BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

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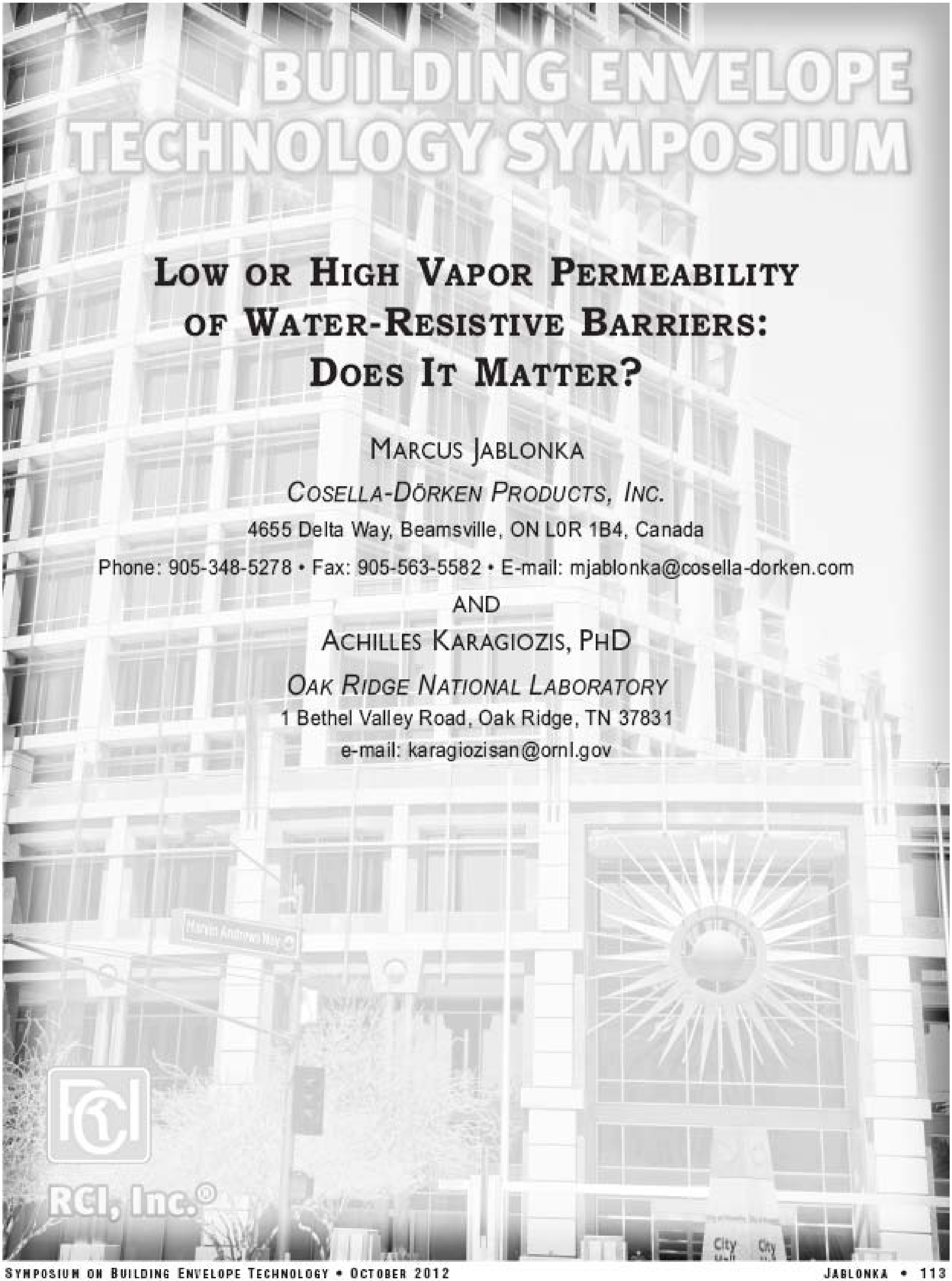

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

LOW OR HIGH VAPOR PERMEABILITY OF WATER-RESISTIVE BARRIERS: DOES IT MATTER?

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ABSTRACT

Advances in the application of polymers brought new polymeric water-resistive barriers (WRB_)with a wide range of vapor permeability to market, commonly referred to as "breathable" housewraps. At this time, there is virtually no guidance available regarding the selection of the optimum vapor permeability of such membranes.

This paper evaluates the impact of various WRB with a large range of vapor permeability on the hygrothermal performance of wall assemblies. The information enables designers to select products with the most suitable vapor permeability for particular conditions. Variations in boundary conditions include climatic locations, cladding type, and type of WRB deployed. The results for the performance of the wall systems are presented in the form of a mold index.

SPEAKER

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LOW OR HIGH VAPOR PERMEABILITY OF WATER-RESISTIVE BARRIERS: DOES IT MATTER?

The variety and characteristics of water-resistive barriers (WRBs) have changed significantly over the past several decades. Advances in the application of polymers brought to market new polymeric WRBs with a wide range of vapor permeability, commonly referred to as "breathable" housewraps. However, a significant information gap has resulted in uncertainty among design professionals and the construction industry at large regarding the in-service performance of various WRB products and the selection of the optimum vapor permeability under specific conditions.

This paper describes a research project that evaluates the impact of various WRBs with a large range of vapor permeability on the hygrothermal performance of different wall assemblies—information vitally important to proper product selection that to this point has not been available to designers in North America. Variations in boundary conditions included climatic conditions (seven climatic locations), cladding type (brick, adhered manufactured stone veneer, cement-board, three-coat stucco), and type of WRB (low versus high vapor permeability) deployed. The research approach was structured into several phases.

1. INTRODUCTION

A WRB performs several different functions in a building enclosure. Its primary function is to serve as a second line of defense and shed water that penetrates the cladding. Even though the building enclosure may be designed properly by design professionals, experience shows that defects created during the construction process or those occurring during the service life of the structure may allow water to enter the wall assembly. Hence, well-functioning wall assemblies are typically designed to permit drainage on the surface of the WRB and—particularly important for wood-frame construction—drying of any excess moisture. Therefore, the WRB needs to be vapor-permeable in order to allow for outward diffusion of water vapor. The moisture balance of the building material adjacent to the water-resistive barrier will be strongly affected by the water vapor flow caused by thermal drive, which may vary, depending on the moisture content and temperature of outdoor air and on solar radiation. A reverse thermal gradient may cause inward vapor diffusion into the wall cavity. For this reason, WRBs need to be evaluated in regard to their effect on the performance of a wall assembly (Jablonka, 2011). Some WRBs, when installed as air barriers, also play an important role by controlling the flow of air through the building enclosure. It has been documented (Plastics, 2000) that the addition of a WRB reduced air infiltration by about 12% on homes that had infiltration rates well below 1.1 air changes per hour at 50 Pa pressure difference.

Depending on the climatic conditions and the type of sheathing and cladding material used, different types of WRBs may be incorporated in the wall assembly to optimize its performance and durability. The available variety and characteristics of such membrane products have changed significantly over the past several decades. Advances in the application of polymers brought a large variety of "breathable housewraps" with a wide range of vapor permeability to market. However, a significant information gap has resulted in uncertainty among design professionals and the construction industry at large regarding the in-service performance of various types of WRBs and the selection of the optimum vapor permeability of such membranes under specific conditions. This paper describes a research project that evaluates the impact of various WRBs with a large range of vapor permeability on the hygrothermal performance of different wall assemblies—information vitally important for proper product selection.

2. OBJECTIVE

The objective of this research project was to understand the performance of different WRBs with various vapor permeabilities in different climates and cladding applications in building wall assemblies. The sensitivity to different types of water ingress (location in the wall assembly) was examined as a function of WRB and climate.

3. SCOPE

Variations in boundary conditions included climatic conditions, cladding type, and type of WRB deployed.

The research approach was structured into several phases.

In the first phase, the water-vapor permeability of different WRBs was determined as per ASTM E96. Subsequently, a subassembly laboratory test was designed to simulate performance of a small component of a wall system during operation under controlled conditions to predict the performance of large-scale assemblies, and to validate the performance simulation tool. A variation of the hygrothermal loads was performed to allow gapping between perfectly built wall assemblies and walls with realistic imperfections (workmanship issues). A number of parameters were varied to understand the sensitivity of the results to the different types of substrate, cladding, and climatic locations. In the next phase, simulations were carried out with a hygrothermal computer model (WUFI PRO 5.1). The sheathing moisture content, temperature, and relative humidities were plotted against time for comparison and analysis, and presented as an index of moisture performance. In the final phase, the results were embedded into a software selection tool, allowing an architect to select a specific climate zone, cladding type, WRB with a particular perm rating, and wall orientation. Results are being presented as a function of moisture performance index (mold index).

4. WATER VAPOR-PERMEANCE TESTING

Material property and subassembly tests were performed to support and strengthen the computer simulations. *Table 1* shows a summary of the WRBs that were tested and their dry-cup and wet-cup

	Method A	Method B
Water-resistive Barrier	**Dry Cup**	**Wet Cup**
	[ng/Pa m^2 s]	[ng/Pa m^2 s]
WRB A	12,284 (214 perms)	13,812 (241 perms)
WRB B	804 (14 perms)	1,597 (28 perms)
WRB C	3,444 (60 perms)	3,737 (65 perms)

Table 1 – Summary of vapor permeance as per ASTM E96 (dry-cup versus wet-cup method).

vapor-permeance values, determined using ASTM E96, Method A and Method B (Straube *et al.*, 2010).

The wet-cup (Method B) testing did result in higher average permeance values than the dry-cup (Method A) testing, as anticipated. The greatest increase in vapor permeance occurred with the WRB B, which nearly doubled in vapor permeance between the dry-cup and wet-cup tests. The wet-cup vapor-permeance test is more appropriate for determining the drying performance of walls, since it predicts performance under moisture loads.

5. SUBASSEMBLY TESTING

Testing the vapor permeance according to ASTM E96 demonstrates how the WRB performs as an individual material, but it is also important to understand how the WRB performs in combination with oriented strand board (OSB) or exterior gypsum sheathing, which more closely simulates a wall assembly. A subassembly laboratory study was undertaken to more clearly understand the drying ability of WRBs in combination with OSB or exterior-grade gypsum sheathing. The subsystem testing was designed to simulate performance of a small component of a wall system during operation under controlled conditions to predict the performance of large-scale assemblies and to validate the performance simulation model.

Two different types of polymeric, vapor-permeable WRBs and #15 asphalt-impregnated building paper were tested in the subassembly test. Twenty-seven subassembly test samples were made using three different WRBs installed on either OSB or exterior-grade gypsum sheathing as shown in the testing matrix in *Table 2*. The differences between interior and exterior wetting are shown in *Figure 1*.

Square samples measuring 330 x 330 mm (13 x 13 in.) were cut from sheets of OSB and exterior-grade gypsum sheathing. The edges of the samples were wrapped with foil tape to create a 305 x 305 mm (12- x 12-in.) active test area.

Four layers of moisture storage media were installed between the sheathing and the WRB to simulate exterior wetting, or installed on the opposite side of the sheathing from the WRB, to simulate wetting on the interior in the stud cavity as shown in the schematic in *Figure 1*. A 0.125-in. ID tube was installed to provide water to the moisture storage media.

Four layers of 6-mil poly were installed on the interior surface of the sheathing and sealed with aluminum foil tape to the edges of the sample. For interior wetting, the water storage media was visible through the poly to inspect the storage media for saturation.

Figure 2 and *Figure 3* show the exterior and interior surfaces of a subassembly test-

	OSB - interior wetting	OSB - exterior wetting	Gypsum sheathing - interior wetting	Gypsum sheathing - exterior wetting
WRB A	4	1	3	1
WRB B	4	1	3	1
Building Paper	4	1	3	1

Table 2 – Testing matrix showing number of subassembly samples of each construction.

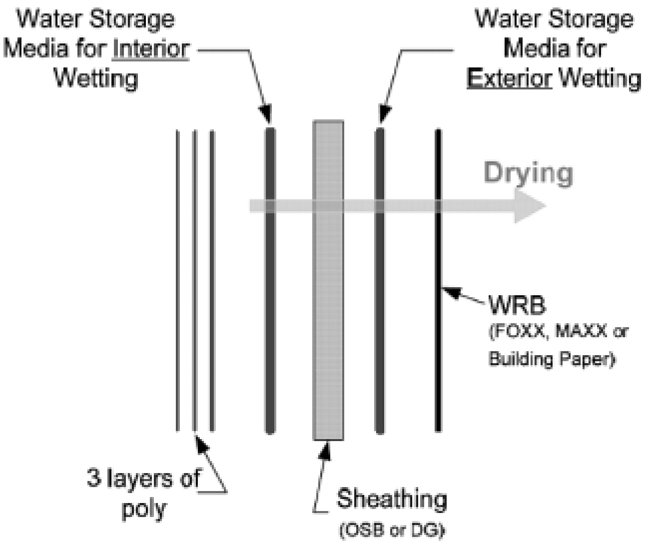


Figure 1 – Subassembly testing sample schematic.

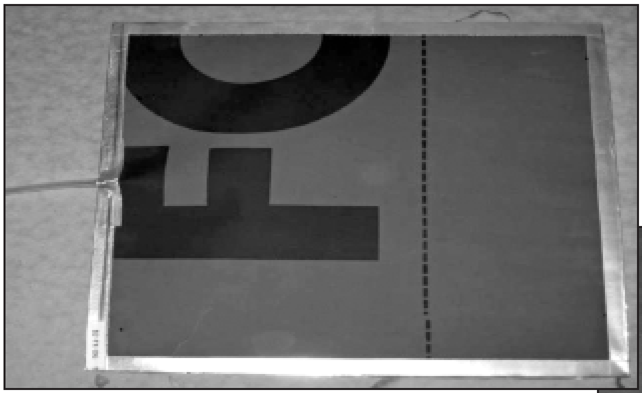


Figure 2 – Exterior surface of subassembly. Test sample with exterior wetting.

Figure 3 – Interior surface of subassembly. Test sample with interior wetting.

ing sample. *Figure 3* shows the wetting storage media on the interior surface through the multiple layers of polyethylene sheet.

5.1 Procedure

The test for each sample began by adding 100 mL (5 doses of 20 mL) by syringe to the water storage medium. Each dose of water was injected over approximately 10 seconds followed by 20 seconds of wait time for water to redistribute into the water storage medium before adding more water. The samples were held at a constant angle for all water injections.

The samples were weighed before and after any water was added to determine the actual mass of water added by syringe. Each subsequent day, the sample was weighed to determine the mass of water lost, and the same amount of water lost was added. The total mass lost and water added were graphed in *Figure 4* to show the rates of both wetting and drying. If the two rates (line slopes) for wetting and drying were similar, the sample was determined to be at equilibrium, and an effective permeance could be calculated.

If no water had been lost from the previous day, 20 more mL of water was added each subsequent day until "ponding" of water was observed in the water storage media through the polyethylene. This occurred when the storage medium was saturated and water was not being absorbed into the substrate quickly enough.

Once the rates of wetting and drying were calculated, repeatability was determined by increasing the amount of water injected into the water storage media for two subsequent days at a rate of twice the daily loss. This dosage was increased to determine if the effective system permeance would change when a higher volume of water was added to the sample. Following the two days of increased loading, only the amount of water lost was added back to the sample.

5.2 Boundary Conditions

The testing was conducted in a constant climate room (CCR) where the RH and temperature can be tightly controlled. The climate controls for the room were set at 23°C (±1°C) and 50% RH (±2%).

To determine the vapor pressure gradient, it was assumed that the relative humidity in the sample during the testing and continuous daily wetting of the water storage medium was 100%. These subassembly tests help simulate real wetting conditions, but in wall systems there are usually temperature gradients across a wall that will affect the drying rate. These tests were run with no temperature gradient across the subassembly system, which is the worst-case scenario for drying perfor-

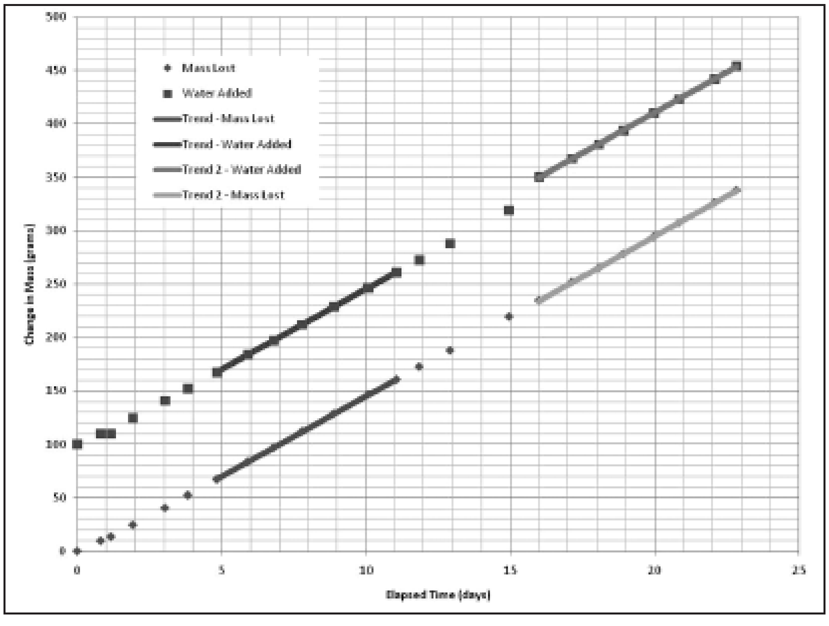


Figure 4 – Sample data set from subassembly testing (Straube et al., 2010).

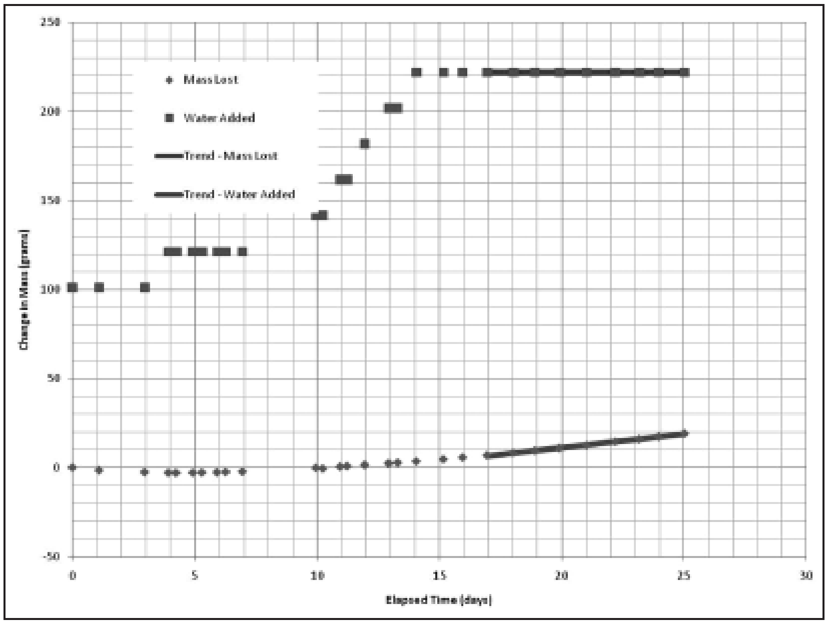


Figure 5 – Data for interior OSB wetting with WRB A (Straube et al., *2010).*

mance. If a temperature gradient was added, the drying rates would increase, but the ratio of drying amounts would remain the same.

5.3 Results

5.3.1 WRB A

The dry-cup vapor permeance of WRB A, according to ASTM E96, Method A, is 214 perms (12,284 ng/Pa·s·m^2), and the wet-cup vapor permeance, according to ASTM E96, Method B, is 241 perms (13,812 ng/Pa·s·m^2). This was the highest vapor-permeance WRB in the subassembly testing.

OSB Substrate

OSB has a vapor permeance of approximately 1 to 2 U.S. perms (57 to 115 ng/Pa·s·m^2), although the vapor permeance will change with RH as well as age of the OSB.

Figure 5 shows a typical data set from samples of OSB with interior wetting. Very little mass was lost over the duration of the test, and the water storage medium became saturated with water and unable to store more. At the beginning of the test, the OSB substrate adsorbed moisture from the constant climate room and gained mass, resulting in negative mass lost on the graph.

The average mass lost for all OSB samples with interior wetting and WRB A was 1.4 grams per day, which is an effective sample vapor permeance of 2.2 U.S. perms (126 ng/Pa·s·m^2).

Simulating an exterior wetting with the water storage medium between the OSB and WRB A resulted in a loss of 40.6 g/day or effective sample permeance of 89 U.S. perms (5107 ng/Pa·s·m^2).

Exterior-Grade Gypsum Substrate

Moisture from interior wetting of exterior-grade gypsum sheathing was able to dry much more quickly than the OSB case. The vapor permeance of the exterior-grade gypsum product used in the test is 23 perms (1,300 ng/Pa·s·m^2), which is a value reported by the manufacturer. The average mass lost for all samples was 37.1 g/day. The effective sample permeance for wetting on the interior of the exterior-grade gypsum sheathing with WRB A is 56 perms (3,240 ng/Pa·s·m^2).

Exterior wetting of the exterior-grade gypsum sheathing was approximately the same as the exterior wetting of OSB, resulting in a daily mass loss of 52.2 g and an effective sample vapor permeance of 52 perms (5,317 ng/Pa·s·m^2).

The interior wetting of the exterior-grade gypsum subassembly with WRB A dried more slowly than the exterior wetting of both OSB and exterior-grade gypsum sheathing, indicating that with the higher-vapor-permeance WRB A, the exterior-grade gypsum sheathing may limit vapor diffusion drying. WRB A is approximately ten times more vapor permeable than exterior-grade gypsum sheathing.

5.3.2 WRB B

The dry-cup vapor permeance of WRB B, according to ASTM E96, Method A, is 14 U.S. perms (804 ng/Pa·s·m^2); and the wet-cup vapor permeance, according to ASTM E96, Method B, is 28 U.S. perms (1597 ng/Pa·s·m^2). WRB B has a much greater vapor permeance than OSB, which is 1 to 2 perms (57 to 115 ng/Pa·s·m^2), and WRB B has approximately the same vapor permeance as exterior-grade gypsum sheathing, which is 23 perms (1,300 ng/Pa·s·m^2) when WRB B is in a high-RH environment (simulated by Method B wet cup ASTM E96).

OSB Substrate

Subassembly testing of OSB and WRB B performed similarly to the WRB A. The vapor permeance of the OSB was the controlling force in drying from interior wetting. The mass lost during interior wetting was 1.7 g/day, which is an effective sample permeance of 1.7 perms (96 ng/Pa·s·m^2).

Exterior wetting of the OSB with WRB B resulted in 16.1 g/day or an effective sample permeance of 24.8 perms (1,423 ng/Pa·s·m^2).

Exterior-Grade Gypsum Substrate

Interior wetting of the exterior-grade gypsum sheathing with WRB B resulted in a mass loss of 15.0 g/day, which is an effective sample permeance of 23 perms (1,327 ng/Pa·s·m^2).

Exterior wetting between the exterior-grade gypsum substrate and WRB B resulted in a mass loss of 16.1 g/day and an effective sample permeance of 24.8 perms (1,423 ng/Pa·s·m^2).

The effective permeance for the exterior and interior wetting of exterior-grade gypsum sheathing, and the exterior wetting of OSB with WRB B all have similar mass loss and effective sample vapor permeances. This means that in the subassembly test of interior wetting on exterior-grade gypsum sheathing, the limiting factor for drying was the WRB B, not the exterior-grade gypsum sheathing. The vapor permeances in all cases were slightly less with WRB B than with WRB A, but in the case of interior wetting of OSB, the difference is insignificant.

5.3.3 Building Paper (#15 Felt)

The range of properties for building paper can vary significantly. According to the NRC, which tested the vapor permeance of different thicknesses of #15 felt, the range in vapor permeances is 0.5 to 40 perms (28 to 2,300 ng/Pa·s·m^2) over a range of relative humidities. For these tests, the relative humidities were quite high, so the permeances were likely at the higher end of the range.

OSB Substrate

Interior wetting of OSB with building paper resulted in an average mass lost of 0.5 g/day or an effective sample permeance of 0.8 perms (45 ng/Pa·s·m^2). This is the slowest drying of all interior OSB wetting.

Exterior wetting of the OSB with building paper resulted in a mass loss of 12.0 g/day or an effective sample permeance of 18.6 perms (1,070 ng/Pa·s·m^2). This is the lowest of all exterior wetting on OSB subassembly tests.

Exterior-Grade Gypsum Substrate

Interior wetting of the exterior-grade gypsum sheathing with building paper resulted in a mass loss of 9.3g/day, which is an effective sample permeance of 13.8 perms (794 ng/Pa·s·m^2). Exterior wetting between the exterior-grade gypsum sheathing and building paper resulted in a mass loss of 10.7 g/day and an effective sample permeance of 15.8 perms (908 ng/Pa·s·m^2).

	Mass Lost [g/day]	Effective Sample Permeance US Perms	Effective Sample Permeance [ng/Pa·s·m^2]
FOXX			
interior wetting on OSB	1.4	2.2	126
exterior wetting on OSB	40.6	89.0	5108
interior wetting on DG	37.1	56.4	3240
exterior wetting on DG	52.2	92.6	5317
MAXX			
interior wetting on OSB	1.1	1.7	96
exterior wetting on OSB	16.1	24.8	1423
interior wetting on DG	15.0	23.1	1327
exterior wetting on DG	16.1	24.8	1423
Building Paper			
interior wetting on OSB	0.5	0.8	45
exterior wetting on OSB	12.0	18.6	1070
interior wetting on DG	9.3	13.8	794
exterior wetting on DG	10.7	15.8	908

Table 3: Summary of subassembly test results and effective sample permeances.

5.4 Summary of Subassembly Testing

Table 3 shows a summary of the subassembly testing results and the effective sample vapor permeances. The following conclusions can be drawn from *Table 3*:

- If water were to enter on the interior of the OSB, it would dry twice as quickly with WRB B as with building paper, and three times as quickly with WRB A as with building paper, although the rate of drying is quite slow, since the permeance in all cases is controlled by the absorptivity and vapor permeance of the OSB.
- If water were to enter on the interior of exterior-grade gypsum sheathing, it would dry 1.5 times as quickly with WRB B instead of building paper, and would dry 2.5 times as quickly with WRB A as with building paper.
- If water were on the exterior of the OSB sheathing between the sheathing and the WRB, it would dry 1.3 times more quickly with WRB B than with building paper, and 3.3 times more quickly with WRB A than with building paper.
- If water were on the exterior of the exterior-grade gypsum sheathing between the sheathing and the WRB, the water would dry 1.5 times more quickly with WRB B than with building paper, and almost five times more quickly with WRB A than with building paper.

These tests were conducted without a temperature gradient across the subassembly sample. Using a temperature gradient would increase the vapor pressure equally for all samples and should increase the drying rate equally.

In all cases, the effective permeance of the samples with WRB A had a higher effective vapor permeance than the similar tests with WRB B, and the WRB B samples had a higher effective vapor permeance than similar tests with building paper.

In all cases of interior wetting of the OSB with no temperature gradient, the drying was very slow and controlled by the OSB sheathing. The type of WRB did not significantly affect the drying rate of the OSB.

Comparing the exterior wetting of OSB and exterior-grade gypsum sheathing with WRB B, the resulting effective vapor permeance is very close to the ASTM E96 Wet Cup value of 28 perms (1597 ng/Pa·s·m^2) determined in phase one of this study. Exterior wetting beneath the WRB A resulted in effective vapor permeances of approximately one third of the ASTM E96 Wet Cup value. WRB A has a high vapor permeance and may not have been maintaining 100% RH between the sheathing and the WRB.

6. SIMULATIONS WITH HYGROTHERMAL MODEL

Permanently increased moisture content in a building enclosure component may result in moisture damages and mold growth. The thermal and hygric behavior of building enclosure components are closely interrelated and therefore have to be investigated, together with their mutual interdependence. Increased moisture content in building components favors heat losses, and thermal conditions affect moisture transport.

To investigate how the water-vapor permeability of a WRB affects the performance of a building enclosure under various climatic conditions and in conjunction with different sheathing materials and cladding materials, hygrothermal simulations were performed with WUFI PRO 5.1. This software model allows the one-dimensional investigation of the hygrothermal performance of building components, including effects such as built-in moisture, driving rain, solar radiation, long-wave emission, capillary transport, and summer condensation (Künzel and Karagiozis, *ASTM Manual 40*).

The following climatic locations were chosen for the hygrothermal simulations (climate zone references as per the International Energy Conservation Code zoning):

- Miami, FL (Climate Zone 1)
- New Orleans, LA (Climate Zone 2)
- Atlanta, GA (Climate Zone 3)
- San Francisco, CA (Climate Zone 3)
- Baltimore, MD (Climate Zone 4)
- Portland, OR (Climate Zone 4)
- Seattle, WA (Climate Zone 4)
- Chicago, IL (Climate Zone 5)
- Minneapolis, MN (Climate Zone 6)
- Fairbanks, AK (Climate Zone 7)

Two different exterior sheathing materials were considered for the hygrothermal simulations: OSB and exterior-grade gypsum board. The following cladding materials were investigated:

- Brick
- Adhered manufactured stone veneer
- Cementitious stucco
- Cementitious siding

Six different WRB scenarios were investigated:

- Building paper
- Low-perm membrane (1 perm)
- WRB A
- WRB B
- WRB C
- Combination of WRB C with ventilated rainscreen membrane (Product D)

The building paper and the low-perm membrane case were used for comparison. The last case (combination of WRB C with Ventilated Rainscreen D) comprised a highly water-vapor permeable WRB with an impermeable, three-dimensional rainscreen membrane that was ventilated on the front and back sides. This scenario was chosen to investigate the beneficial effect of combining drying potential for any moisture within the wall cavity (via vapor diffusion through the permeable WRB into the ventilated cavity outside) and an impermeable layer outboard of the ventilated airspace in order to prevent inward moisture movement from absorptive cladding due to solar drive. The beneficial effect of a ventilated vapor-impermeable rainscreen product has been evaluated and discussed in detail by Straube *et al.* (2009), and by Jablonka, Karagiozis, and Straube (2010).

The key properties for WRBs that were measured earlier on in the project were used in the analysis. The heat (conduction) and moisture transport (vapor diffusion and capillary conduction) were deployed in the simulations in one-hour time steps. Hourly indoor and outdoor climatic conditions as per ASHRAE Standard SPC160 were used, and the assumption was applied that 1% of the precipitation water that hits the cladding would leak through or enter behind the cladding. Additional analysis was performed where 0.75% water penetration took place between the WRB and sheathing board, and 0.5% of water penetration between the sheathing board and insulation were also included in the parametric. Analysis was performed in one-hour steps for a two-year period for the selected wall enclosure systems. The interior conditions were calculated from the exterior weather file used in the hygrothermal simulation by applying the intermediate method from ASHRAE SPC 160.

Connection of Model and Subsystem Testing

As with all modeling activities, it is important to capture the subsystem effects. When these subsystem effects are properly captured, the accuracy of the predictions is expected to be higher. Prior to the execution of the hygrothermal analysis, the basic properties of the WRBs were measured (Straube *et al.*, 2010). Then a series of subsystem tests were performed as described in the previous sections. The 1-D hygrothermal model (WUFI-ORNL) was used to validate the drying performance of the various experimental results. Good agreement was found between the model predictions and the measured drying rates for the various laboratory subsystems tested. The validation provided the necessary confidence in the results to engage in the comprehensive hygrothermal parametric analysis.

For the simulation cases that included the Ventilated Rainscreen D, two air cavities were included into the WUFI 5.1 model. The air exchange rates within the two air cavities were calculated based on the procedure developed within ASHRAE TRP 1091 (Burnett, Straube, and Karagiozis), which was also detailed in the Journal of ASTM International by Karagiozis and Kuenzel. The effects of stack pressures, wind pressures, and moisture concentration gradients are combined to produce a net force for driving air flow in each of the two cavities that the Ventilated Rainscreen D creates. A thermal analysis was initially simulated from which the temperature distribution and the stack effect were computed. Once this was completed, the air changes per hour were computed for each air space cavity and input files were created for the hygrothermal analysis using WUFI.

Three surfaces were selected as the critical layers for detailed analysis: The exterior surface of the exterior sheathing board (P1), the interior surface of the exterior sheathing board (P2), and the interior side of the insulation layer in the wall cavity (P3). Selection points—both on the interior and exterior side of the wall cavity—ensured that the climatic effects were captured in the performance analysis.

The maximum mold growth index for each point was investigated. The mold growth index, as described in depth by Viitanen (Viitanen, 2010), makes it possible to analyze the critical conditions needed for the start of mold growth and to measure the progress of mold growth.

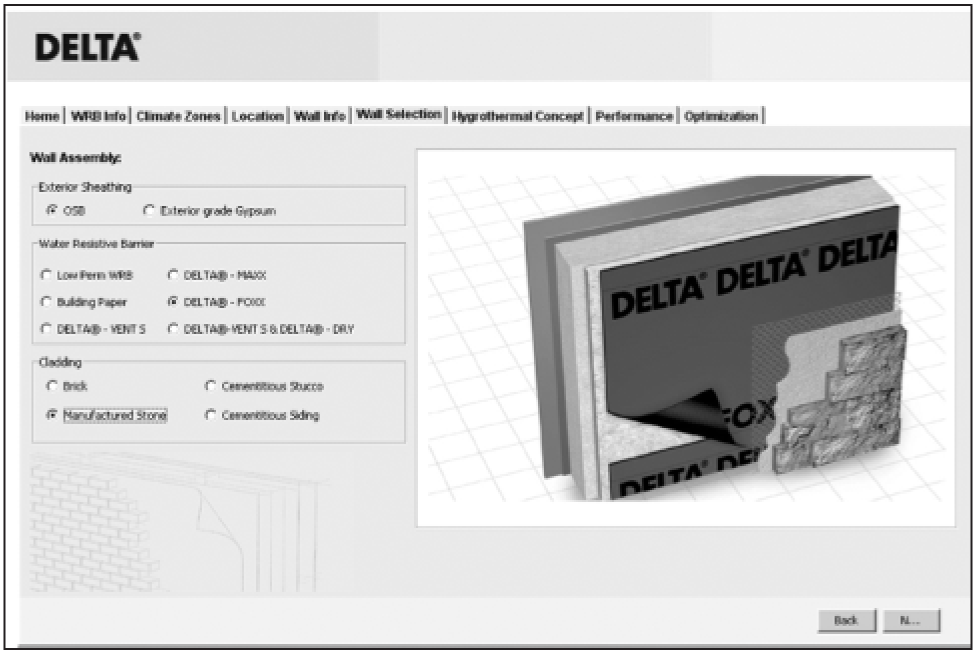
First, all points were checked against a reference value. The average of the maximum mold growth index of these three points was calculated, and this value was then used as a performance indicator for ranking. The lowest value has the highest ranking, representing the best wall performance in regard to moisture management.

7. SOFTWARE SELECTION TOOL AND CONCLUSIONS

Wall assemblies with various cladding types in different climates demand the proper selection of WRBs for optimal performance. The results of the measurements and hygrothermal simulations described in this paper were summarized in a software tool that helps the designer simply and effortlessly choose the most suitable WRB for a particular wall assembly configuration. Furthermore, it provides a design recommendation for optimal wall performance based on a performance ranking by WRB type.

The software tool allows for a step-by-step selection process as shown in *Figure 6*.

The user gets prompted to select the location from a list or map. Only the locations described in chapter 6 are available for selection. However, these locations were carefully selected in order to cover all cli-



Wall Assembly:

Exterior Sheathing
● OSB ○ Exterior grade Gypsum

Water Resistive Barrier
○ Low Perm WRB ○ DELTA® - MAXX
○ Building Paper ● DELTA® - FOXX
○ DELTA® - VENT S ○ DELTA®-VENT S & DELTA® - DRY

Cladding
○ Brick ○ Cementitious Stucco
● Manufactured Stone ○ Cementitious Siding

Figure 6 – Software tool for simple selection of the most suitable WRB.

matic zones of the U.S.; the user would choose the location that would be closest to the location of interest within the same climate zone. In the next step, the user is prompted to choose the type of exterior sheathing (OSB or exterior-grade gypsum board). Furthermore, the user can choose from one of six options for WRBs with a wide range of water vapor permeability. The last step in the selection process allows the user to decide between four different cladding options: brick, adhered manufactured stone veneer, cementitious stucco, and cementitious cladding.

The performance results for the selected wall assembly for that particular climatic location are then presented in a summary screen as shown in *Figure 7*.

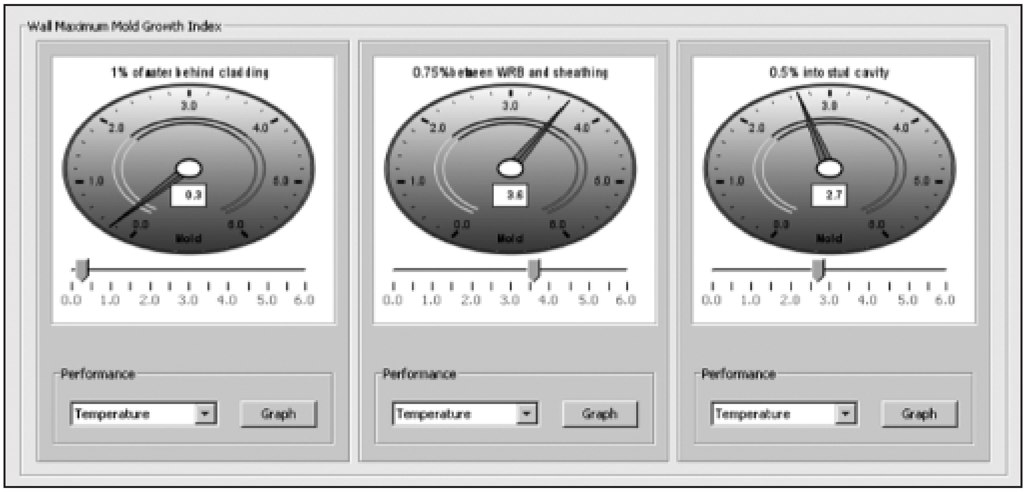
The summary screen provides three gauges with a range from 1 to 6. In this way, the designer is provided with a simple overview of how well a particular wall assembly would function under the chosen conditions.

The first gauge (on the left) provides the maximum mold growth index for the assumed "ideal" case that 1% of the precipitation water that hits the façade will leak through the cladding but remain on the outside of the WRB. The second gage (in the middle) provides the maximum mold growth index for the assumed case that 0.75% of that water enters between the WRB and the sheathing board. The third gauge on the right presents the maximum mold growth index for the assumed case that 0.5% of that water enters into the wall cavity (backside of the exterior sheathing material). By presenting all three gages in one view, the designer gets a quick impression how well a wall assembly would perform under ideal or less ideal (more realistic) conditions (e.g., missing flashing, penetrations in WRB, etc.).

If desired, the designer can pull up detailed graphs for temperature, relative humidity, and moisture content for each of the three scenarios. The graph in *Figure 8* shows a typical example for temperatures measured in the three sensor locations—P1, P2, and P3—for the simulated two-year period.

For simplicity, a performance overview is provided to the designer as shown in *Figure 9*.

The performance overview chart shows the six different of WRB scenarios that were analyzed. Lowest mold growth index (optimum hygrothermal performance) is achieved in the center of the diagram. The further the red line moves to the outside of the diagram, the more mold growth has to be expected under the chosen circumstances. The list below the diagram shown in *Figure 8* provides a performance ranking of the different WRB scenarios for that particular climate zone and the chosen sheath-



1% of water behind cladding: 0.3 — Performance: Temperature

0.75% between WRB and sheathing: 3.6 — Performance: Temperature

0.5% into stud cavity: 2.7 — Performance: Temperature

Figure 7 – Summary screen for wall performance under selected conditions.

ing board and cladding type.

It is apparent that the vapor permeability of the WRB has an influence on the average mold growth index, as it affects the drying of interior moisture via diffusion.

Figures 10 and *11* show the average mold growth index for Chicago for adhered manufactured stone veneer and cementitious siding, each with OSB as exterior sheathing material.

Figures 12 and *13* show the relative humidity in the three different sensor locations for the same location and cladding materials.

Figure 12 shows that in the Chicago climate, the use of a highly vapor-permeable WRB used behind adhered manufactured stone veneer would lead to elevated levels of relative humidity for long time periods per year (between 90% and 100% RH). The same WRB used behind cementitious siding would lead to significantly lower RH values for most of the year (between 70% and 90%). The elevated levels can be explained with solar moisture drive from highly absorptive claddings within the wall cavity. A highly vapor-permeable membrane would allow moisture from the inside of the cavity to easily diffuse to the outside; but in case of reverse vapor pressure differential, moisture can also easily diffuse inwards and elevate the moisture levels inside the wall assembly.

The reverse moisture flow can be prevented by using a ventilated, vapor-impermeable rainscreen outboard of a highly vapor-permeable WRB as shown in *Figures 14* and *15*.

The graphs in *Figures 13* and *14* show that by utilizing a highly vapor-permeable WRB in conjunction with an impermeable rainscreen product on the outside, the relative humidity levels drop noticeably.

Similar results can be seen for other climate zones. Hence, the best wall performance in any climate zone can be achieved by combining a highly vapor-permeable WRB with an impermeable, ventilated rainscreen material. This combination allows for quick drying of moisture from within the wall assembly to the outside, while moisture from the outside (i.e., stored in absorptive cladding material like adhered manufactured veneer) cannot migrate inward.

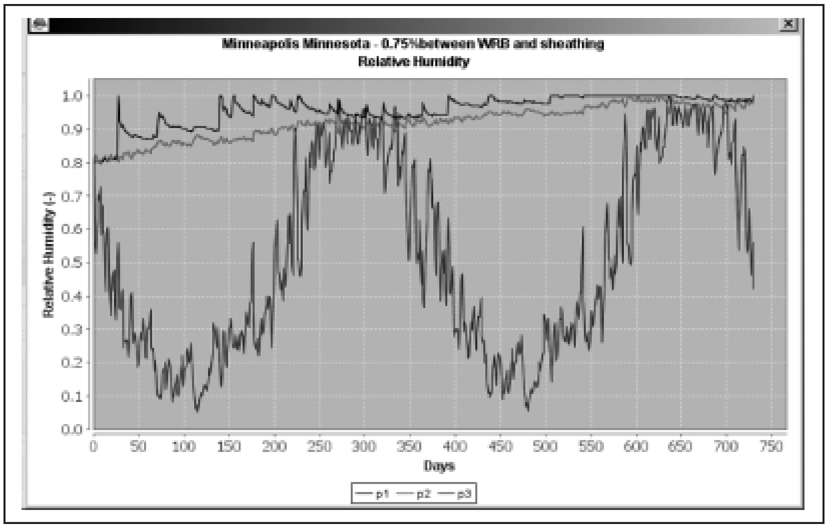
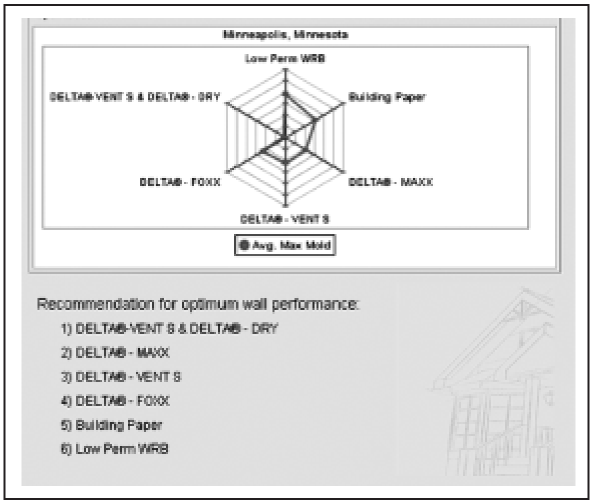


Figure 8 – Relative humidity measured over two years in locations P1, P2, and P3 for selected conditions.



Recommendation for optimum wall performance:

1) DELTA®-VENT S & DELTA®-DRY
2) DELTA® - MAXX
3) DELTA® - VENT S
4) DELTA® - FOXX
5) Building Paper
6) Low Perm WRB

Figure 9 – Performance overview and performance-based ranking for various WRB options.

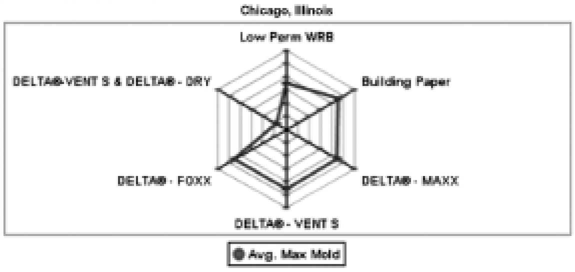


Figure 10 – Average mold growth index, Chicago, adhered manufactured stone veneer, OSB as exterior sheathing.

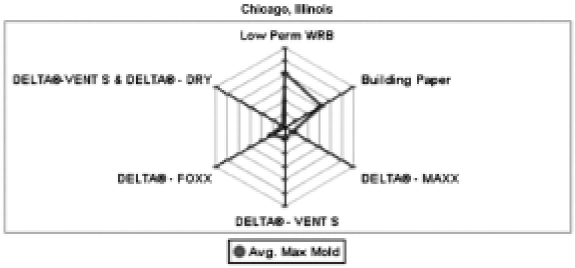


Figure 11 – Average mold growth index, Chicago, cementitious siding, OSB as exterior sheathing.

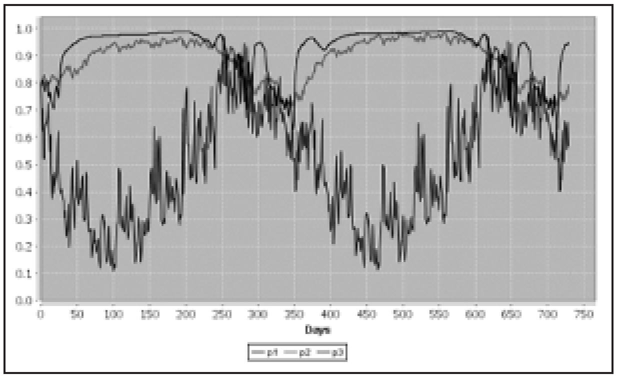


Figure 12 – Relative humidity, adhered manufactured stone veneer, OSB and WRB C.

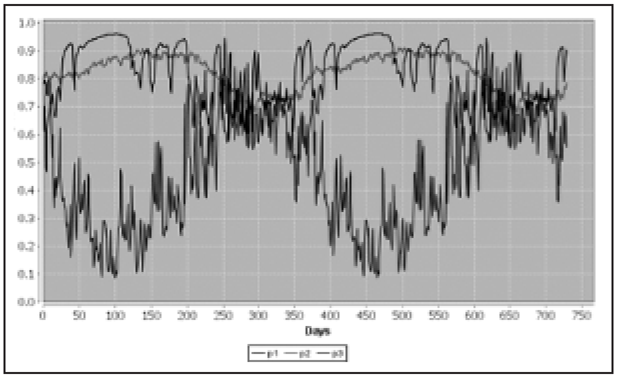


Figure 13 – Relative humidity Chicago, cementitious siding, OSB and WRB C.

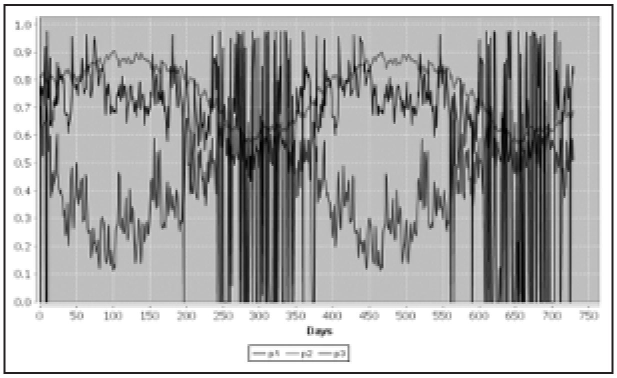


Figure 14 – Relative humidity, adhered manufactured stone veneer, OSB and WRB C with rainscreen.

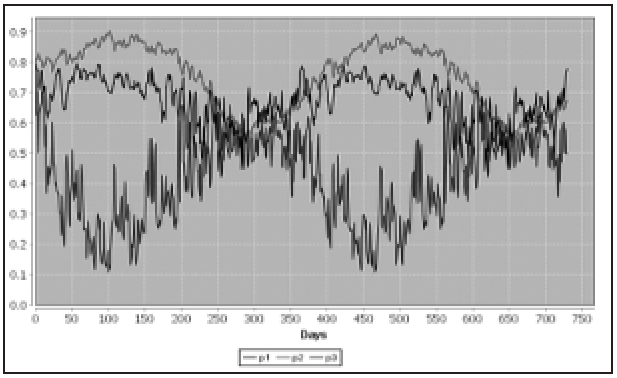


Figure 15 – Relative humidity, Chicago, cementitious siding, OSB and WRB C with rainscreen.

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