ROXUL

Drainage Balance Testing and Wall Comparison

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Prepared by

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Introduction

Modern building enclosure designs often make use of rainscreen cladding and a layer of continuous insulation installed outboard of a drainage plane / water control layer.[1] Although mineral wool insulation has been used successfully in rainscreen and masonry cavity walls for several decades, the relative unfamiliarity of the North American building industry with the product has generated questions regarding the moisture-related performance of mineral wool. Some published reports even imply that Roxul mineral wool insulation absorbs water when it is installed on the exterior of a wall assembly and that its performance is affected by this water absorption. Such claims have led to uncertainty in the specification phase for new designs by architects and design professionals.

Building Science Laboratories (BSL) was retained to design and conduct laboratory testing to determine if Roxul CavityRock DD (the most common Roxul product used in drained wall systems) would absorb water during rain events and if the insulation performance would be affected.

BSL designed a test in which water was sprayed over the exterior cladding surface of wall assemblies using both CavityRock and XPS as the continuous insulation on the exterior of a water barrier. Various configurations were tested and their performance compared by measuring both the change in weight of the wall assembly (water stored), and the volume water that drained off different surfaces within the assembly (water drained). After the water spray was stopped, the residual amount of water in the assembly and its drying rate were measured.

Approach/Scope

Rather than conduct simple and unrealistic tests that immerse small samples of insulation under water, or spray high-pressure water at material samples, full-scale wall assemblies representative of real life rainscreen/drained wall insulation applications were chosen for performance testing.

For performance testing, two 4' wide by 8' test walls were constructed (Figure 1 and Figure 2). The assemblies consisted of:

- Light-gauge steel framing
- Exterior-grade glass-mat faced gypsum sheathing
- Fully-adhered air and water barrier
- Continuous exterior insulation, either
    - 2" extruded polystyrene (XPS) or
    - 3" Roxul CavityRock Dual Density (DD)
- Vertical Z-girts on the face of the insulation attached to the framing only with screws
- Simulated horizontal open-joint cladding of acrylic sheet 6" high with a ½" gap between pieces (8% open area).

Steel stud frames and acrylic cladding were used in the wall assemblies to reduce the amount of absorptive and hygroscopic material and thereby reduce the impact of changes in the laboratory's relative humidity (RH) on the mass of the wall system. Extruded polystyrene was used as the comparison wall because XPS is non-absorptive (under these conditions) and is widely accepted for use in rainscreen wall systems.

[1] Lstiburek, J. Building Science Insight-001 : The Perfect Wall, www.buildingscience.com, 2008

Figure 1 : XPS test wall assembly

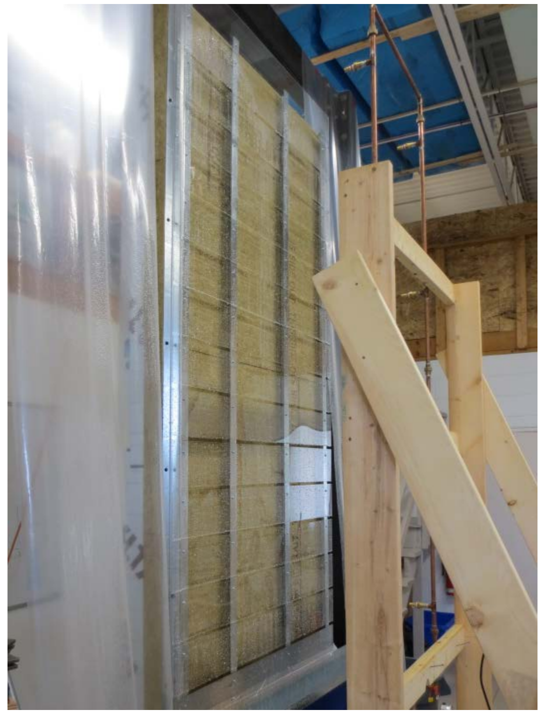


Figure 2 : Roxul CavityRock DD test wall assembly

A spray rack was used to apply water to the surface of the wall. A spray rate of approximately 3.4 L/m^2·min (5.0 US gal/ft^2·h) was chosen based on the application rate specified in ASTM Standard E547 *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference*. This is a high rate of application which is put into context following an analysis of measured driving rain data on page 7. Using a constant measured flow rate however, does provide a basis of comparison between the wall assemblies.

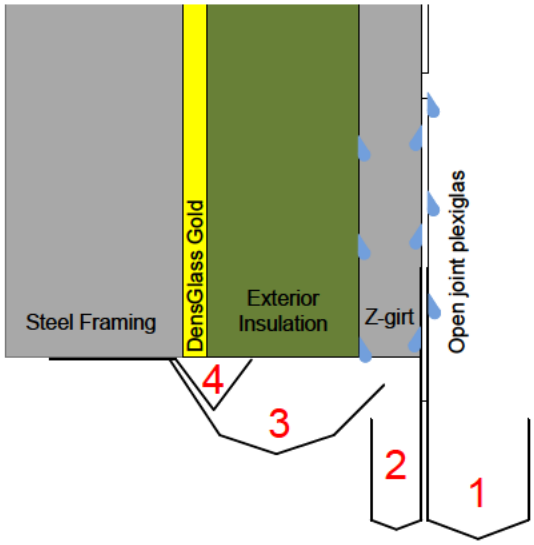
Two testing protocols were developed and completed. In the first test protocol, water was applied to the test assemblies for ten minutes at 2.6 gallons/minute (4.9 US gal/ft^2·h) for a total water volume of 26 gallons. In the second protocol, water was applied consecutively four times in sequence for 3 minutes, followed by fifteen minute drainage intervals. The spray rates used in testing are explained in more detail in the testing procedure section on page 9.

Figure 3 : one of eight spray rack nozzles

Figure 4 : Flow meter and pressure gauge

The distribution of water in the assembly was measured in some tests using a combination of four troughs that collected water from four different layers in the wall system (Figure 5):

1. Exterior surface of the cladding (this cannot be seen in Figure 6)
2. Interior surface of the cladding
3. Exterior surface of the continuous insulation layer
4. Exterior surface of the fully adhered membrane (behind the continuous insulation)



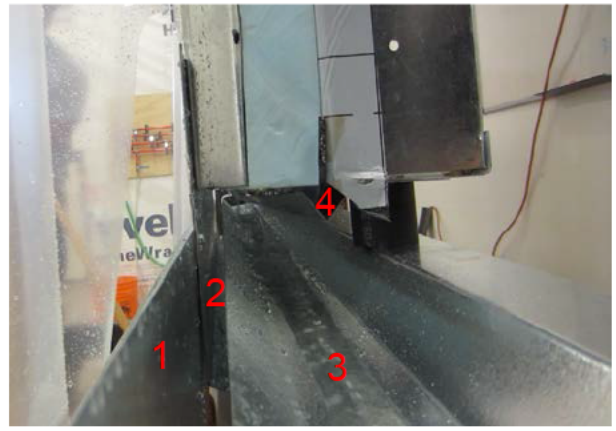


Figure 5 : Drainage trough schematic

Figure 6 : Troughs installed on XPS test wall

The test walls were hung on BSL's custom laboratory wall balance to allow the water stored within the assembly to be weighed continuously (Figure 7) with a precision of a few grams (less than 1/10 of an ounce). A load cell was used to measure the mass of the wall after counter-balance weights were applied to offset the dry starting weight of the wall within approximately 10lbs (4.5kg). Only the change in mass is subsequently measured and recorded using a Campbell Scientific CR1000. The calibration procedure used before testing is explained in the Testing Procedure section of the report.

Analysis Criteria

The performance of the test walls was compared based on three main criteria:

1. The amount of water stored in the assembly following the application of water
2. The length of time required for the wall to dry any stored water
3. The measured volume of water that was collected from each wall surface in the drainage troughs

Figure 7 : Drainage balance apparatus

Testing Variables

A series of 18 tests were conducted to characterize the wall assemblies. These tests are shown below in Table 1. Because the methodology was newly developed, some of the 18 tests were conducted to show the repeatability of the results and the instrumentation, and other tests were used in the development of the experimental program. The first eight tests were conducted on the XPS insulated wall assembly, and the remaining nine tests were of the Roxul insulated wall assembly.

Table 1 : Drainage tests conducted

Date	Test #	Insulation	Flow [GPM]	Application Time [min]	Drainage Troughs	
18-Jun	1	XPS	2.6	5.7	YES	
19-Jun	2	XPS	2	10	YES	
26-Jun	3	XPS	2.6	10	YES	
28-Jun	4	XPS	2.6	10	YES	
02-Jul	5	XPS	2.6	10	YES	
03-Jul	6	XPS	2.6	10	NO	
04-Jul	7	XPS	2.6	3min x 4	NO	
09-Jul	8	XPS	2.6	3min x 4	NO	
11-Jul	9	ROXUL	2.6	10	YES	
15-Jul	10	ROXUL	2.6	10	YES	
17-Jul	11	ROXUL	2.6	10	YES	
19-Jul	12	ROXUL	2.6	10	YES	taped openings directly in front of nozzles
23-Jul	13	ROXUL	2.6	10	NO	
24-Jul	14	ROXUL	2.6	3min x 4	NO	
26-Jul	15	ROXUL	2.6	10	NO	taped openings directly in front of nozzles
09-Sep	16	ROXUL	2.6	10	NO	vinyl siding
13-Sep	17	ROXUL	2.6	10	NO	vinyl siding
03-Oct	18	ROXUL	2.6	10	YES	vinyl siding

Water Application Rates

To put the water application rates used in standardized testing and in this study into context, driving rain calculations are presented below.

Rainfall analysis was conducted for Toronto, Ontario using hourly climate files of the years 1965 to 1989 measured at the Toronto International Airport (now Pearson)[2]. The data was analyzed and rainfall figures calculated on an hourly basis (8760 hours, for 25 years), with most results reported as annual averages (e.g., the total over 25 years divided by 25 years). The average annual rainfall and maximum annual driving rain calculated for Toronto are:

- Total Rainfall – 718 mm/year
- Maximum Driving Rainfall (on the plane facing worst direction) – 292 mm/year

The frequency distribution of rainfall intensity is shown below in

Table 2. The data shows that 90% of the rainfall occurred with an intensity of less than 3mm/hr. This was calculated based on the finding that during an average year it is raining for 482 hours of which 432 of those hours are during rainfall events with less than 3mm/hr intensity.

[2] Straube, J.F, and Schumacher, C.J. *Driving Rain Loads for Canadian Building Design*, External Research Program Report for Canada Mortgage and Housing Corporation, Ottawa, October, 2005.

Table 2 : Binned rainfall intensity distribution from 25 years of measured data in Toronto, Ontario

(mm/hr)	Rainfall Intensity Binned Distribution (hrs)
0-1	249.1
1-3	182.4
3-5	27.6
5-7	12.1
7-10	5.7
>10	4.8

For the understanding of wall performance, it is driving rain (i.e., wind-driven rain) not rainfall that is of interest. In most locations, driving rain occurs predominantly from one direction, so one orientation of the building will experience a larger quantity of driving rain while the others will experience much less. The frequency distribution of driving rain intensity for the orientation that receives the most driving rain over the year in Toronto is shown below in Table 3. It can be seen that 94% of the driving rain occurs in events with an intensity of less than 3mm/hr. Fully 71% of hours with driving rain on the worst orientation occur at an intensity of 0-1 mm/hr and 23% occur at intensities of 1-3 mm/hr.

Table 3 : Binned driving rain distribution from 25 years of measured data in Toronto, Ontario

(mm/hr)	Cumulative Driving Rain Distribution, Worst Plane (hrs)
0-1	281.8
1-3	90.5
3-5	18.3
5-7	5
7-10	2
>10	0.5

A spray intensity of approximately 3.4 $L/m^2 \cdot min$ (5.0 US $gal/ft^2 \cdot h$) was targeted in most of these tests, based on ASTM Standard E547. This is equivalent to a driving rain event of 205 mm/hr (3.4*60). This is approximately 70 times more rain intensity than 94% of the driving rain events and 20 times more than the worst hour in the year that occur on the worst wall orientation in Toronto, Ontario. This test is similar to applying 2/3 of the total annual driving rain for Toronto in one rain event. This translates to a specimen flow rate of 2.6 GPM (9.8 L/min) on a test wall assembly of 32 ft^2 ($2.9m^2$) area.

Testing Procedure

The following describes the procedure used after initial testing and the development of the experimental protocol.

After each test wall was counterbalanced with weight and connected to the load cell, it was calibrated to accurately measure changes in its mass. The calibration was conducted by adding known weights, measuring the change in voltage on the load cell, and calculating the linear relationship of voltage versus mass for the system. Once the system was calibrated, the data acquisition system calculated the mass based on the measured voltage of the load cell and the calibrated linear relationship. Prior to each test, the calibration was verified. If, for some reason the change in mass on the wall was different than the mass of the weight added, the test walls were recalibrated. Figure 8 shows an example of a pretest calibration check.

The black numbers on Figure 8 represent the average readings of the data acquisition system, and the red values are the difference between the black numbers. The red numbers are the most critical, as the black numbers could be affected by an offset during the analysis of the data and can be easily corrected during analysis by correcting the offset value. If the calibration is accurate, the red numbers (difference between measurements) should correspond to the weight measurements from the benchtop scale, which is accurate to within 0.1g.

For the calibration check shown in Figure 8, the calibration weights were

- 100.0g, (-100 + 742.8)g, 100.0g, -742.8g, -100.0g

For this calibration check, the measured average values from the load cell are very close to the measured weights from the benchtop scale. The largest discrepancy is a measured difference of 1.5grams, or approximately 0.2% of the full reading value which was 741.3g from the load cell when 742.8g was added.

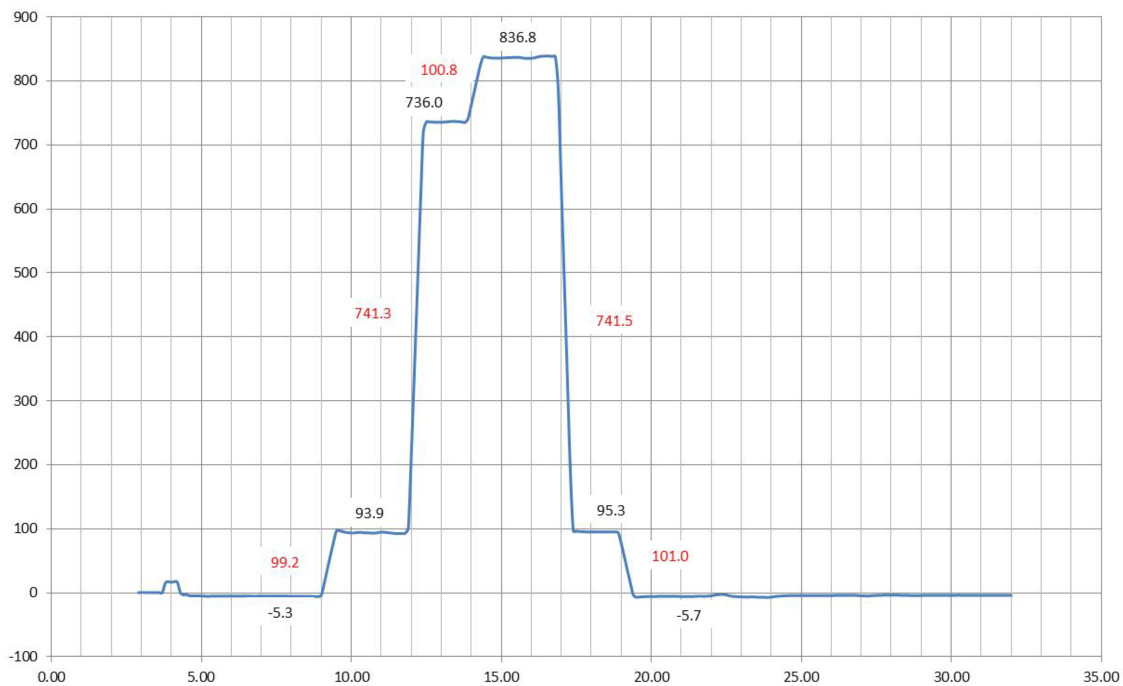


Figure 8 : Example calibration check

Following the calibration check, water was applied based on the specific test from 1 to 18. For most of the tests, water was added at a measured flow rate of 2.6 GPM (9.8 L/min), for a total of ten minutes. In three cases, the water was applied at 2.6 GPM (9.8 L/min) for a duration of three minutes, an interval of 15 minutes allowed, and then this was repeated four times. This application rate was based on previous testing that had been conducted and used for the development of the experimental program.

Following the wetting, the wall was monitored until it returned back to equilibrium with the laboratory. In some cases, the wall did not return to exactly zero grams because small changes in the laboratory relative humidity do affect the weight of the wall as a result of adsorption and desorption of water vapor molecules[3].

In most cases, a single calibration weight was applied to the test wall at the end of the test to check the calibration. This step was a modification to the experimental program and was not completed for all tests.

Results and Observations

XPS Assembly

Tests 1- 5 (XPS assembly, 2.6 GPM, 5.7 minutes)

Tests 1 through 5 were all conducted on the same XPS wall assembly with drainage troughs attached at the base of the wall. The summary data from the drainage tests is presented numerically in Table 4, and graphically in Figure 9. All of the individual test graphs can be found in the Appendix to this report.

For the XPS test assembly, a bead of caulking was installed along the entire width on the bottom edge of the XPS, near the exterior surface, to act as a drip edge so that water draining down the surface of the XPS was properly directed into Trough 3 rather than Trough 4. Trough 4 was installed to collect any water that drained between the exterior insulation and the fully adhered air and water barrier (Figure 5). Following Tests 1 and 2, no water was observed in the collection container at the end of Trough 4, meaning that no water drained between the XPS and fully adhered membrane. During Tests 3 and 4, water did accumulate in the collection container hanging on the end of Trough 4, which was indicated by an upturn in the weight curve. Water was observed draining down the exterior surface of the XPS, and some water did drain horizontally along the bottom of the XPS towards the interior directly over and past the drip edge/sealant bead along the width of the insulation. As a percentage of the total water, the amount bypassing the sealant drip edge was calculated to be very small. Drainage balance curves for Tests 3 and 4 were calculated based on the amount of water measured in the container from Trough 4, to match the shape of the curve during Testing 2 and 5. Tests 2 and 5 could be used to control for measurement error caused by contact between the collection container on Trough 4 and the assembly.

The original measured curves, and calculated curve corrections are shown in the appendix.

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[3] Straube, J.F., Burnett, E.F., *Building Science for Building Enclosures*. Building Science Press, Sommerville, MA, 2005.

For Test 5, the water collection container was removed from contact with the wall assembly, so the small amount of water (0.1%) that drained through Trough 4 did not affect the total mass of water accumulated on the wall.

Table 4 shows the amount of water that was captured by the drainage troughs during each of the tests. The total amount of water drained from the system and captured was between 77% and 89% with three of the tests capturing exactly 83% of the water applied. The water that was not captured deflected off the wall surface over the drainage trough onto the floor.

Table 5 shows more clearly the distribution of water collected from the surfaces during the water application on the XPS wall assembly. The values are relatively consistent for all five of the comparison tests. With the open joint cladding used for this testing, the exterior of the cladding and the exterior of the insulation collect approximately the same volume of water. The interior surface of the cladding was consistently a little lower in collected volume.

Test 1 was conducted with a flow rate of 2.6 GPM (9.8 L/min) but only for 5.7 minutes, as the drainage collection device on the surface of the insulation had reached capacity.

Test 2 was conducted with a flow rate of 2.0 GPM (7.6 L/min) to determine if there was any noticeable difference in results.

The catch basin at the front of the assembly was changed and Tests 3, 4 and 5 were all conducted with a flowrate of 2.6 GPM (9.8 L/min) for ten minutes to test the repeatability of the wall assembly, as well as the load cell and data logger equipment.

Figure 9 shows the similarity of tests 1-5 on the XPS wall assembly.

Table 4 : Water storage summary of XPS assembly tests 1 to 5

	C.I.	Flow Rate	Duration	Total Vol [gal]	Total Vol [L]	Drainage Location	Amout Drained [L]	Amout Drained [% of total applied]
Test 1	XPS	2.6 GPM	5.7 min	14.82	56.1	Front of Cladding	15.4	28%
						Back of Cladding	12.4	22%
						Front of Insulation	18.7	33%
								83%
Test 2	XPS	2.0 GPM	10 min	20	75.7	Front of Cladding	27.0	36%
						Back of Cladding	20.9	28%
						Front of Insulation	19.2	25%
								89%
Test 3	XPS	2.6 GPM	10 min	26	98.4	Front of Cladding	30.8	31%
						Back of Cladding	21.4	22%
						Front of Insulation	30.0	30%
								83%
Test 4	XPS	2.6 GPM	10 min	26	98.4	Front of Cladding	30.3	31%
						Back of Cladding	20.1	20%
						Front of Insulation	25.8	26%
								77%
Test 5	XPS	2.6 GPM	10 min	26	98.4	Front of Cladding	31.2	32%
						Back of Cladding	22.5	23%
						Front of Insulation	27.8	28%
						Back of Insulation	0.13	0.13%
								83%

Table 5 : Summary of water collection volumes

Test	Exterior of Cladding	Interior of Cladding	Exterior of Insulation
1	28%	22%	33%
2	36%	28%	25%
3	31%	22%	30%
4	31%	20%	26%
5	32%	23%	28%
Average	31%	23%	29%

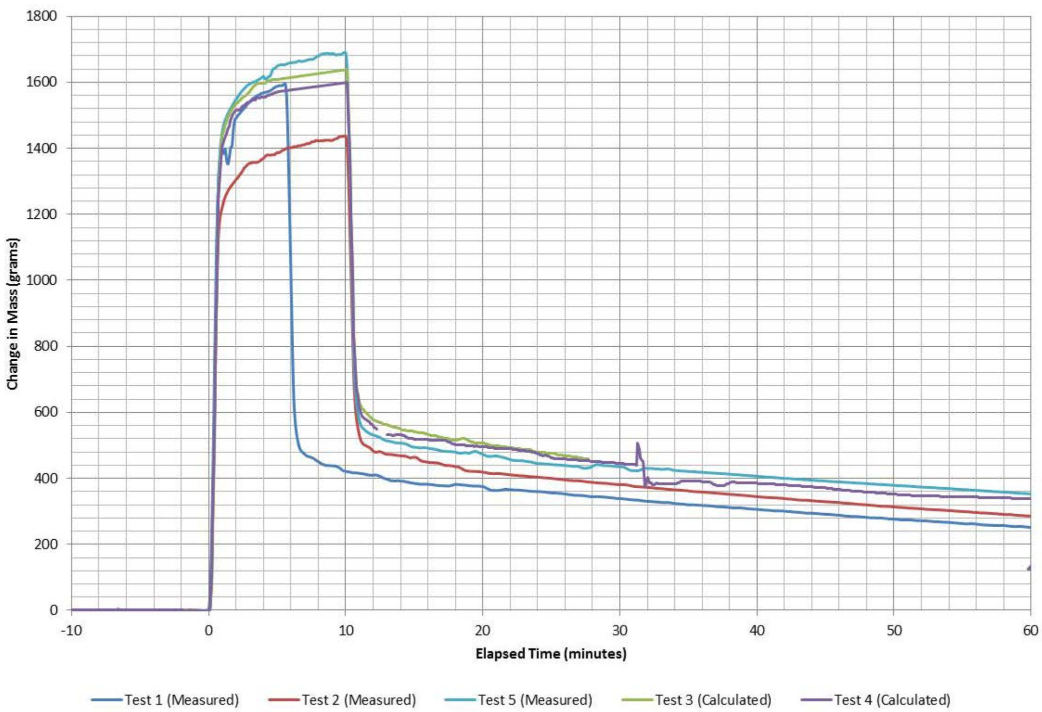

Figure 9 : Comparison of Tests 1-5, XPS wall assemblies

All four tests with a 2.6 GPM (9.8 L/min) application rate reached a higher peak mass during the water application because there was more water accumulating in the troughs before it drained, compared to Test 2 (red line) with an application rate of 2.0GPM (7.6 L/min).

All four tests conducted at a flow rate of 2.6 GPM (9.8 L/min) had very similar storage values once initial drainage was complete. The values for comparison for water storage were typically measured at 12 minutes following the end of the 10 minute water application to ensure that all the excess water had dripped from the test wall, and drained out of the troughs. The total water stored in the full system with troughs at 22 minutes was between 370 and 490g.

This series of tests shows that the XPS wall assembly achieves repeatable results when tested with the new methodology.

Test 6 was conducted on the same XPS wall assembly as Tests 1-5 but the drainage troughs were removed, so the only water stored on the wall in Test 6 was on the wall assembly itself. Figure 10 shows a difference of approximately 860 grams between the peak values of tests with and without troughs. This difference indicates that water was accumulating in the troughs faster than it could drain during the water application. Figure 10 also shows that in the configuration with drainage troughs there is approximately 150g of water stored in the four troughs following the gravity drainage of all applied water.

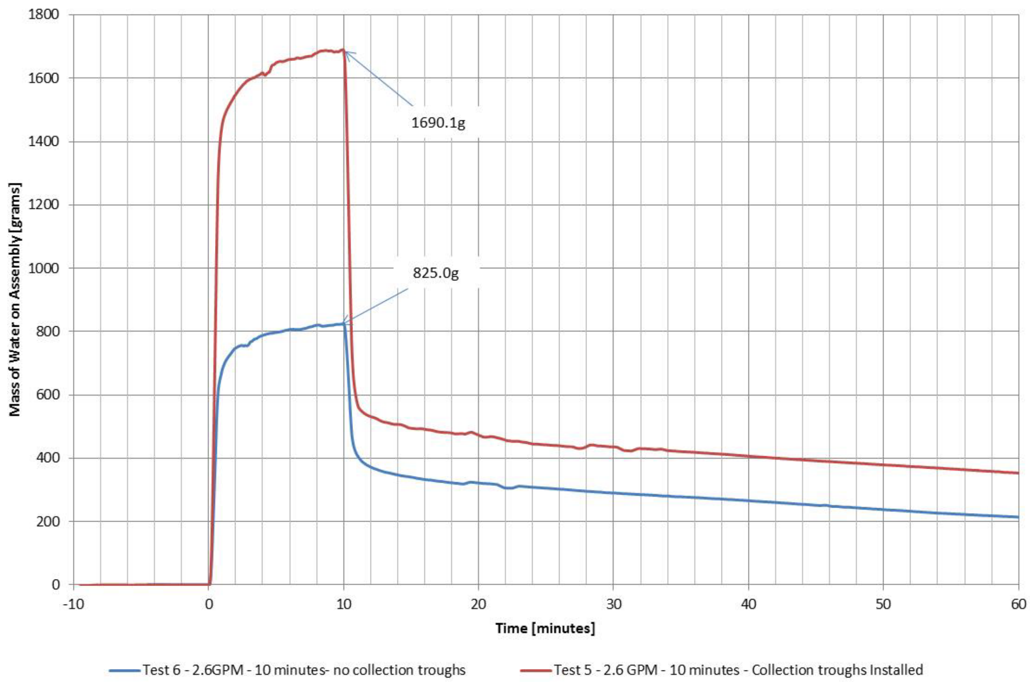

Figure 10 : Comparison of Test 5 and 6

Tests 7 and 8 were conducted on the same wall assembly as Test 6 but the water application rate was changed to a 3 minute water application every 15 minutes. This water application technique was based on previous balance testing that had been conducted. Figure 11 shows that Tests 7 and 8 yielded nearly identical test results. These results are compared to a similar test on the Roxul assembly in the drying analysis section on page 21.

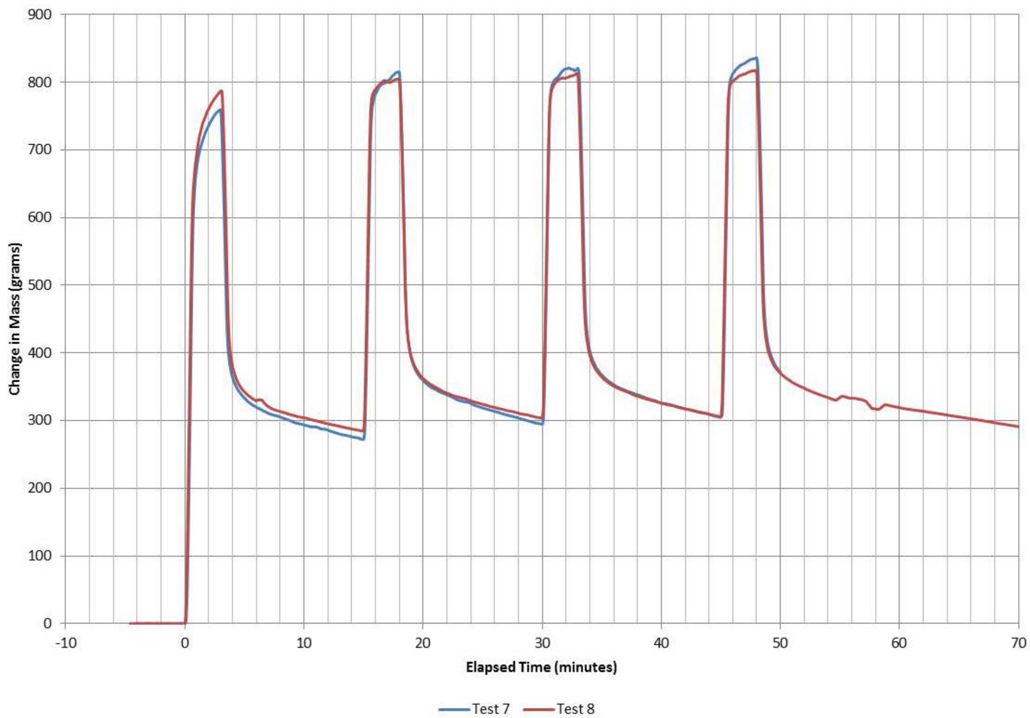

Figure 11 : Comparison of XPS assemblies Test 7 and Test 8

Table 6 : Storage results on the test wall assembly (grams/mL) at 15 minutes from start of test (12 minutes from end of water application)

	Test 7 (15 min)	Test 8 (15 min)
First Water Application	272.3	285.4
2nd Water Application	294.9	304.1
3rd Water Application	305.0	306.0
4th Water Application	- *	319.3

* - a PEBCAK related error resulted in the loss of some data

Roxul CavityRock DD Assembly Testing

Tests 9, 10, and 11 were conducted on the Roxul CavityRock DD insulated assembly, with drainage troughs, to determine if the Roxul test assembly produced repeatable results in terms of storage and drainage (Figure 12). The water application curves are very similar, showing the repeatability of the Roxul wall assembly. A summary of the amount of water collected in the three collection containers is shown in Table 7. The ratio of the amount collected in the troughs during the Roxul test assemblies is nearly identical to the XPS wall assemblies. For the Roxul wall, a strip of aluminum was used at the bottom edge of the wall to act as a drip edge, and was much more effective than the bead of sealant used on the XPS wall assembly. No water drained past the drip edge into the 4th drainage collection trough during the Roxul wall drainage tests.

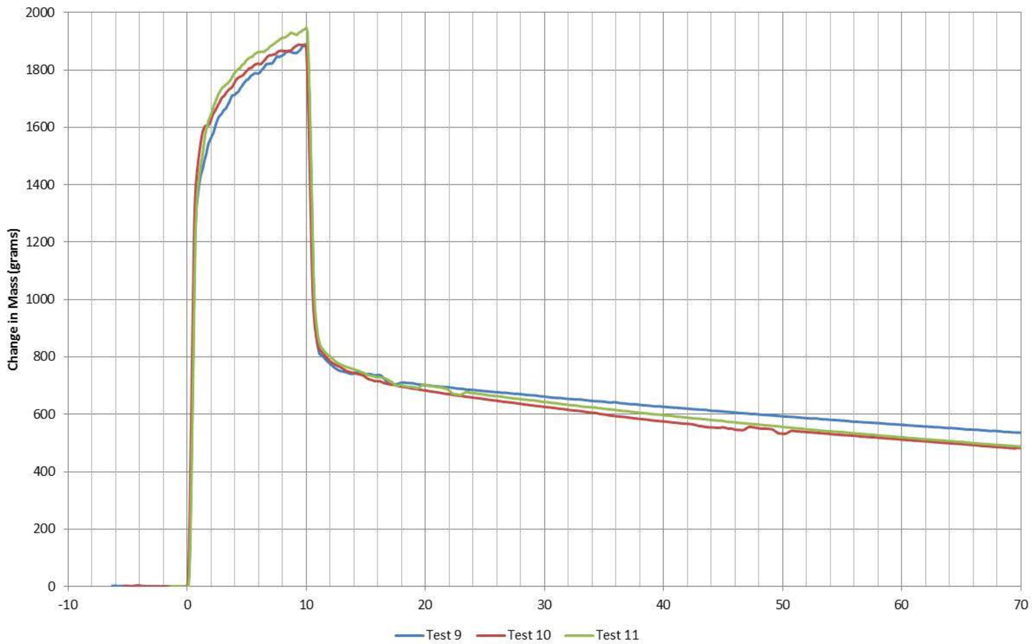

Figure 12 : Comparison of Roxul Wall tests showing repeatability

Table 7 : Summary of water distribution of Roxul assembly tests compared to the Average of XPS assembly tests 1-5 (Table 5)

Test	Exterior of Cladding	Interior of Cladding	Exterior of Insulation
9	34%	24%	28%
10	31%	21%	28%
11	33%	21%	29%
Average	33%	22%	29%
XPS Average	31%	23%	29%

Figure 13 shows the results from Test 12 compared to Tests 9, 10 and 11 to show the change in stored water on the balance corresponding to the removal of the drainage troughs. The difference at the 22 minute mark was approximately 120g (very similar to the XPS assembly results of 150g reported earlier.) The discrepancy of 30 grams or 1 ounce of water in the drainage trough collection volumes is very small considering the volume of water added to the system at 98,000 grams. A small amount of water did bypass the drip edge on the XPS wall which may account for the greater difference in storage values with and without the collection troughs.

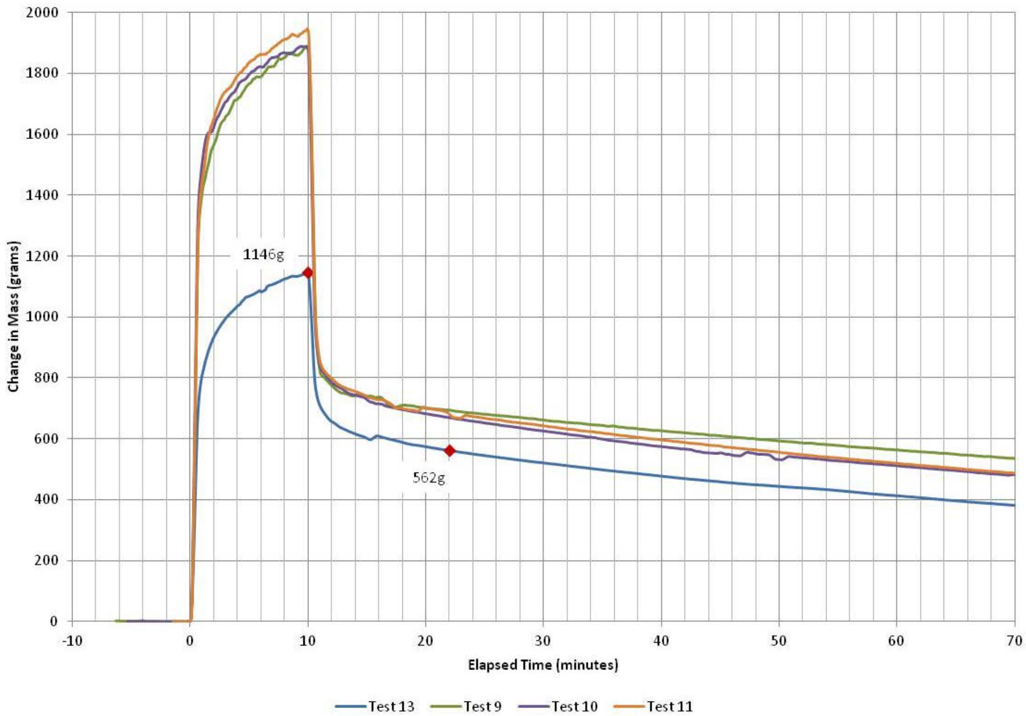

Figure 13 : Comparison of Roxul test wall assemblies with and without drainage troughs

Because the same drainage troughs were installed in the same manner on both the Roxul and XPS wall assemblies, the drainage results from Test 5 on the XPS assembly were compared to the drainage results from Test 9 on the Roxul assembly in Figure 14. The Roxul assembly did store more water than the XPS assembly, approximately 235g at the 22 minute point. **This difference is equivalent to 79 grams (79 mL) per square meter of wall, when the wall is subjected to a horizontal driving rain event that is 70 times higher than 90% of the rainfall events that occur in Toronto.**

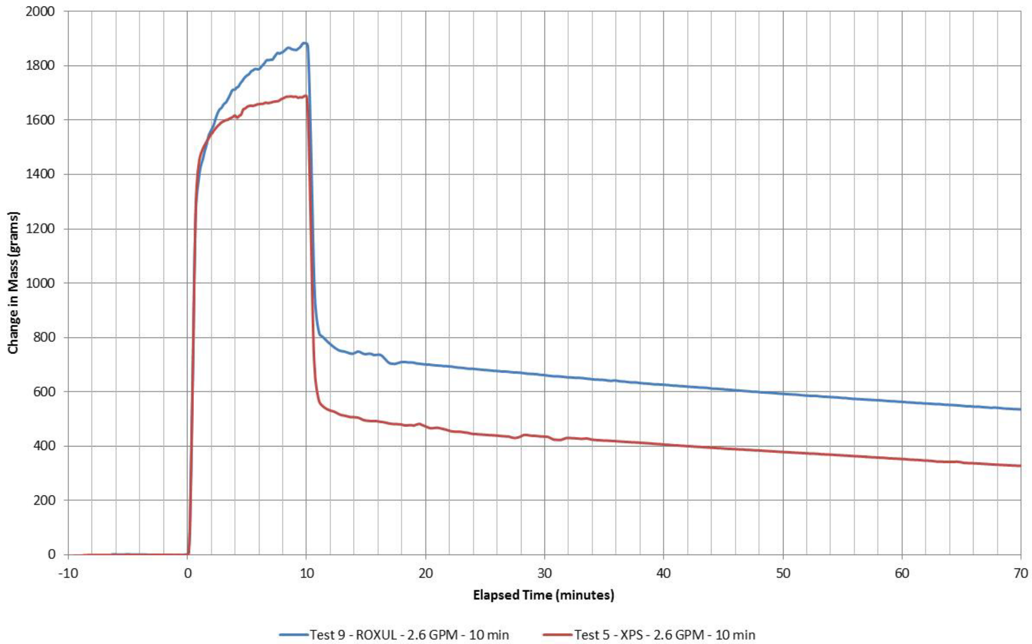

Figure 14 : Comparison of water storage in Test 9 (Roxul assembly) and Test 5 (XPS assembly) with drainage troughs

A test was conducted with some of the open joints covered with tape to determine the distribution of collected water (Figure 15). Figure 16 shows the test results for this test and the amount of water collected from the four collection troughs. The objective of this test was to show that even a small decrease in the open joint area, by reducing the amount of simulated rain that could enter horizontally, would significantly reduce the amount of water contacting and needing to be drained from the continuous insulation. The open area was reduced from 8% to 4% by taping 7 of 15 open joints. The water collected from the exterior of the insulation decreased from an average of 29% of the total water applied (Table 7) to only 11% (Table 8).

Figure 15 : Drainage test showing taped joints

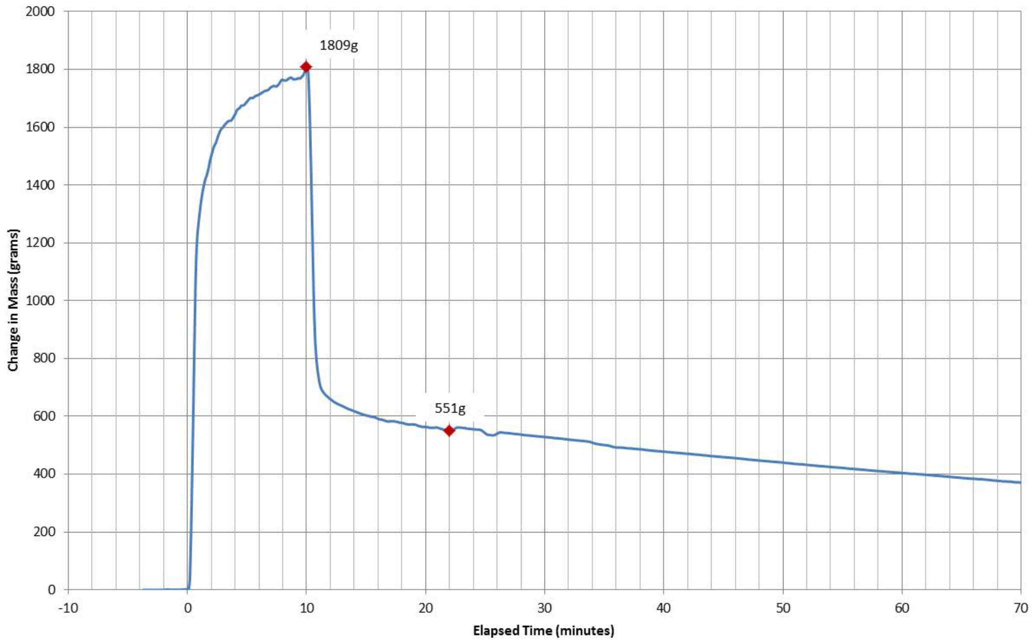

Figure 16 : Roxul wall assembly drainage test with some taped cladding joints

Table 8 shows increases in the water collected on the interior and exterior surfaces of the cladding, and a significant decrease in the water collected on the exterior surface of the insulation as a result of covering some of the open joints.

Table 8 : Comparison of Test 12 test data with taped joints to Tests 9, 10, 11

	Test 9	Test 10	Test 11	Average 9, 10, 11	Test 12
Front of Cladding	34%	31%	33%	33%	40%
Back of Cladding	24%	21%	21%	22%	27%
Front of Insulation	28%	28%	29%	29%	11%

Drying Comparisons

Analysis of the drying rates for the different wall assemblies was also conducted to determine the measured performance differences in the different assemblies following water application. These tests were conducted in a laboratory and the walls were subjected to the same temperature on all sides, with no driving forces added such as wind and sun. Based on our experience, both the XPS and Roxul wall assemblies would dry more quickly with the effects of solar heating, wind pressures, or temperature gradients over the assembly.

Figure 17 shows the drying curves for XPS Tests 3, 4, and 5 compared to Roxul Tests 9, 10, and 11. Two distinct groups of lines are visible on Figure 17, but the lines converge at approximately the 4 hour mark, when both of the assemblies are storing similar amounts of water. Both of these assemblies dry quickly after a significant wetting.

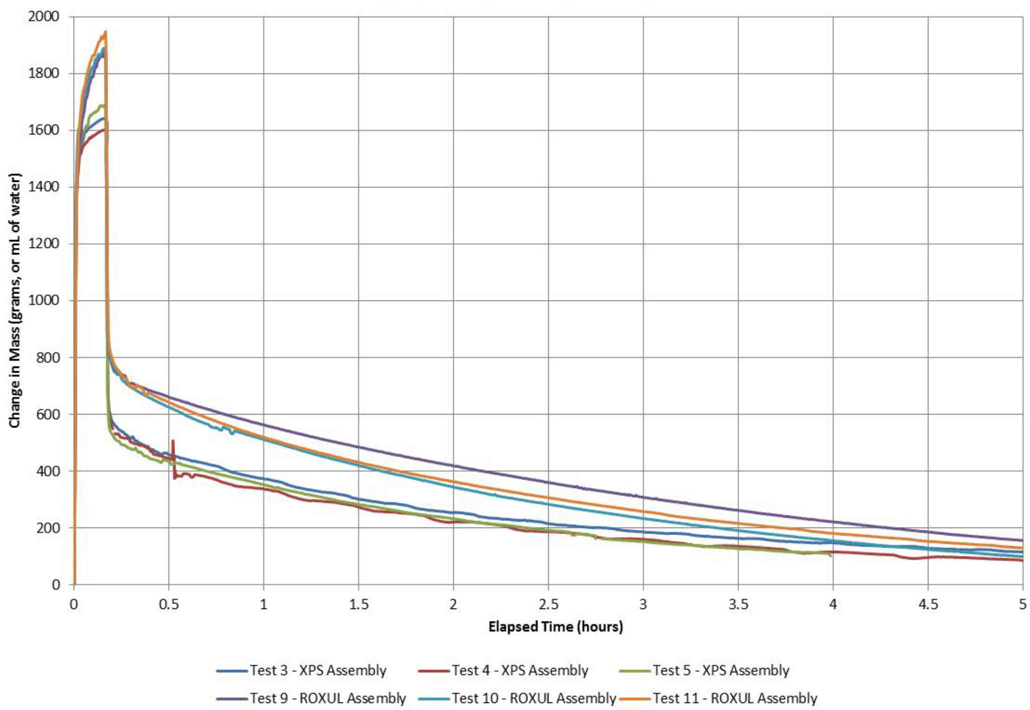

Figure 17 : Comparison of drying after a 10-minute wetting test at 2.6 GPM with drainage troughs

Figure 18 shows the drying comparison for the tests that were conducted with 4 shorter applications of water to the test wall assembly. Initially, the Roxul test wall assembly does store more water following the water applications. After 4 hours of drying, the water storage measurements for the XPS and Roxul test assemblies are within 128g (or 43 g/m^2) of eachother meaning that at 4 hours, the Roxul wall only stores 43 g more water in a meter squared of wall area. After seven hours of drying, the Roxul wall only stores 54 g more total, or 18 g/m^2. This means that 7 hours after an intense simulated driving rain event on open-jointed cladding, one square meter of the Roxul-insulated wall assembly stores approximately half an ounce more water than the XPS wall assembly.

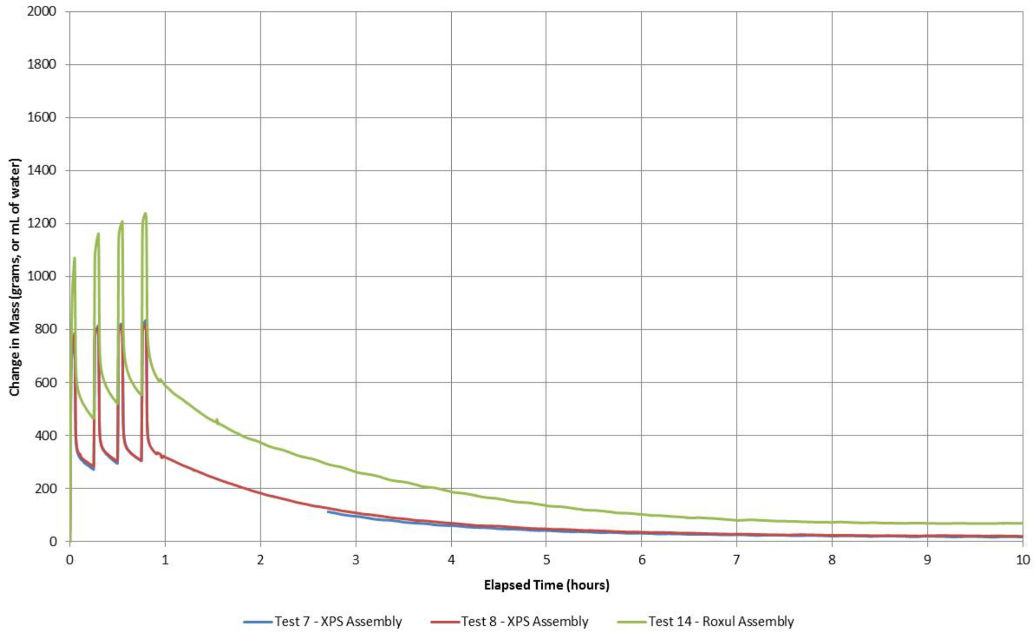

Figure 18 : Drying Comparison - 2.6 GPM, 4 x 3min wetting events, without drainage troughs

Figure 19 shows a comparison between Test 6 (XPS assembly) and Test 13 (Roxul assembly) without drainage troughs. This comparison is similar to Figure 17 but the results shown in Figure 17 included drainage troughs.

Five hours following wetting the difference in the measured water is 30 g/m^2 or about 1 ounce of water per square meter. Extrapolating from this data, both systems would dry within approximately 12 hours.

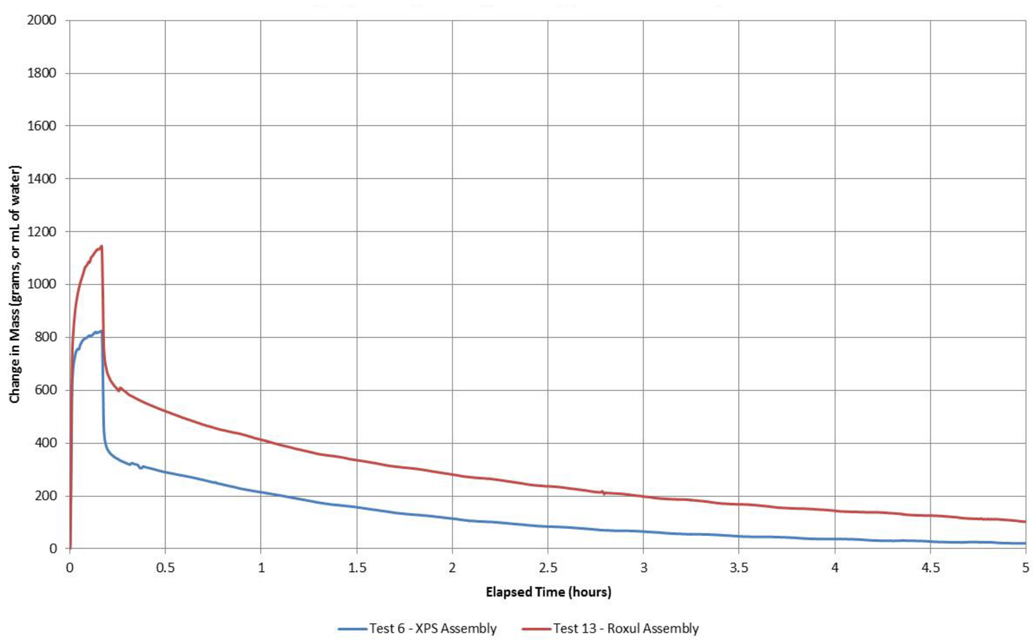

Figure 19 : Comparison of drying after 4x3-minute wetting test at 2.6 GPM without drainage troughs.

Vinyl Siding Testing

During the testing of the open-joint rainscreen, it was determined that the water collected from the surface of the insulation could be significantly decreased by taping some of the open joints. Based on this result, a test was conducted with vinyl siding (Figure 20). The open-joint cladding was removed from the Roxul test wall, and vinyl siding was installed on the z-girts.

A drainage test was conducted on the vinyl siding with the same water application rate of 2.6 GPM (9.8 L/min) for 10 minutes with the collection troughs installed. Table 9 shows the water collection results from the drainage troughs compared to the Roxul test walls average, XPS test walls average and the taped joints test (Test 12). Following the vinyl siding test, there was no water collected in the drainage troughs on the back of the cladding, or the surface of the insulation.

There is a decrease in the total water collected when the joints are taped, and a further decrease for the vinyl siding, as more water was reflected from the higher percentage of cladding, and splashed over the collection trough onto the floor.

This test result means that if the cladding is not a high-percentage open-jointed rainscreen, the amount of water actually coming into contact with the insulation layer in a wall assembly with a realistic driving rain is likely very small, assuming there are no gross deficiencies in construction.

Figure 20 : Roxul wall assembly with vinyl siding installed typically

Table 9 : Drainage trough summary and collection

	Roxul assembly average	XPS assembly average	Taped Open Joints	**Vinyl Siding**
Front of Cladding	33%	31%	40%	**70%**
Back of Cladding	22%	23%	27%	**0%**
Front of Insulation	29%	29%	11%	**0%**

Analysis

The cladding used for full-scale assembly testing in this analysis was intentionally constructed with large and frequent gaps to let water in. This is not of typical of claddings that are installed on residential or commercial construction projects but is becoming more popular in architectural design. Typical cladding systems (siding, panel, EIFS, etc.) would stop a much greater percentage of the water at the exterior surface of the cladding.

The water application was typically 2.6 GPM (9.8 L/min) for the 4'x8' wall area which is based on ASTM E547. An analysis of driving rain measured data was conducted for Toronto, Ontario, and it was found that the 203 mm/hr application rate corresponding to 2.6 GPM (9.8 L/min) is nearly 70 times more than most typical driving rain events on the worst orientation of a building. During this testing the water was applied horizontally from spray nozzles but during typical rainfall the rain falls nearly vertically, so it is less likely for water to be driven through any gaps in the cladding and fall on the surface of the insulation.

In every comparison in this study, the Roxul wall assembly stored more water than its comparison XPS wall. However, the amounts stored by the Roxul insulation were still relatively small. The values for comparison for water storage were typically measured at 12 minutes following the end of water application to ensure that all the excess water had dripped from the surface of the test wall and drained out of the troughs. A summary of these comparison results is shown in Table 10 below.

Table 10 : Comparison of water storage amounts in comparison walls following the completion of water application

	Roxul CavityRock DD	XPS	Difference
2.6 GPM (9.8 L/min), 10 minutes, drainage troughs	682g (24oz) (average of Tests 9,10,11)	480g (17oz) (average of Tests 3,4,5)	203g (7oz)
2.6 GPM (9.8 L/min), 10 minutes, no drainage troughs	562g (20oz) (Test 13)	306g (11oz) (Test 6)	255g (9oz)
2.6 GPM (9.8 L/min), 4 x 3 minutes	589g (21oz) (Test 14)	319g (11oz) (Test 8)	270g (10oz)

The drying analysis was conducted on three similar drainage tests:

- 2.6 GPM (9.8 L/min), 10 minutes, with drainage troughs

- 2.6 GPM (9.8 L/min), 4 x 3min, without drainage troughs
- 2.6 GPM (9.8 L/min), 10 minutes, without drainage troughs.

The drying occurred in the lab, with the same boundary conditions on all sides of the assembly so there were no applied forces to assist with drying. In building enclosures, the walls are often subjected to thermal gradients, wind pressures, ventilation air and solar energy that often help moisture to redistribute and dry more quickly.

Based on the drying analysis, it was concluded that the Roxul test assemblies dried to similar water storage amounts as the XPS wall assemblies in less than five hours after the high water application rate test through open joints in the rainscreen. The measured weight of the water stored in the assembly during drying is shown below in Table 11. A difference of approximately 30 grams (30mL) is approximately one ounce of water on the entire 4'x 8' wall assembly.

Table 11 : Comparison of water storage amounts in comparison walls after 5 hours of drying under laboratory conditions

	Roxul CavityRock DD	XPS	Difference
2.6 GPM (9.8 L/min), 10 minutes, drainage troughs	129g (5oz) (average of Tests 9,10,11)	100g (4oz) (average of Tests 3,4,5)	28g (1oz)
2.6 GPM (9.8 L/min), 10 minutes, no drainage troughs	102g (4oz) (Test 13)	20g (0.7oz) (Test 6)	82g (3oz)
2.6 GPM (9.8 L/min), 4 x 3 minutes	136g (5oz) (Test 14)	45g (2oz) (average of Tests 7 and 8)	91g (3oz)

In the vinyl siding assembly drainage test, which is more typical of current construction practices than an open jointed rain screen, no water was observed behind the vinyl siding during the first two drainage tests (Test 16 and Test 17), and during Test 18 with the drainage troughs installed, no water was visible in the drainage trough on the interior surface of the cladding, or on the exterior surface of the insulation. This means that it is likely in a typical rain event that very little to no water will get through the cladding to the insulation surface. It is expected that some water may enter the cavity based on flashings, and water management details, but this water will dry quickly.

All wall assemblies could experience moisture-related performance issues if there are design deficiencies in the water management system of the wall and the integration with penetrations and interfaces of adjacent surfaces.

Water Uptake Testing

The drainage balance testing protocol developed was used to measure CavityRock DD. Performance of other Roxul products may differ and should be tested individually; however, by comparing their absorption rates to CavityRock DD, the test results from this initial study may be provisionally extended.

There are several tests that are referenced by foam plastic insulation manufacturers, most of which require complete immersion in water. Immersion in water for any length of time is one way to compare different materials, but immersion tests are not an indicator of performance in a wall system, as materials will not be immersed in water unless there is a significant failure of the enclosure control layers. The objective of the drainage balance research was to use a more realistic scenario to determine the worst case of water contact with the insulation with extremely high rain deposition on the surface. Based on the drainage balance testing results, it was determined that maintaining the exterior surface of the insulation in contact with water is more realistic, although still extreme, as this situation is also not expected to occur in a well-designed and constructed enclosure wall assembly.

This report presents the wetting and drying of small samples of mineral wool insulation using a modified ASTM C67 Part 10 test intended for masonry samples. This standard was designed to characterize and compare the water absorption and drying of masonry in continuous surface contact with water, and was modified to be used with continuous exterior mineral wool insulation.

Testing Procedure

Three types of Roxul insulation were used for this laboratory testing:

1. ComfortBoard IS (2” thick)
2. CavityRock DD (3” thick)
3. CIS (2” thick)

Three samples were cut of each type of insulation measuring 12” (30.5cm) x 12” (30.5cm) (1 square foot or 0.093m^2).

The samples were placed with the surface of the insulation in direct contact with water (Figure 21), so the water did not exert hydrostatic pressure on the edges of the sample and all water absorbed into the material was trasfered by capillarity, similar to insulation in a wall assembly.

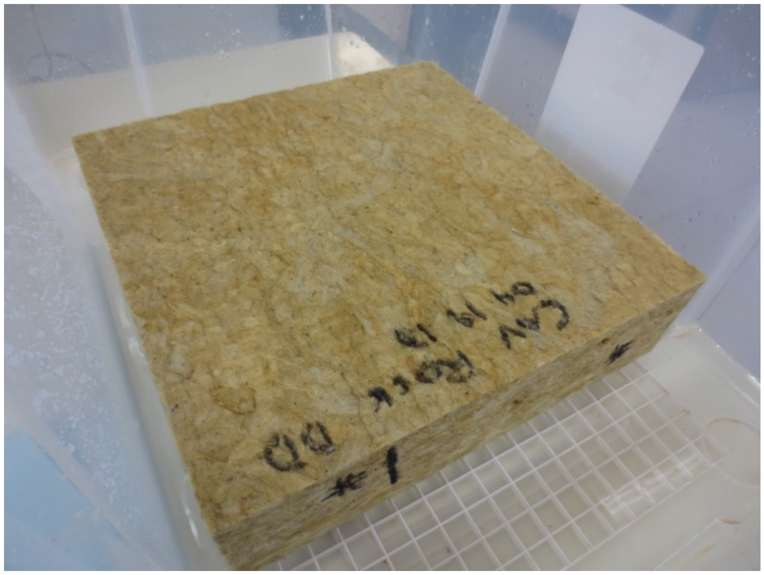

Figure 21 : insulation in contact with water

The sample was removed from the water and weighed to determine the absorbed water at set intervals. The results of these measurements are presented in Figure 22.

When the sample was removed from the water to be weighed, it was held above the water for five seconds to allow the water to run off the surface of the insulation, and then the sample was placed on the scale. Following the five seconds of liquid water runoff, water still accumulated on the surface of the scale while the sample was being weighed.

Fourteen water uptake tests were conducted on the three different insulation types. The results are shown graphically in Figure 22 and numerically in Table 12. All of the tests except for ComfortBoard IS 1 absorbed between 25.9 grams and 14.7 grams. To put that in terms that may be easier to understand, 30 grams of water is equal to one ounce, so a 12” by 12” sample area absorbed approximately 0.5-1.0 ounces of water after being in direct contact with water for 24 hours. This is an insignificant amount of water in a worst-case situation that should never occur with good enclosure design. Even the outlier data point from ComfortBoard IS that was inconsistent with the other five samples only absorbed 37g of water, which is just over an ounce of water.

It can be seen in Figure 23 that even after 24 hours in contact with water, only the very bottom surface of a 2” thick sample is wetted, and that there is no capillary redistribution in the sample.

Based on the very similar water uptake test results when the samples are placed in contact with water, it is expected that full scale drainage balance testing results for ComfortBoard IS and CIS would be very similar to the results obtained for CavityRock DD.

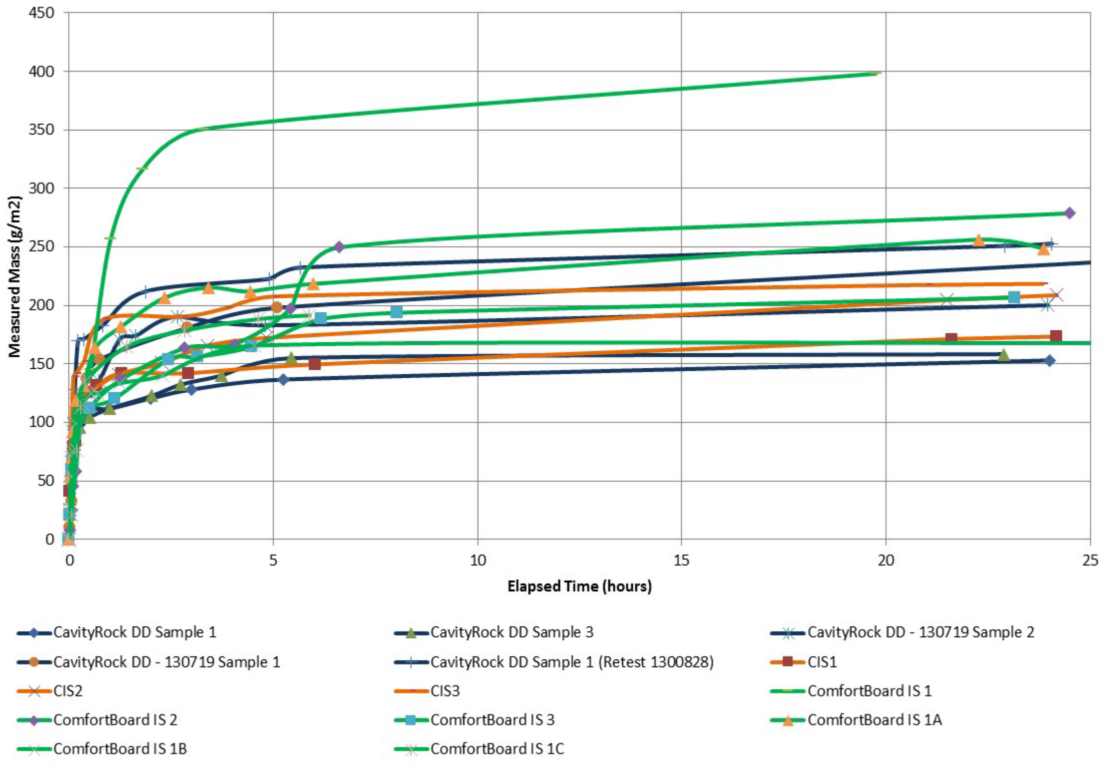

Figure 22 : Water Uptake Testing Results

Table 12 : Summary of water uptake testing results

	Length of Test [hours]	Total Measured Storage [g]	Storage [g/m^2]	Storage [lb/ft^{2}]	Storage [% of dry weight]
ComfortBoard IS 1	19.8	37.0	398	0.082	6%
ComfortBoard IS 2	24.5	25.9	279	0.057	4%
ComfortBoard IS 3	23.2	19.2	206	0.042	3%
ComfortBoard IS 1A	23.9	23.1	248	0.051	4%
ComfortBoard IS 2A	28.8	15.6	168	0.034	3%
ComfortBoard IS 3A	7.8	20.0	215	0.044	3%
CavityRock DD 1	24.0	14.2	153	0.031	2%
CavityRock DD 1*	24.1	23.5	253	0.052	4%
CavityRock DD 3	22.9	14.7	158	0.032	3%
CavityRock DD 1A	25.0	22.0	237	0.049	4%

CavityRock DD 2A	24.0	18.6	200	0.041	4%
CIS 1	24.2	16.1	173	0.035	2%
CIS 2	24.2	19.4	209	0.043	2%
CIS 3	23.8	20.3	218	0.045	2%
* Retesting same sample					

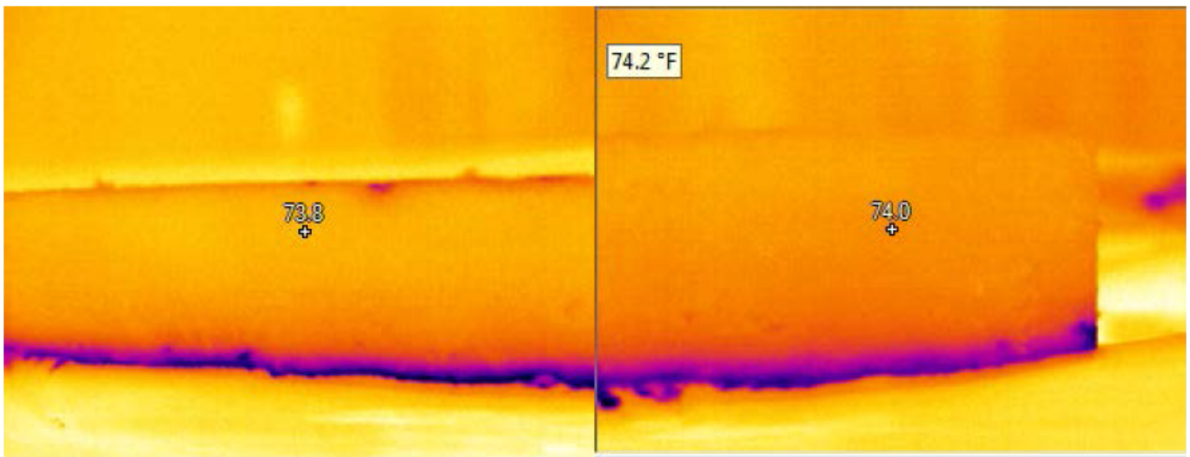

Figure 23 : Thermal images of ComfortBoard IS following 24 hours of water uptake

Conclusions

A novel drainage balance/spray rack test method was developed to address perceptions in the industry that exterior mineral wool insulation in rainscreen applications absorbs enough water to compromise the performance of the wall assembly. The test method was designed to realistically simulate worst-case driven rain on a properly constructed and sealed wall. Using this method, a Roxul wall assembly with exterior continuous CavityRock DD insulation was compared to a wall with exterior continuous XPS, which will not absorb water in this application but does hold water in droplet form on its surfaces.

Under test conditions, the full scale wall assembly of Roxul CavityRock DD assembly was found to store approximately 21 ounces (562-589 g) of water, which dried to insignificant levels within 5 hours.

Based on this research project, it can be concluded that using Roxul CavityRock DD as continuous exterior insulation will not result in excessive moisture storage or result in performance issues relating to the storage of rainwater provided that the control layers in the wall are designed and constructed correctly.

To support the extension of these results, water uptake testing was conducted on CavityRock DD, ComfortBoard IS, and CIS. Because the water uptake results for all three products were very similar, it is expected that drainage balance test results for ComfortBoard IS and CIS would be very similar to those obtained for CavityRock DD.

APPENDIX

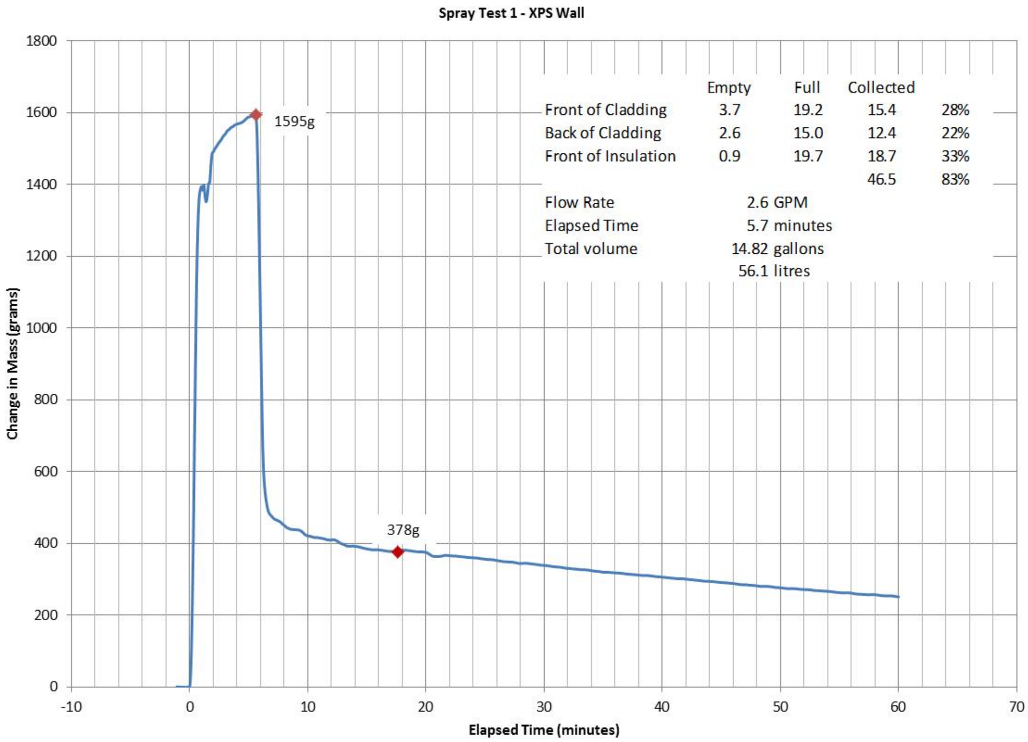

Figure 24 : Test 1 – XPS Assembly – 8% Open Joints – 2.6GPM – 5.7 min – Drainage Troughs

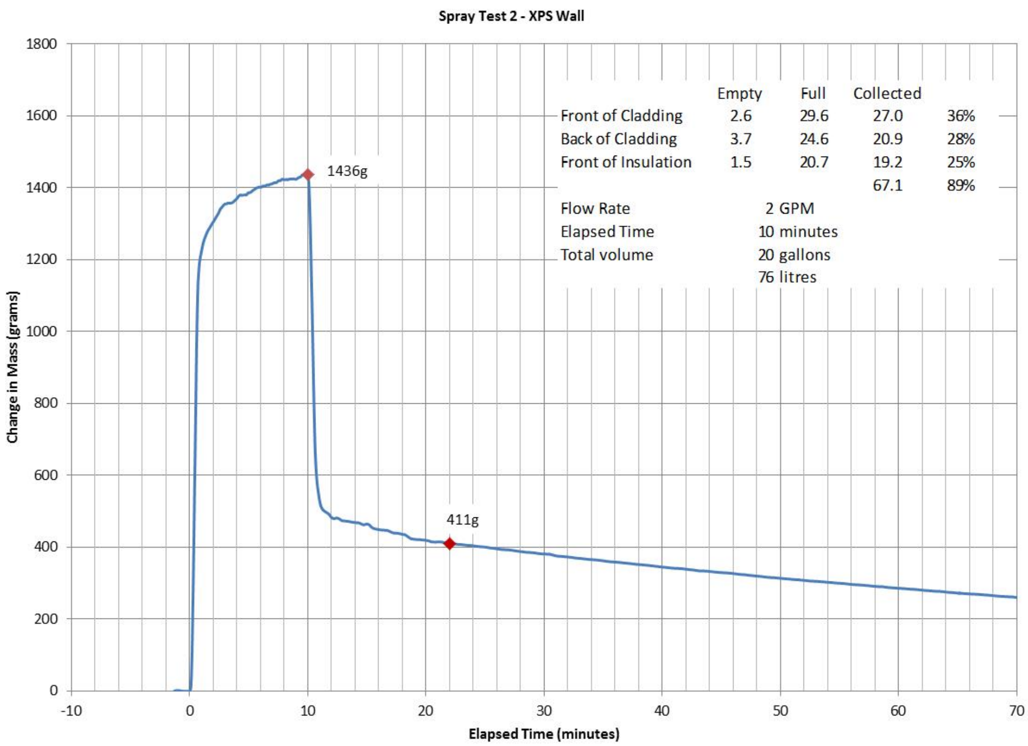

Figure 25 : Test 2 – XPS Assembly – 8% Open Joints – 2.0GPM – 10 min – Drainage Troughs

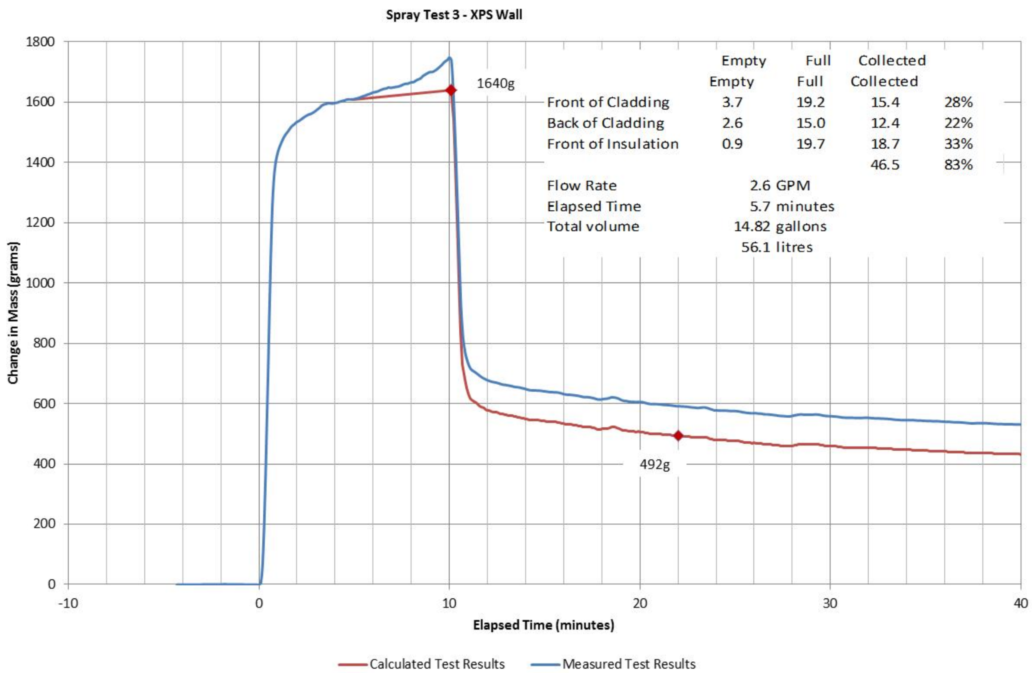

Figure 26 : Test 3 – XPS Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

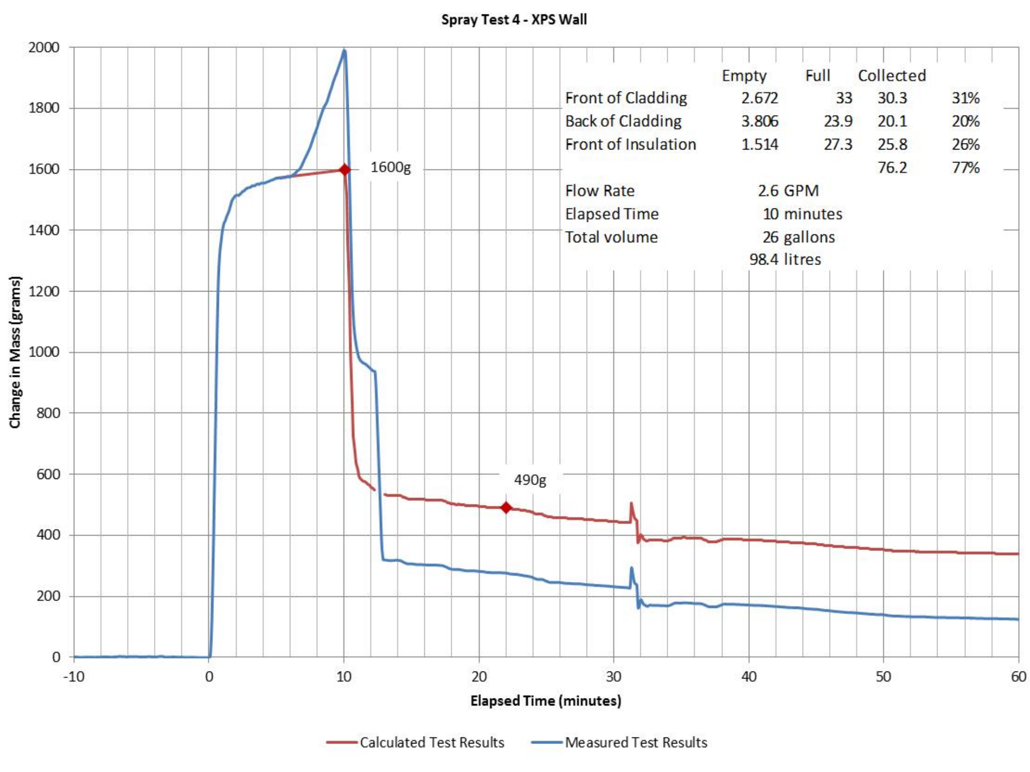

Figure 27 : Test 4 – XPS Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

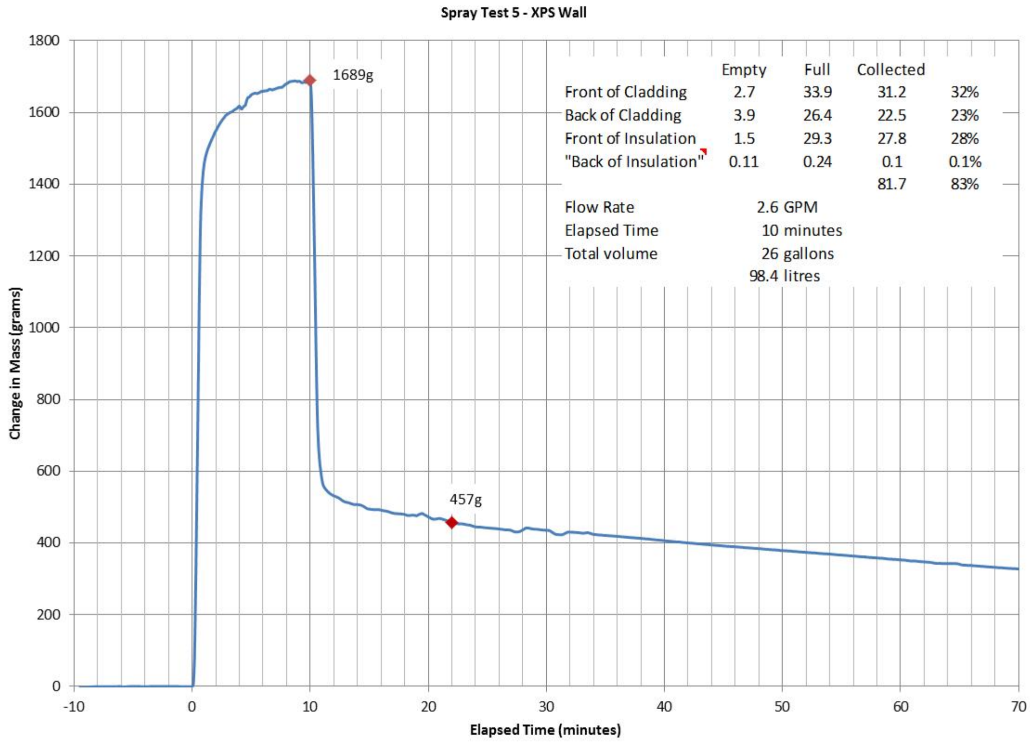

Figure 28 : Test 5 – XPS Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

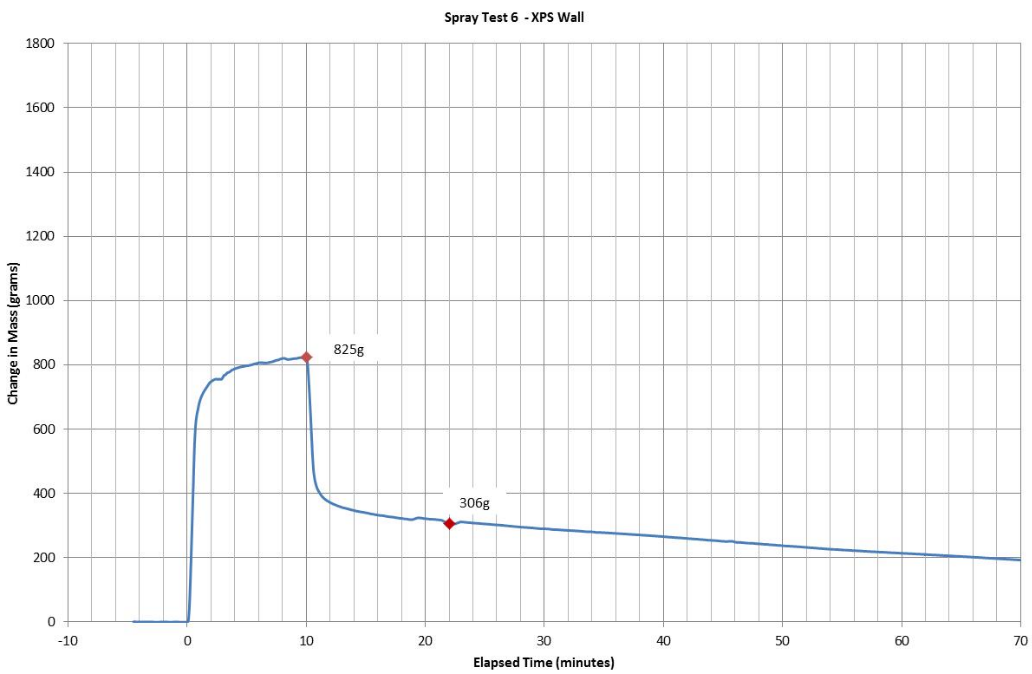

Figure 29 : Test 6 – XPS Assembly – 8% Open Joints – 2.6GPM – 10 min – NO Drainage Troughs

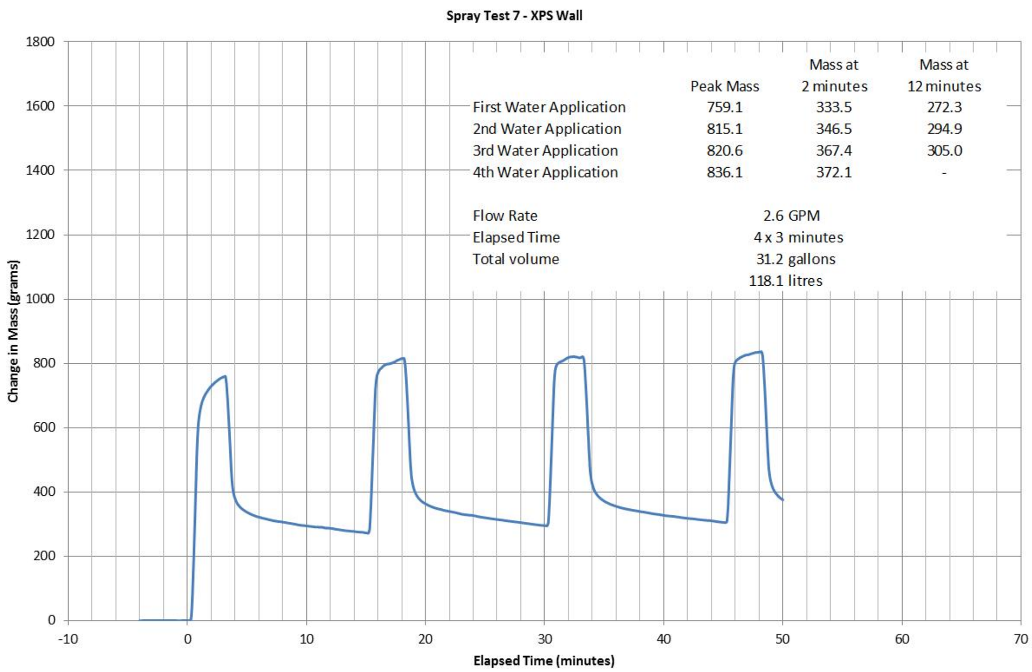

Figure 30 : Test 7 – XPS Assembly – 8% Open Joints – 2.6GPM – 3x4 min – NO Drainage Troughs

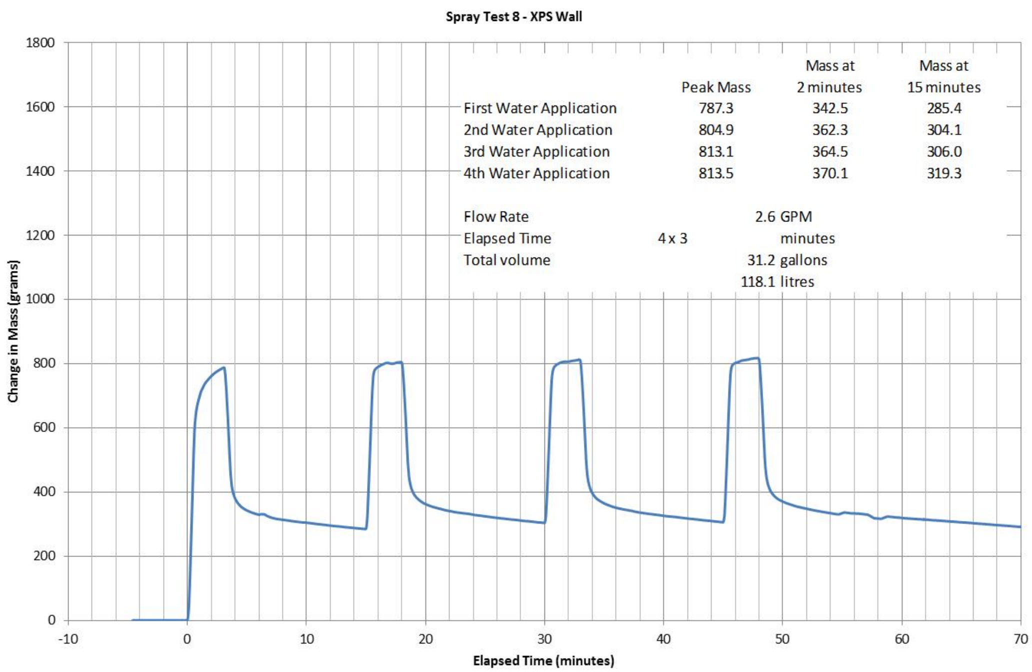

Figure 31 : Test 8 – XPS Assembly – 8% Open Joints – 2.6GPM – 3x4 min – NO Drainage Troughs

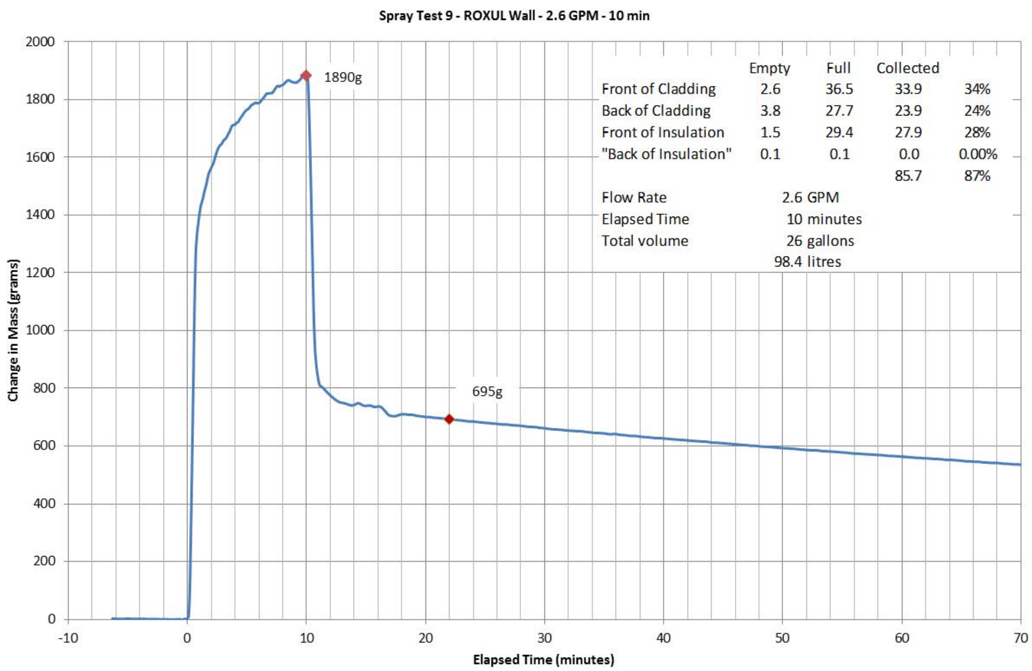

Figure 32 : Test 9 – Roxul Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

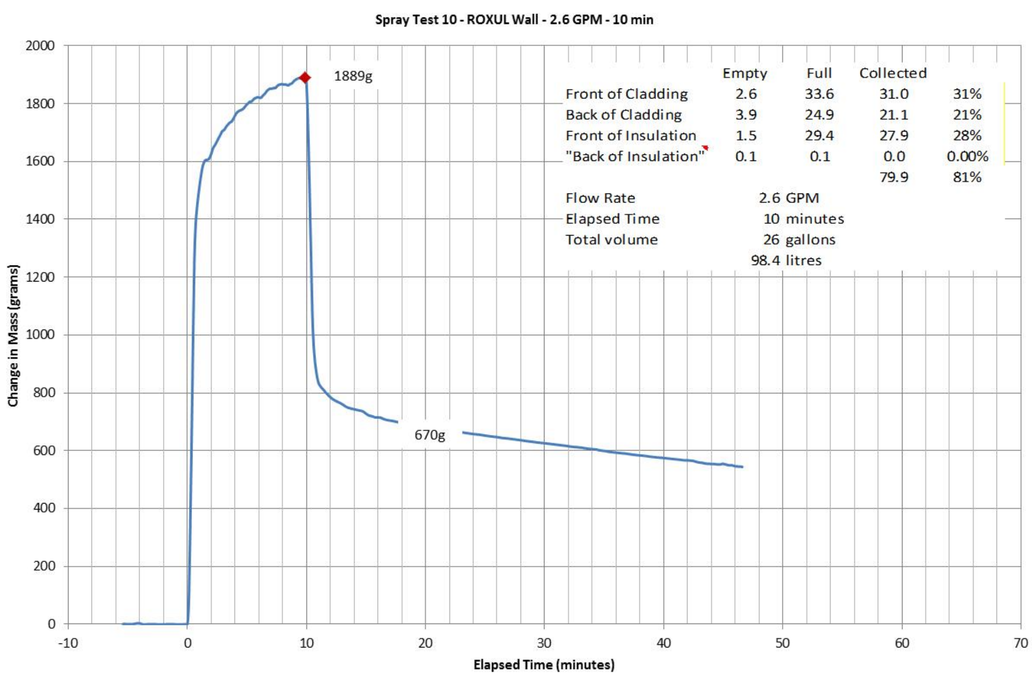

Figure 33 : Test 10 – Roxul Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

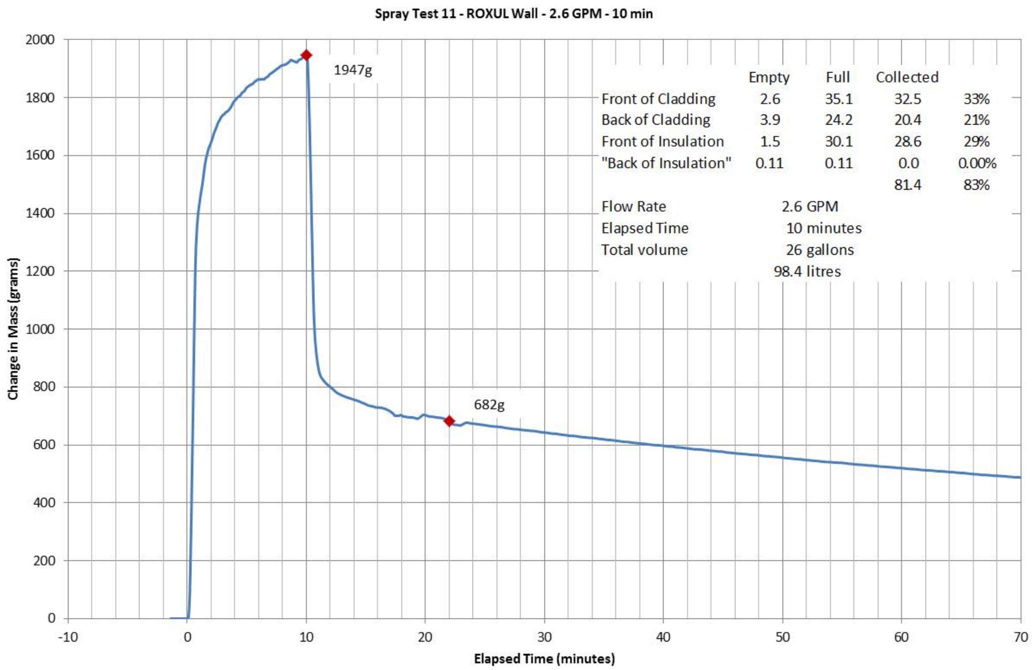

Figure 34 : Test 11 – Roxul Assembly – 8% Open Joints – 2.6GPM – 10 min – Drainage Troughs

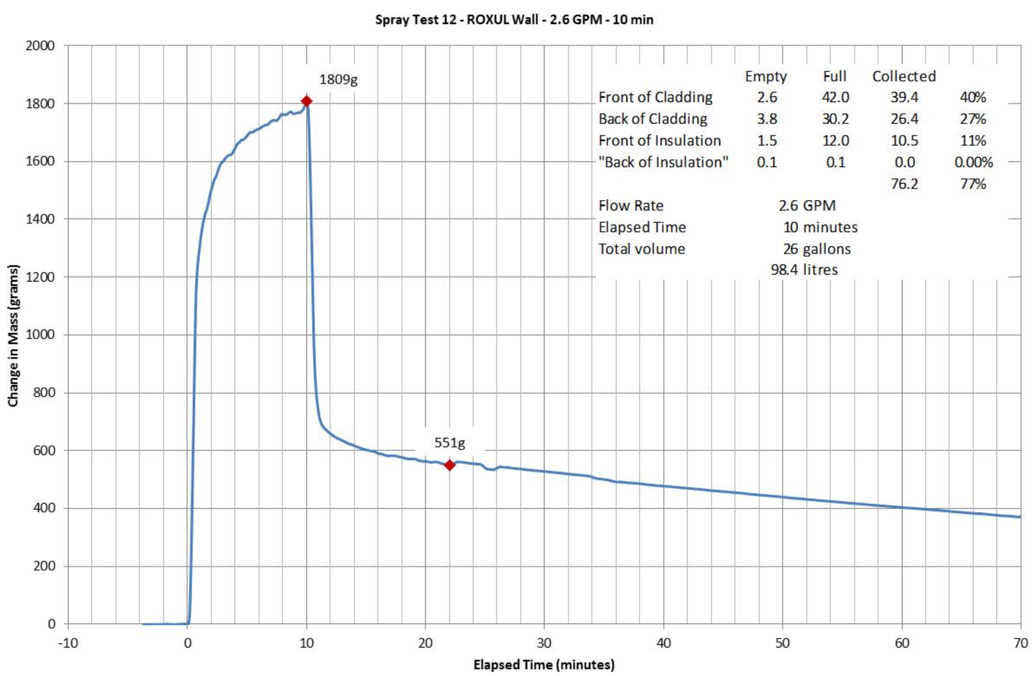

Figure 35 : Test 12 – Roxul Assembly – 4% (taped) Open Joints - 2.6GPM – 10min – Drainage Troughs

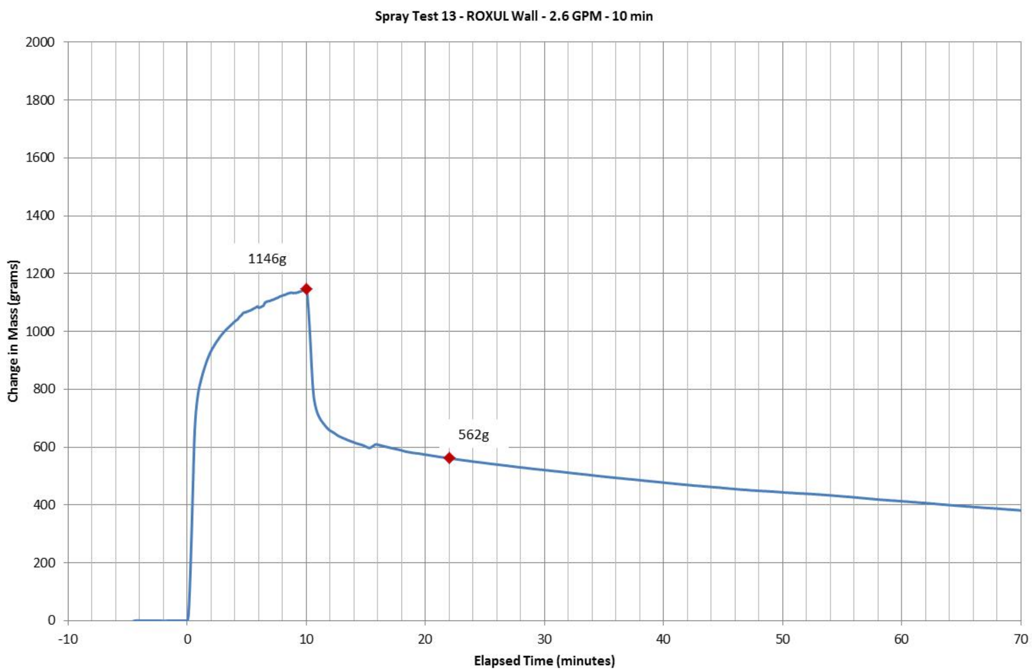

Figure 36 : Test 13 – Roxul Assembly – 8% Open Joints – 2.6GPM – 4 x 3min – NO Drainage Troughs

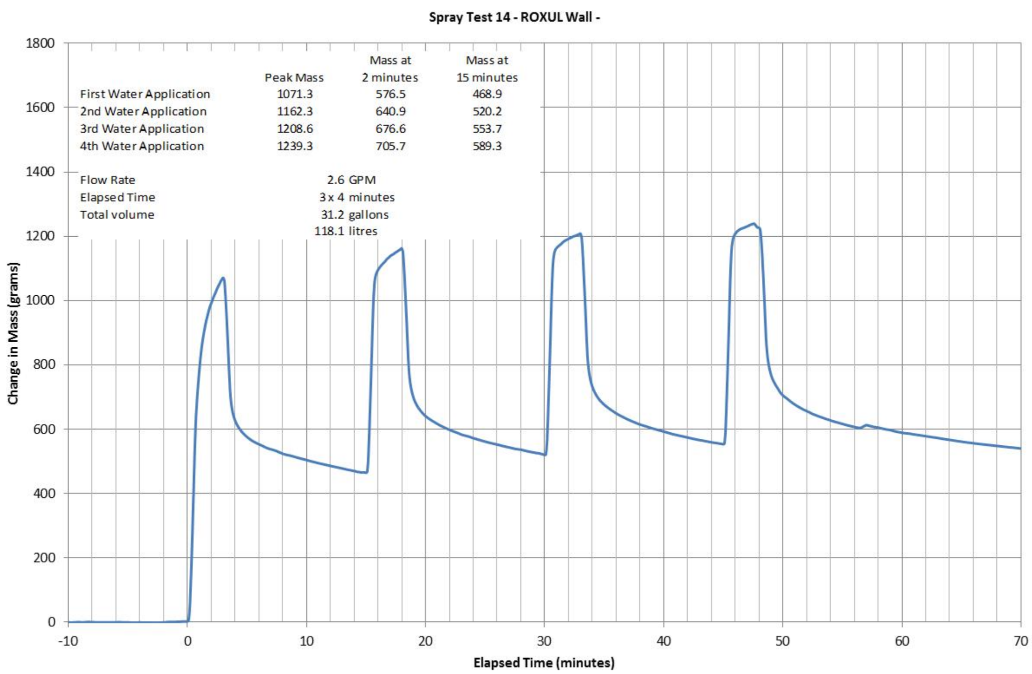

Figure 37 : Test 14 – Roxul Assembly – 8% Open Joints – 2.6GPM – 4 x 3min – NO Drainage Troughs

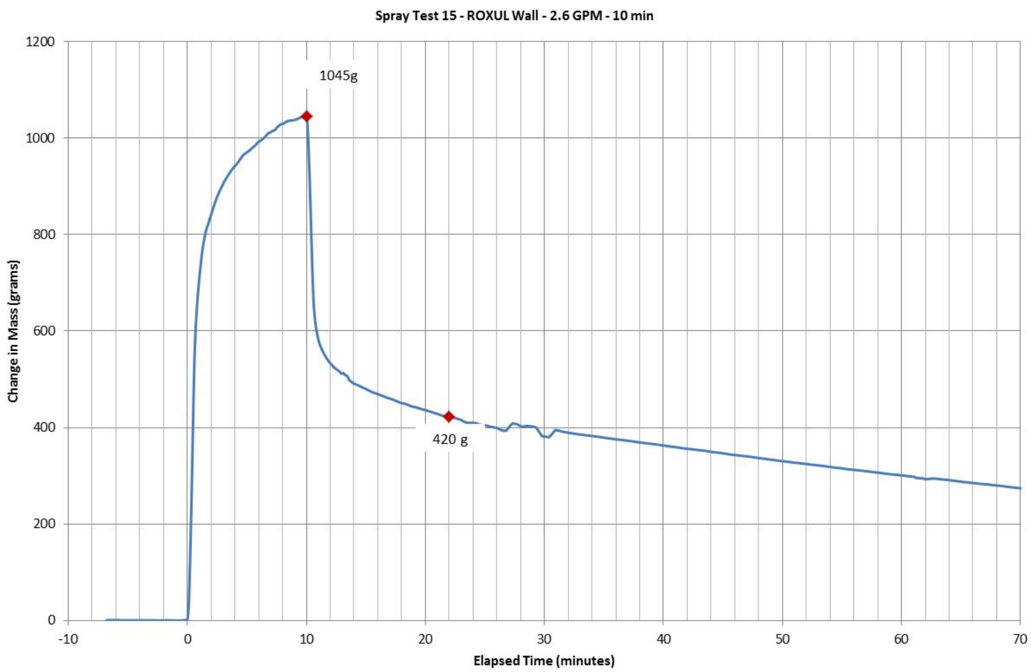

Figure 38 : Test 15 – Roxul Assembly – 4% (taped) Open Joints - 2.6GPM – 10min – NO Drainage Troughs

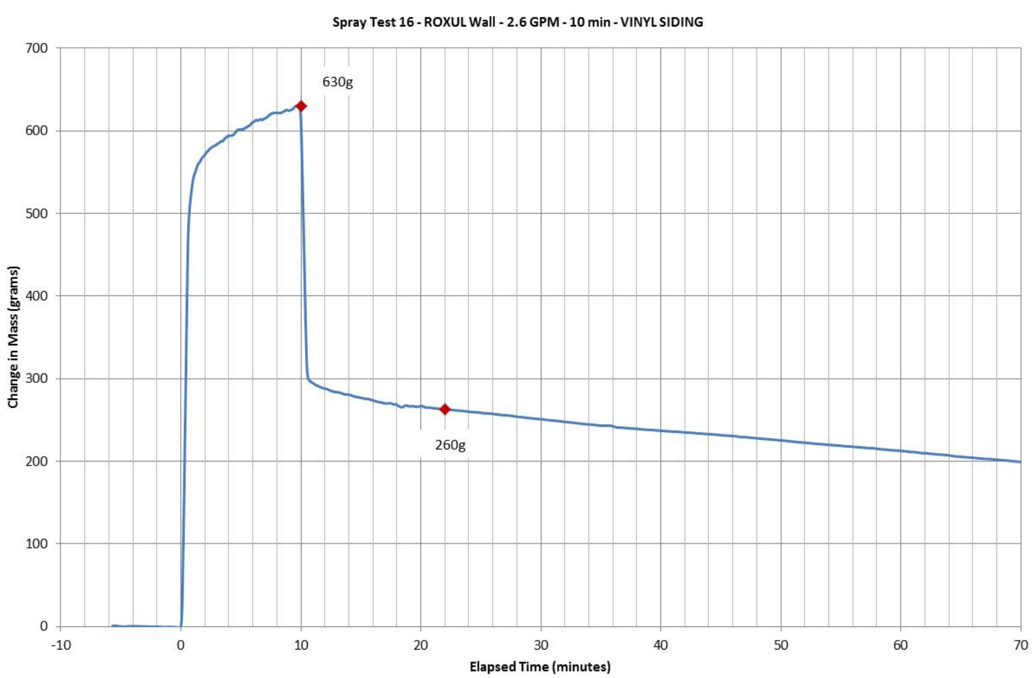

Figure 39 : Test 16 – Roxul Assembly – Vinyl Siding – 2.6GPM – 10min – NO Drainage Troughs

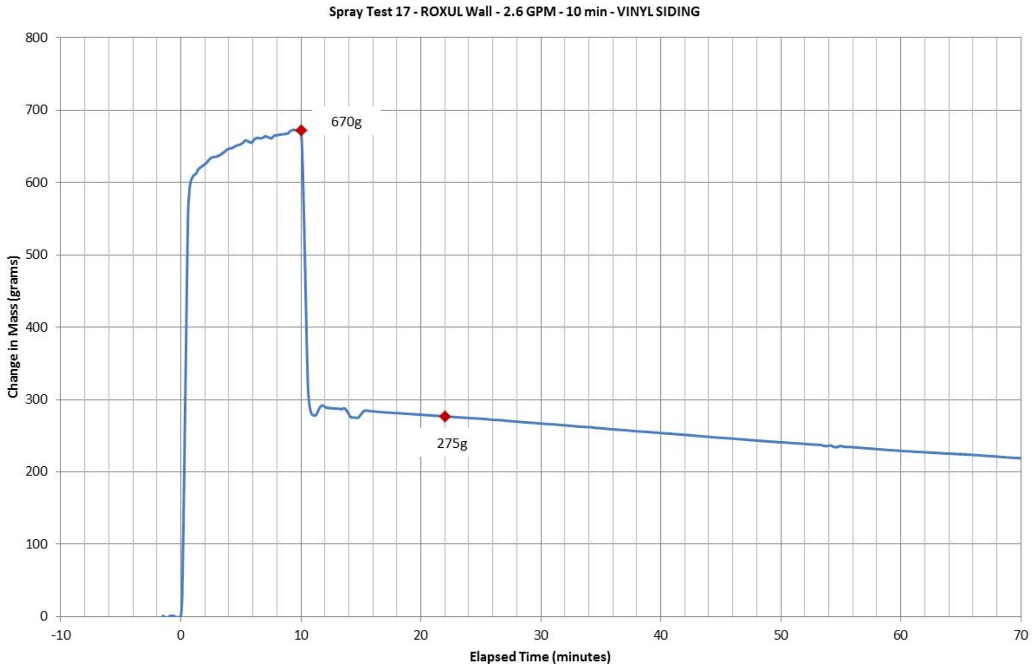

Figure 40 : Test 17 – Roxul Assembly – Vinyl Siding – 2.6GPM – 10min – NO Drainage Troughs

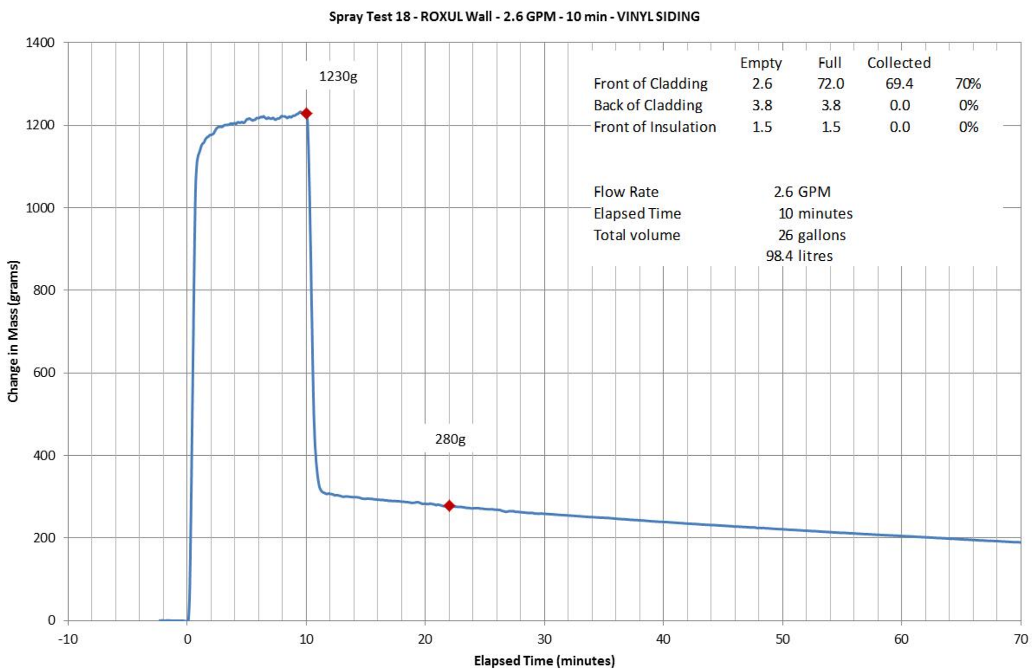

Figure 41 : Test 18 – Roxul Assembly – Vinyl Siding – 2.6GPM – 10min – Drainage Troughs