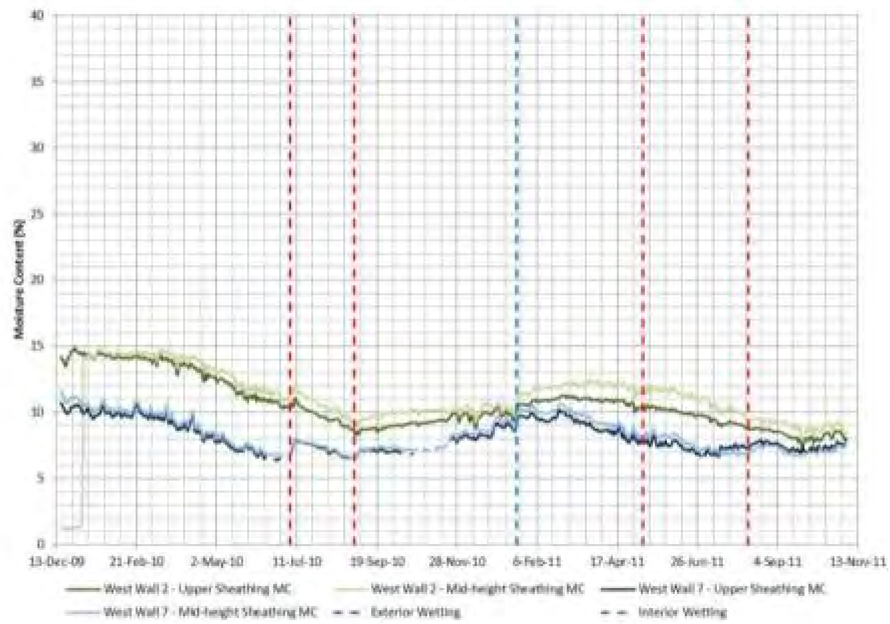


Figure 28 : West Wall 2 and West Wall 7 Middle and upper OSB sheathing measured moisture content comparing exterior insulation

Comparison of Sheathing Temperatures and Interior Dew point

The measured and calculated performance improvements to the building enclosure by using exterior insulation are not new ideas. In 1964, Neil Hutcheon[3] demonstrated how the temperature gradients across a masonry wall changed when the insulation was moved from the interior of the structure to the exterior of the structure. He showed that condensation issues at 35% interior relative humidity were solved by moving the insulation to the exterior. These same principles have been more recently illustrated by John Straube[4] using more current construction practices.

The analysis in this report discusses the potential for interior air leakage condensation based on the measured interior air dewpoint and the measured sheathing temperature. This analysis is a measure of moisture durability **risk**, and not actual moisture durability because it is assumed the vapor control of the enclosure is adequate and condensation will only occur if there is a path for air leakage from the interior to the sheathing, and the sheathing is below the dew point of the air.

Field experience with air tightness and blower door testing has demonstrated that the enclosure will always have some air leaks, and their location and size depends on the type and quality of construction. It is not uncommon to find air leakage pathways through electrical outlets, switches, and other interior finish penetrations. This means that with air permeable cavity filled insulation, which is the most commonly used, it is not uncommon to find evidence of moisture condensation on the interior surface of the exterior OSB behind penetrations. Figure 29 shows an example of an air leakage condensation problem behind an electrical outlet in a six year old house with an interior poly vapor barrier. The OSB and framing are stained and dark with surface mold and the nails are corroding.

Figure 29 : Example of air leakage condensation durability issues.

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[3] Hutcheon, N., CBD-50 Principles Applied to an Insulated Masonry Wall. National Research Council Canada (NRC) 1964

[4] Straube, J., BSD-163: Controlling Cold-Weather Condensation Using Insulation. Building Science Corporation, www.buildingscience.com 2011

The condensation potential is directly related to the interior conditions and the sheathing temperature. Generally speaking, dry air has less moisture available to condense, so there will be less concern for lower humidity interior conditions. For this analysis, two time periods were used over the colder winter months, and these two periods are shown on both the temperature (Figure 30) and relative humidity (Figure 31) graphs. The interior temperature was approximately 20°C for the entirety of both comparison periods, with some small variations. The interior relative humidity was set to 40% for the winter months and maintained with a humidifier controlled by the data acquisition system.

The temperature and relative humidity are used to calculate the hourly dew point of the interior air, for comparison to the sheathing temperature. The temperature of the sheathing is taken at the mid-height mid-thickness of the sheathing and not at the interior surface, but the difference in temperature is negligible over half the thickness of OSB,

The comparison results of this analysis are summarized numerically in Table 4 for both comparison time periods, and graphically in Figure 33 and Figure 32 for the individual analysis time periods. The results show that there is a significant decrease in the number of measured potential hours of air leakage condensation when 38mm (1 ½") of XPS is installed as exterior insulation.

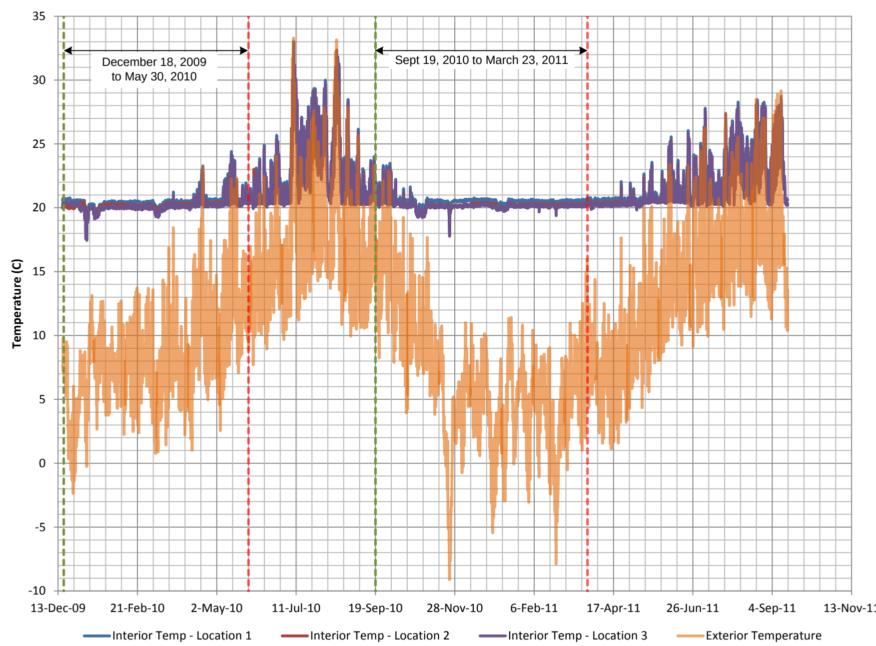

Figure 30 : Measured interior and ambient temperatures

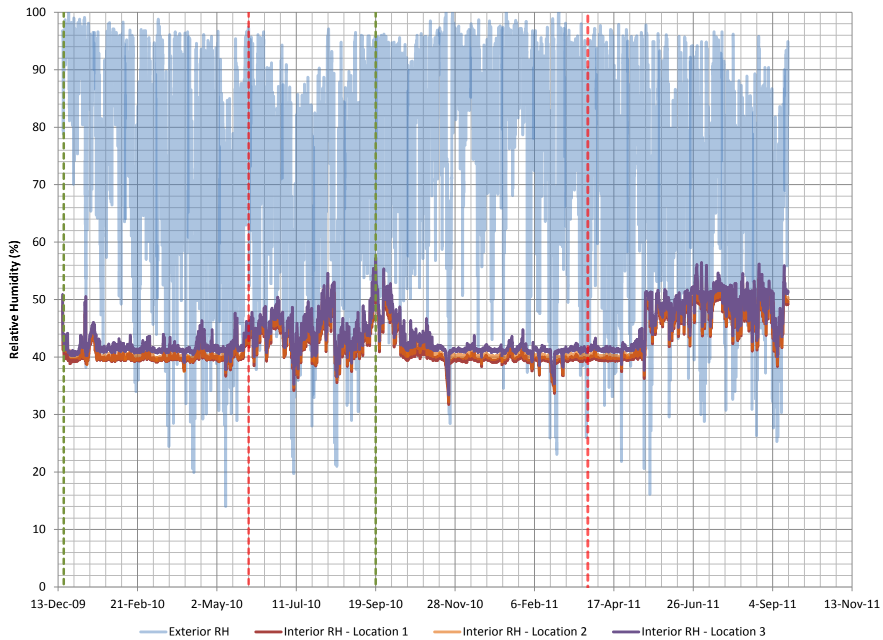

Figure 31 : Measured interior and ambient relative humidity

Table 4 : Number of hours of potential air leakage condensation based on the interior dew point and sheathing temperature. Measure of moisture related durability risk, not moisture related durability

	Potential hours of condensation between December 18, 2009 – May 30, 2010 (3936 Total hours)	**Potential hours of condensation between Sept 19, 2010-March 23, 2011** (4441 Total hours)
North Wall 2	1252	2417
North Wall 7 (XPS)	91	551
East Wall 2	1165	2293
East Wall 5	519	1879
East Wall 7 (XPS)	72	478
South Wall 2	1050	1980
South Wall 7 (XPS)	51	320
West Wall 2	741	2011
West Wall 5	716	1680
West Wall 7 (XPS)	94	518

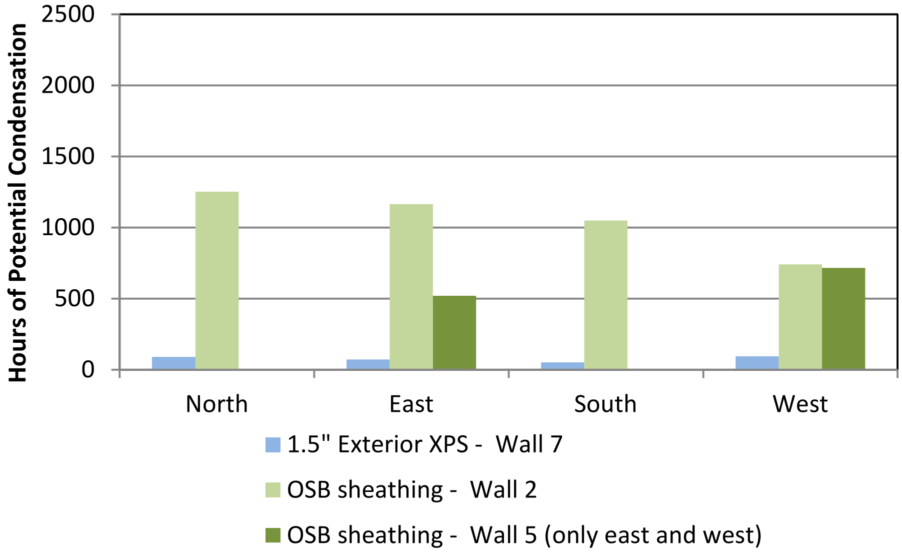

Figure 32 : Comparison of the hours of potential condensation between Wall 2 and Wall 7 from December 18, 2009 to May 30, 2010 using measured interior dew point and sheathing temperature

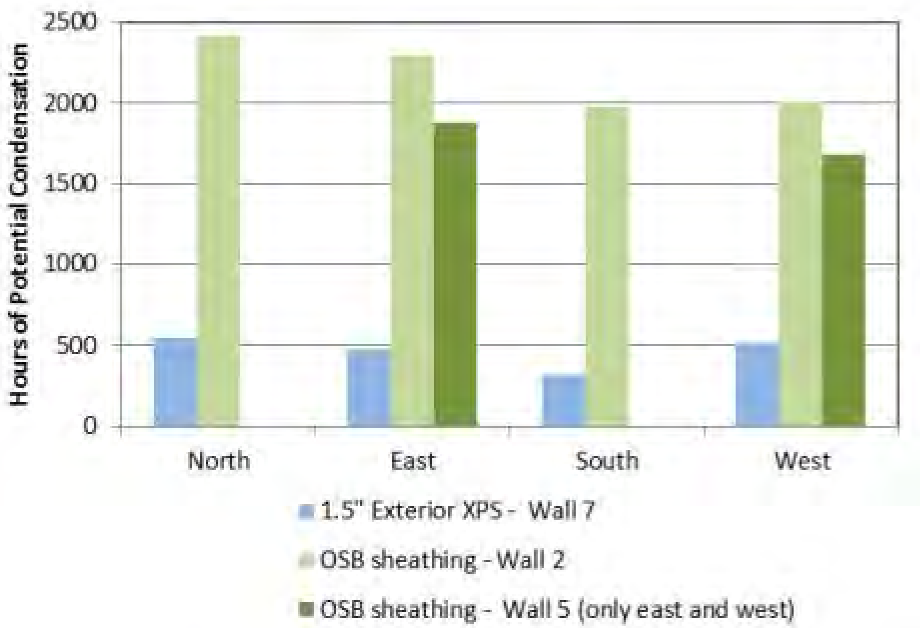

Figure 33 : Comparison of the hours of potential condensation between Wall 2 and Wall 7 from September 19, 2010 to March 23, 2011 using measured interior dew point and sheathing temperature

The degree of potential risk in terms of vapor diffusion and air leakage moisture condensation is proportional to the length of time that the sheathing temperature is continuously below the dew point without any drying potential, and the magnitude of the difference between the dew point and the sheathing temperature. This means that a sheathing temperature 10 degrees below the dewpoint will condense more water than a sheathing temperature 2 degrees below the dewpoint, all other factors being equal. If the temperature of the sheathing is below freezing, condensation will occur as frost or ice, and then melt when the sheathing temperature increases.

The following four figures show the measured interior dew point and simultaneous measured sheathing temperature for Walls 5 and 7 or Walls 2 and 7 for both analysis time periods. The green line in all cases is the measured sheathing temperature of Wall 7, and the blue line is the sheathing temperature of Wall 2 or Wall 5, depending on the comparison graph.

The black line is the measured interior dew point. When the sheathing temperature falls below the dew point temperature, condensation will occur if the interior air contacts the interior surface of the sheathing.

The following four figures show that the sheathing temperature for Walls 2 and 5 were much lower than Wall 7 for extended periods of time, which agrees with the numerical results of Table 4. This means that even with 1.5" of exterior XPS insulation, there is still a potential for a small amount of condensation, but significantly less than most building code minimum approved wall systems. If condensation does occur in Wall 7, it will be able to dry much more quickly to the interior because latex paint is the only form of vapor control, compared to Walls 2, and 5 with a polyethylene vapor barrier.

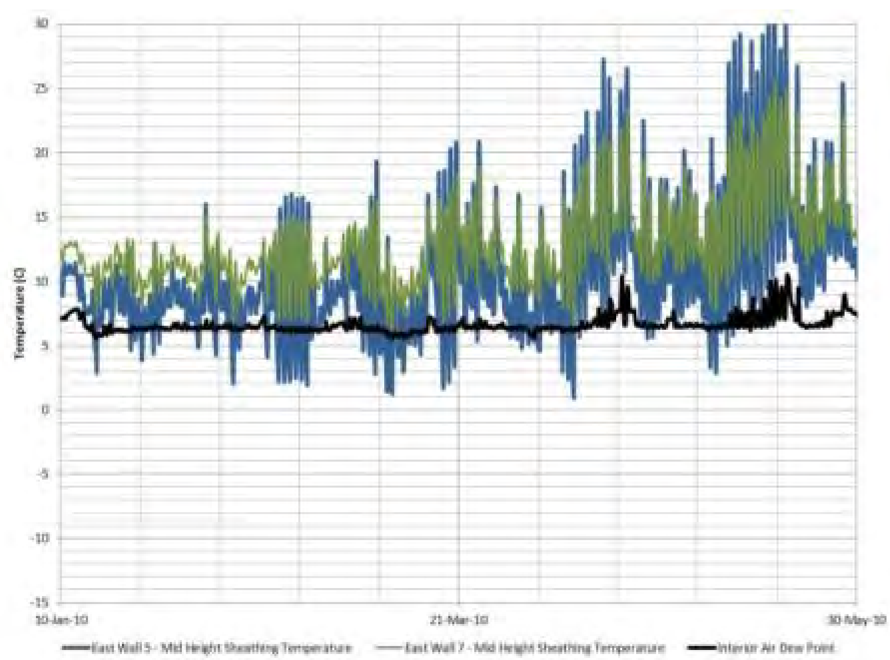

Figure 34 : Comparison of condensation potential between East Walls 5 and 7, Jan to May 2010

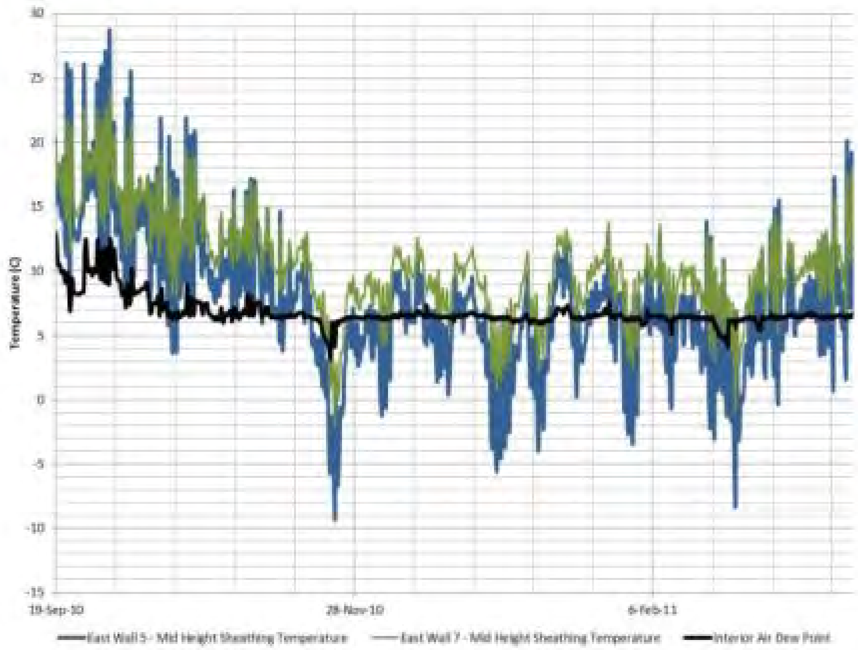

Figure 35 : Comparison of condensation potential between East Walls 5 and 7, Sept to March 2010

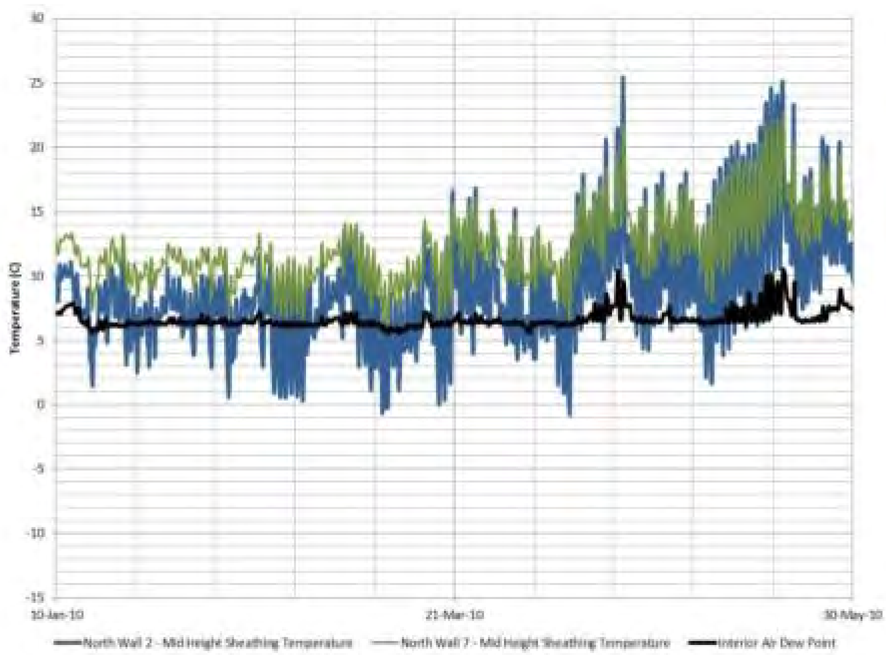

Figure 36 : Comparison of condensation potential between North Walls 2 and 7, Jan to May 2010

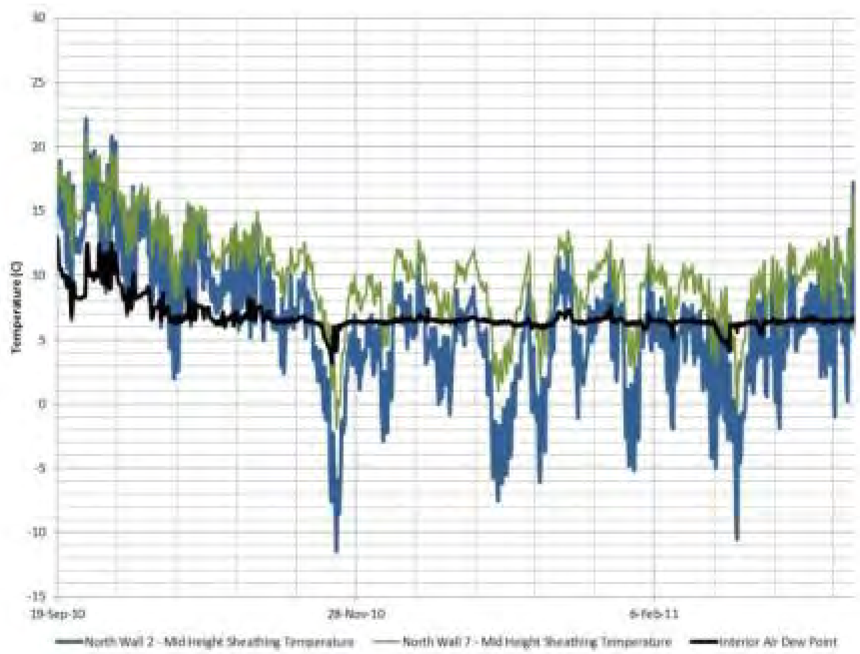

Figure 37 : Comparison of condensation potential between North Walls 2 and 7, Sept to March 2010

4. Test Wall Deconstruction

The deconstruction of Phase III test walls was conducted on November 2 and 3, 2011. The deconstruction was conducted carefully and systematically so that each component of each wall system could be photographed, examined, and compared. Disassembly is critical because it was very informative to inspect all aspects of all layers of the test walls. It is important to see if the visual observations correlate to, and validate, the measured results.[5]

It is important with this qualitative comparison analysis to keep in mind the boundary conditions that the walls were subjected to, both on the interior and exterior. Figure 30 and Figure 31 show the interior and exterior temperature and relative humidity, and Table 1 shows the amount of water added to the surface of the sheathing.

The testing was conducted for approximately 2 years of time, so the conditions will require extrapolation to determine what the OSB might look like after many years in service.

North Orientation

On the north orientation, the exterior of the OSB on Wall 2 was quite dark and stained, particularly in the vicinity of the wetting apparatus (Figure 38 and Figure 39). Both Walls 5 and 7 on the north orientation appeared to be in pristine/good condition. The area immediately behind the wetting apparatus was a little darker on Wall 7 than Wall 5, corresponding to the measured quicker drying rate of Wall 5, likely due to ventilation drying. Overall, the rest of the North Wall 7 was marginally better than North Wall 5.

On the interior surface of the OSB, Wall 2 had the most staining, again, surrounding the wetting apparatus. Walls 5 and 7 looked undamaged on the interior of the OSB.

[5] Lstiburek, J. Parthenon, Eh!, ASHRAE Journal (March 2011)

Figure 38 : Exterior OSB sheathing on the north orientation immediately following deconstruction

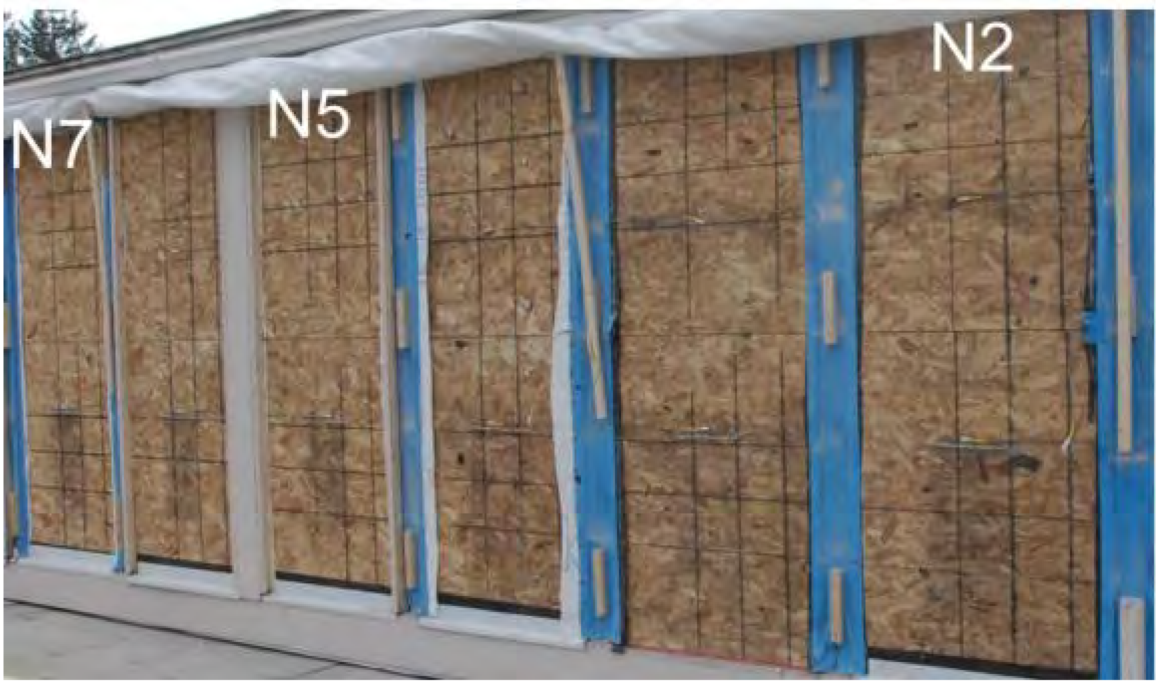

Figure 39 : Exterior OSB sheathing on the north orientation immediately following deconstruction (photo taken from the opposite direction of Figure 38)

East Orientation

Of the three comparison walls on the east orientation (Figure 40), Wall 2 is the most stained in the area surrounding the wetting apparatus and on the upper portion of OSB. There are no visual differences in the photo between Walls 5 and 7. Overall, Wall 7 looked the best of all east walls, but both Wall 5 and Wall 7 looked like new over most of the surface of the OSB.

Figure 40 : Exterior OSB sheathing on the east orientation immediately following deconstruction

South Orientation

The exterior surface of the OSB on South Wall 2 is clearly the darkest and most stained of the three comparison walls (Figure 41). There was some staining in the vicinity of the wetting apparatus on both Walls 5 and 7, but overall, the exterior surface of the sheathing showed no signs of moisture related damage on Wall 5, and looked like new on Wall 7.

Figure 41 : Exterior OSB sheathing on the south orientation immediately following deconstruction

West Orientation

Unfortunately, unlike the other orientations, there was no photo taken of the entire West elevation immediately following deconstruction, due to weather constraints that required tarping of the deconstruction site. Individual photos were taken of the walls, but it is more difficult to use the individual photos than a photo of all the walls due to different lighting and shading at various times for the individual photos.

On the west orientation, Wall 2 was not as dark and stained as the other orientations, but did have some staining of the OSB, particularly around the area of the wetting apparatus. The OSB on Wall 5 was in good condition with staining only in the vicinity of the wetting apparatus. On Wall 7 the OSB looked like new except for the area immediately behind the wetting apparatus.

5. Conclusions

Wall 5 (East and West) and Wall 7

- Following the interior wetting events, both Wall 5 (East and West) and Wall 7 dried very similarly. Neither wall outperformed the other during interior wetting events.
- Following the exterior wetting events, Wall 5 (East and West) dried more quickly than Wall 7
- Moisture content monitoring of the mid-height and upper sheathing demonstrated no significant performance differences between Wall 5 and Wall 7.
- In dew point analysis, Wall 5 had significantly higher moisture durability risk with respect to interior air leakage condensation than Wall 7. This is not a durability problem unless interior air reaches the surface of the sheathing
- During the wall deconstruction, the OSB surfaces of Walls 5 and 7 both appeared to be in good condition, with very little staining only around the wetting apparatus, although Wall 7 did appear a little more pristine overall than Wall 5.

Wall 2 and Wall 7

- Moisture content monitoring of the mid-height and upper sheathing showed that the sheathing moisture content of Wall 2 was always higher than Wall 7, but did not exceed criteria for moisture related durability concerns
- Following the interior wetting event, Wall 7 dried more quickly to safe levels than Wall 2, because the vapor control layer on Wall 7 was Class III, and the vapor control layer on Wall 2 was Class I eliminating drying to the interior.
- Following the exterior wetting events, the drying rates were relatively similar between Walls 2 and 7. Generally the moisture content was higher on Wall 2, so even though the drying rates were similar, the moisture content of the sheathing on Wall 2 remained elevated compared to Wall 7.
- In dew point analysis, Wall 2 had significantly higher moisture durability risks with respect to interior air leakage condensation than Wall 7. This is because the exterior insulation in Wall 7 keeps the sheathing at a higher temperature, reducing the number of hours that the sheathing is below the interior air dew point. This is not a durability problem unless interior air reaches the surface of the sheathing
- Observations from the wall deconstruction showed that the exterior surface of the OSB for Wall 2 was quite stained behind and around the wetting apparatus.

There was also staining on the upper portion of the OSB on Wall 2, as well as a general overall darker appearance to the entire OSB sheet compared to Wall 7. The OSB on Wall 7 looked like new except directly behind and under the wetting apparatus.

It was shown through data analysis and wall deconstruction that there were no moisture related durability concerns of the wood structural sheathing in the Vancouver, BC climate (DOE 4C) when 1.5" of exterior insulation was installed. Liquid water was intentionally placed in direct contact with the exterior surface of the sheathing behind the low vapor permeance XPS exterior insulation four times through the monitoring period as described in the report and there were no moisture related durability concerns measured or observed.

About the Authors

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