The Hygrothermal Performance of Wood-Framed Wall Systems Using a Relative Humidity-Dependent Vapor Retarder in the Pacific Northwest

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ABSTRACT

The Pacific Northwest region of North America is considered to be a mixed-humid climate with moderate temperatures and high moisture levels due to precipitation and relative humidity (RH) throughout the year. Research has been conducted to evaluate the heat and moisture transfer performance of wood-framed wall systems common in residential and multifamily construction using a relative-humidity-dependent vapor retarder. One-dimensional hygrothermal modeling results will be compared to measured data collected in an occupied residential home and a natural exposure testing facility in the Seattle, Washington, area. Wall systems using traditional interior vapor control strategies will be compared with the innovative variable permeability vapor retarder. Building envelope moisture content and RH results were used to support recent national code language changes regarding interior vapor retarder requirements.

INTRODUCTION

North America is a mixture of cold, mixed, and hot climates with varying relative humidity (RH) levels. Briggs et al. (2003a, 2003b) describe a new climate classification for use in characterizing the performance of energy-efficiency measures for buildings. The proposed changes categorized North America into several hygrothermal regions, which account for exterior temperature, RH, and precipitation. The changes were incorporated into the 2003 International Energy Conservation Code (ICC 2003) and impact energy efficiency and interior vapor retarder requirements. The Pacific Northwest is identified uniquely as a marine climate (Zone 4C), as illustrated in Figure 1. Moderate temperatures combined with high precipitation and RH create a difficult building envelope design environment. One moisture management concern is determining the use, type, and placement of interior vapor retarders.

Two North American building codes, the International Code Council (ICC 2003) and the National Building Code of Canada (CCBFC 2005), require that vapor retarders have a water vapor permeance of 1 perm (5.7×10^{-11} kg/m^2·s·Pa) or less when tested in accordance with the American Society for Testing and Materials standard test method ASTM E 96 (ASTM 2005), using standard dry cup conditions of 0% and 50% RH, creating a mean RH of 25 percent. Gatland (2005) presented experimental water vapor permeance results for several common interior building materials over a wide range of mean RHs. Figure 2 displays a simplified version of the data between 25% and 95%. The permeance data were plotted on a log scale in order to visualize the differences between materials. If building materials are placed into four categories with respect to water vapor permeance, vapor barrier (0.1 perm [0.57×10^{-11} kg/m^2·s·Pa] or less), vapor retarder (1 perm [5.7×10^{-11} kg/m^2·s·Pa] or less), semipermeable (1 to 10 perms [5.7 to 57×10^{-11} kg/m^2·s·Pa]), and permeable (greater than 10 perms [57×10^{-11} kg/m^2·s·Pa]), then products can be described as fitting into one or several categories.

Historically, continuous polyethylene films have been used as interior vapor retarders in the Pacific Northwest. Data published through the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2005) and

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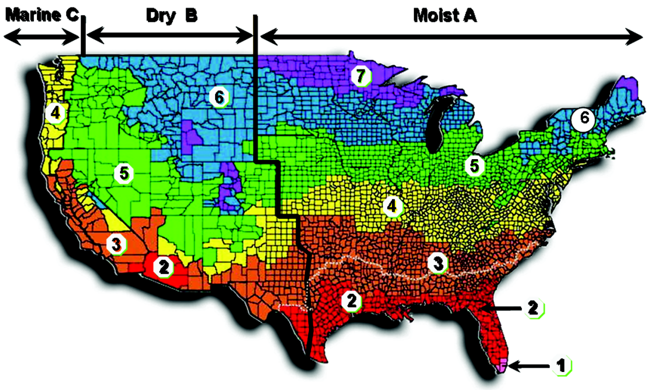

Figure 1 *International Energy Conservation Code climate zone map (ICC 2002, 2003).*

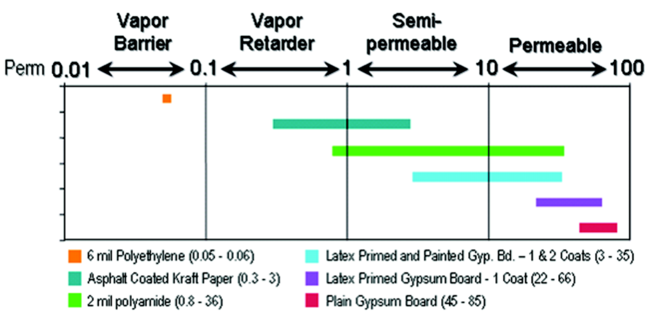

Figure 2 *Common interior building materials water vapor permeance range.*

hygrothermal modeling suggest that smart vapor retarders, materials that are vapor retarders under dry conditions and become water vapor permeable under very humid conditions, will perform well in moderate and cold climates. Also, data suggest that latex-painted interior gypsum board systems in conjunction with good wintertime interior moisture load control may be suitable as interior vapor retarders in moderate temperature climates.

The purpose of this paper is to compare the above three interior vapor control strategies in wall systems common to the Pacific Northwest. One residential and one multifamily wood-framed wall assembly was evaluated for hygrothermal performance at a natural exposure testing facility in Puyallup, Washington, and an occupied residential home in Olympia, Washington. Three different interior vapor control strategies, 2 mil (50 µm) polyamide film (SVR), 4 mil (100 µm) polyethylene film (PE), and a polyvinyl acetate primer/latex paint coating (Paint) were compared over a year at both locations. The thinner 4 mil (100 µm) polyethylene film was specified as a more common application in the Seattle market. Air, surface, and insulated wall cavity conditions were monitored for temperature, RH, and moisture content. In addition, hygrothermal modeling performed in accordance with Proposed BSR/ASHRAE Standard 160, *Design Criteria for Moisture Control in Buildings* (ASHRAE 2006), was compared to the measured data.

NATURAL EXPOSURE TEST FACILITY—PUYALLUP, WASHINGTON

Washington State University established a natural exposure testing (NET) facility (Tichy and Murray 2003) at the Puyallup campus designed to monitor moisture transport in building assemblies (see Figure 3). Facility instrumentation allows data to be collected on an hourly basis. Wall systems are monitored for moisture content, RH, incidence of condensation, and temperature distribution through the cross section of each wall.

Cement stucco finished, nominal 2 × 6 in. (38 × 140 mm), wood-framed exterior walls are common assemblies in multifamily construction in the Pacific Northwest (see Figure 4). Historically, the interior gypsum board finish has been one-coat of latex primer and two coats of latex paint, and the interior vapor retarder has been a 6 mil (150 µm) polyethylene film. The more common interior finish used by builders today is one coat of polyvinyl acetate (pva) primer with one coat of latex paint.

Three identical directly applied cement stucco walls with different interior vapor control strategies—a 2 mil (50 µm) polyamide film with an interior gypsum board finish, a 4 mil (100 µm) polyethylene film with an interior gypsum board finish, and a one-coat pva primer/latex paint interior gypsum board finish without an additional vapor retarder—were compared between October 2003 and September 2004. The individual wall systems were identified as SVR, PE, and Paint, respectively. Each wall assembly included the building material layers described in Figure 4.

NET FACILITY TEST RESULTS—PUYALLUP, WASHINGTON

The establishment of relevant interior temperature and RH conditions were critical to the operation of the test facility. Wall systems were exposed to indoor environments well within the operating parameters of the majority of homes monitored in the Pacific Northwest (Aoki-Kramer and Karagiozis 2004). The test conditions were also within the parameters outlined by Proposed BSR/ASHRAE Standard 160 (ASHRAE 2006).

The interior environment was maintained at 21°C (69°F) and 50%–55% RH. Weekly running-average temperature and RH conditions, based on hourly measured data, are displayed in Figures 5 and 6, respectively.

A year's worth of hourly temperatures, RHs, and moisture content data were collected, averaged, and compared for the three wall systems from October 2003 through September 2004. Figures 7 and 8 provide weekly running-average RH data for the cavity-side oriented strand board (OSB) and

Figure 3 *Natural exposure testing facility—Puyallup, Washington.*

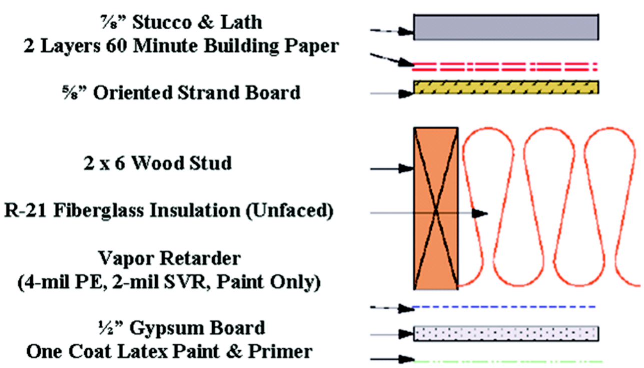

Figure 4 *Common multifamily wall construction—cross section.*

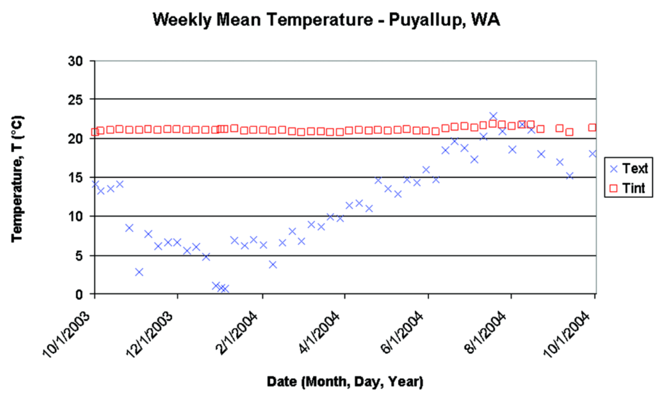

Figure 5 *Weekly running average exterior and interior air temperature—Puyallup, Washington.*

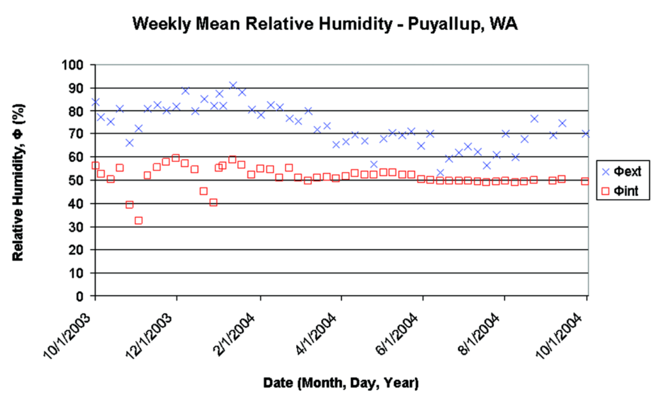

Figure 6 *Weekly running average exterior and interior RH—Puyallup, Washington.*

vapor retarder surfaces, respectively. Figure 9 provides weekly running-average data for the OSB moisture content. Measurements were located at the center of the 16 in. (406 mm) stud cavity width, centered vertically between the top and bottom plates.

In the fall and winter, the weekly running-average surface RH for the 2 mil (50 µm) SVR and 4 mil (100 µm) PE test walls did not reach critical levels for moisture accumulation in the wood materials, as illustrated in Figure 7. Additionally, surface condensation did not occur. The Paint test wall's cavity-side OSB surface RH exceeded critical levels. A high, constant RH was maintained for many hours, causing significant wintertime condensation.

Figures 7 and 8 indicate that the SVR and Paint only wall cavities dried more quickly than the PE system through the spring and summer months. Surface RH was higher for the PE test wall at both cavity surfaces from the spring through the fall.

NET FACILITY HYGROTHERMAL MODELING COMPARISON—PUYALLUP, WASHINGTON

Weekly running-average OSB moisture content is provided in Figure 9. The 2 mil (50 µm) SVR and 4 mil (100 µm) PE test walls did not experience a detrimental increase in OSB sheathing moisture content, while the Paint test wall realized a significant and sustained increase in sheathing moisture. Critical wood moisture content above 24% was exceeded for many hours during the winter in the Paint wall. Visual

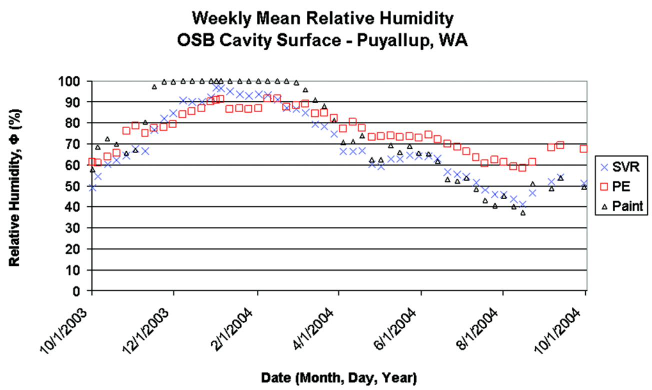

Figure 7 *OSB cavity-side surface RH data—Puyallup, Washington.*

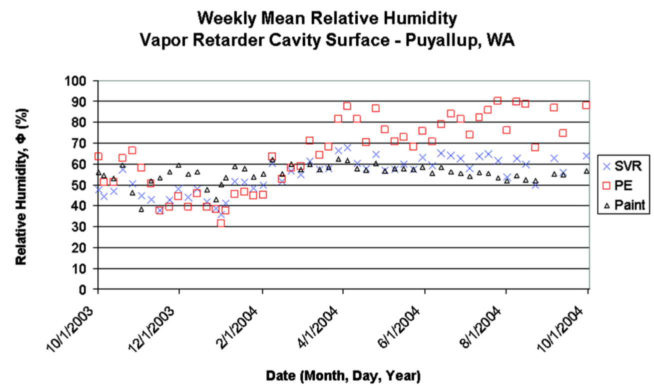

Figure 8 *Vapor retarder cavity-side surface RH data—Puyallup, Washington.*

examination of the Paint wall in the spring of 2004 indicated mold growth on the cavity-side surface of the OSB sheathing.

Computer simulations were performed on the same three wall systems using a professionally available one-dimensional hygrothermal analysis software package (Fraunhofer Institute 2003). Sufficient material properties were available in the software's data library to accurately model each wall assembly. The walls were oriented in a south-facing direction with full solar exposure. The stucco finish had a solar reflectance of 0.29. Also, data available in several references (Gatland 2005; Hens et al. 1996; Kumarin 1996, 2001; Trechsel 2001; Wilkes et al. 2003, 2004) were used to enhance the material database. Simulations were conducted over a twelve-month period using 30-year averaged coldest-year weather data for the Seattle area. Hourly calculations were downloaded to a customized report in order to compare the three systems directly.

The hygrothermal analysis results are graphically displayed in Figure 10. Modeling criteria provided in Proposed BSR/ASHRAE Standard 160 (ASHRAE 2006) were followed with exception to the 1% moisture intrusion rate. The recommended moisture intrusion rate of 1% at the exterior sheathing surface was not possible due to the limitations of the software. In addition, all materials started the simulation with an equivalent equilibrium moisture content at 80% RH.

The moisture content estimates of the OSB sheathing for the Paint wall system closely match the measured results given in Figure 9. Significant moisture accumulation occurs during the winter period. The SVR and PE wall systems maintain safe moisture content levels in the OSB sheathing over the course of the year. The peak moisture content of the OSB generated during the simulation lags the data by approximately two months. The delay in OSB wetting may be due to the use of historical data rather than measured weather data to perform the simulation, as well as differences in material properties. Differences due to possible moisture intrusion or air leakage should have been minimized since the assemblies were constructed under controlled conditions and assembled to be airtight.

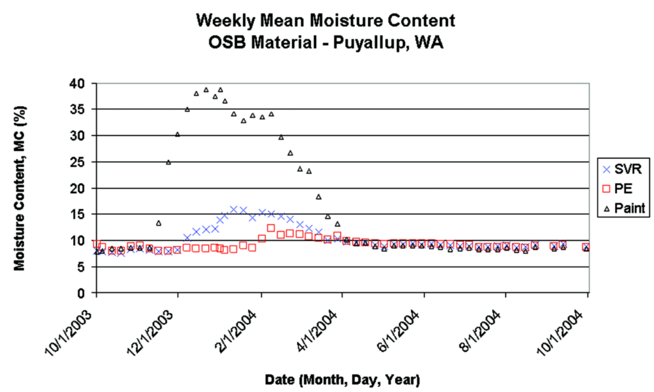

Figure 9 *OSB moisture content data—Puyallup, Washington.*

OCCUPIED RESIDENCE—OLYMPIA, WASHINGTON

Building envelope research was conducted through the U.S. Department of Energy's Building America program on a room addition to an existing manufactured home in Olympia, Washington (Ueno 2003 and 2004). An existing carport was converted to a guest/exercise room. The nominal 2 × 6 in. (38 × 140 mm) wood-framed exterior wall construction, from the interior to the exterior, consisted of 0.5 in. (12.5 mm) gypsum board, unfaced R-19 fiberglass insulation, a spun bonded polyolefin water resistive barrier, and an in. (16 mm) OSB panel siding (see Figure 12). The interior gypsum board surface was finished with one coat of pva primer and one coat of exterior latex paint. The exterior OSB panel siding surface was factory primed and site finished with one coat of latex paint.

Three identical OSB panel siding walls with different interior vapor control strategies—a 2 mil (50 μm) SVR, a 4 mil (100 μm) PE, and a Paint—were compared between December 2003 and June 2005. Two other vapor control strategies—asphalt coated kraft paper (Kraft-faced) and smart vapor

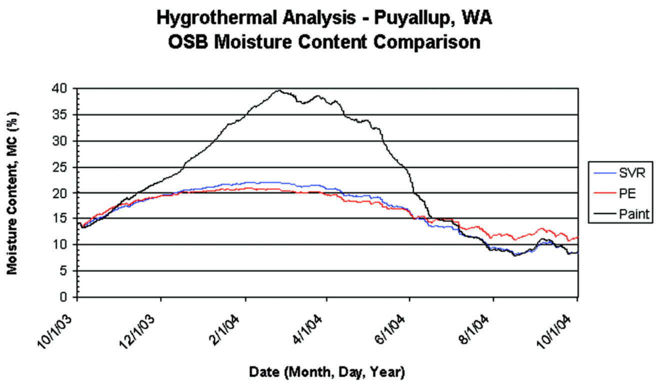

Figure 10 *Twelve-month simulated OSB moisture content—Puyallup, Washington.*

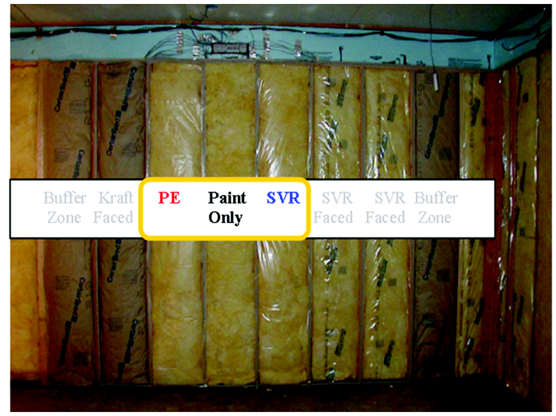

Figure 11 *Occupied residence test walls—Olympia, Washington.*

retarder (SVR-faced) faced fiberglass insulation—were evaluated at the same time but were not reported in this paper. The test wall configuration is shown in Figure 11.

Wall systems were monitored for moisture content, RH, incidence of condensation, and temperature distributed through the cross section of each assembly (see Figure 12). Measurements were conducted on an hourly basis.

OCCUPIED RESIDENCE TEST RESULTS—OLYMPIA, WASHINGTON

The indoor environment was controlled to simulate the typical temperature and RH conditions in a Seattle, Washington, area residence. Space heating was provided by a direct-vent propane stove, run off of a thermostat. Since residential air conditioning is not common in the Pacific Northwest, an exhaust fan was used to simulate the typical summertime cooling strategy of opening windows. The data acquisition system was programmed to respond to outdoor temperature and high interior humidity levels by running the exhaust fan. In addition, the fan was wired in parallel with the wall switch to allow occupant-controlled operation. Weekly running-average air temperature and RH data are displayed in Figures 13 and 14. Conditions changed based on the time of year and room utilization.

Eighteen months worth of hourly temperature, RH, and moisture content data were collected, averaged, and compared for the three wall systems from December 2003 to June 2005. Figures 15 and 16 provide weekly running-average RH data for the OSB panel siding and vapor retarder surfaces, respectively. Figure 17 provides weekly running-average data for the OSB moisture content. Some data was lost due to a data acquisition failure in the fall of 2004 and the winter of 2005. Measurements were located at the center of the 16 in. (406 mm) stud cavity width, centered vertically between the top and bottom plates.

In the fall and winter, the weekly running-average surface RH for the 2 mil (50 μm) SVR and 4 mil (100 μm) PE test walls did not reach critical levels for moisture accumulation in the wood materials, as illustrated in Figure 15. Surface condensation did not occur. The Paint test wall's cavity-side OSB surface RH exceeded critical levels. A high, constant RH was maintained for many hours, causing significant wintertime condensation. However, the differences among the three vapor control strategies during the wintertime was lessened due to the lower moisture storage capacity of the OSB panel siding.

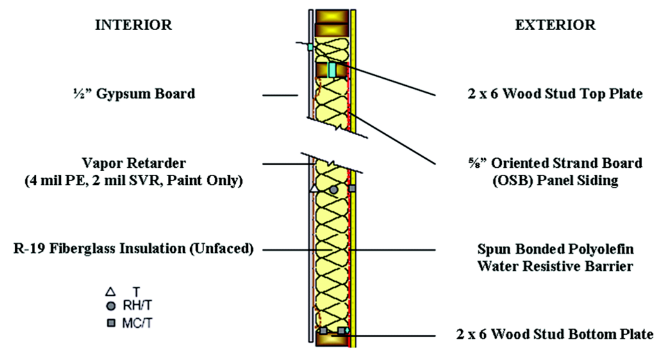

Figure 12 *Occupied residence wall construction and sensor location—Olympia, Washington.*

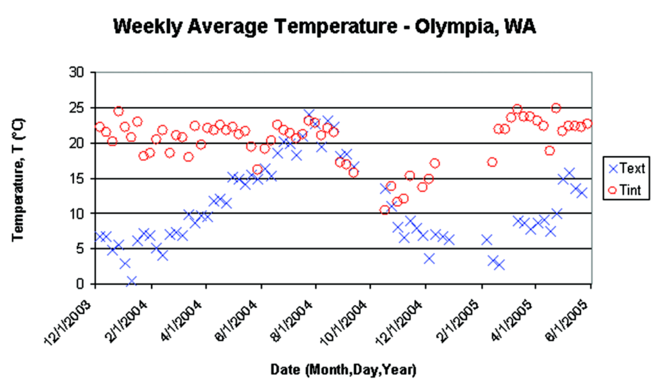

Figure 13 *Weekly running average exterior and interior air temperature—Olympia, Washington.*

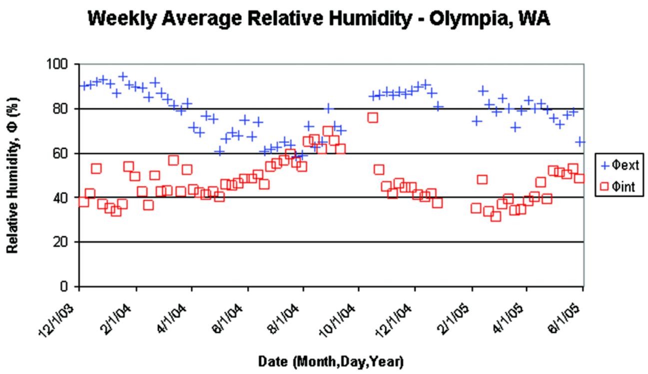

Figure 14 *Weekly running average exterior and interior RH—Olympia, Washington.*

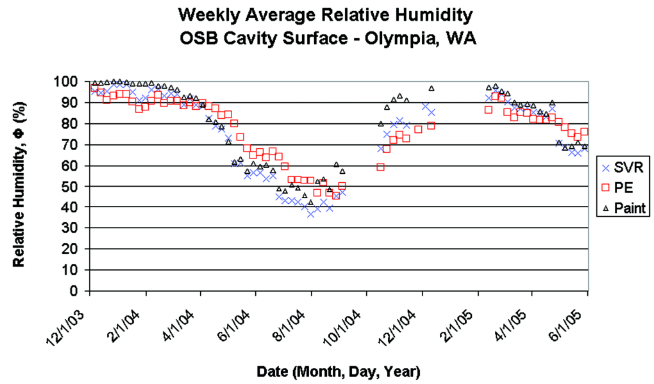

Figure 15 *OSB panel siding cavity-side surface RH data—Olympia, Washington.*

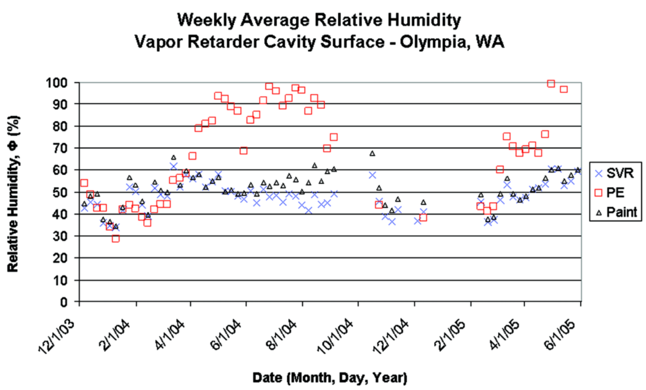

Figure 16 *Vapor retarder cavity-side surface RH data—Olympia, Washington.*

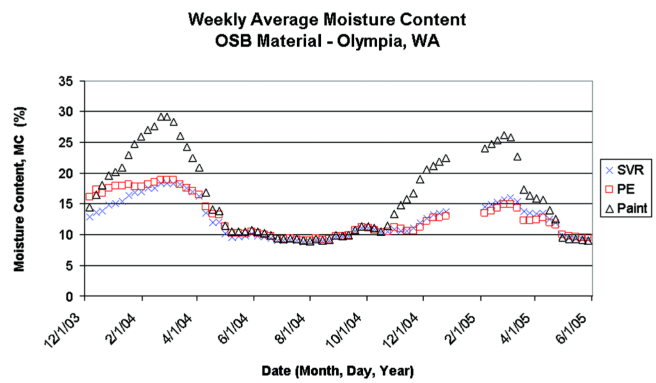

Figure 17 *OSB panel siding moisture content data—Olympia, Washington.*

Figures 15 and 16 indicate that the SVR and Paint wall cavities dried more quickly than the PE system through the spring and summer months. Surface RH was higher for the PE test wall at both cavity surfaces from the spring through the fall.

OCCUPIED RESIDENCE HYGROTHERMAL MODELING COMPARISON—OLYMPIA, WASHINGTON

Weekly running-average OSB panel siding moisture content is provided in Figure 17. The 2 mil (50 μm) SVR and 4 mil (100 μm) PE test walls did not experience a detrimental increase in OSB panel siding moisture content, while the Paint test wall realized a significant and sustained increase in sheathing moisture. Critical wood moisture content above 24% was exceeded for many hours during the winter in the Paint wall.

A decrease in OSB panel siding moisture content was observed between years one and two. The reduction may be due to the fact that the interior gypsum board surface was not finished with pva primer and latex paint until the spring of 2004. Unpainted gypsum board is much more vapor-open than painted gypsum board, which allows for more wintertime water vapor diffusion and cavity condensation.

Computer simulations were performed on the same three wall systems using a professionally available one-dimensional hygrothermal analysis software package (Fraunhofer Institute 2003). Sufficient material properties were available in the software's data library to accurately model each wall assembly. The walls were oriented in a west-facing direction to have full solar exposure.

Simulations were conducted over an 18-month period beginning in December, using 30-year averaged coldest-year weather data for the Seattle area. Hourly calculations were downloaded to a customized report in order to compare the three systems directly. The hygrothermal analysis results are shown in Figure 18. Modeling criteria provided in Proposed BSR/ASHRAE Standard 160 (ASHRAE 2006) were followed with exception of the 1% moisture intrusion rate. The recommended moisture intrusion rate of 1% at the exterior sheathing surface was not possible due to the limitations of the software.

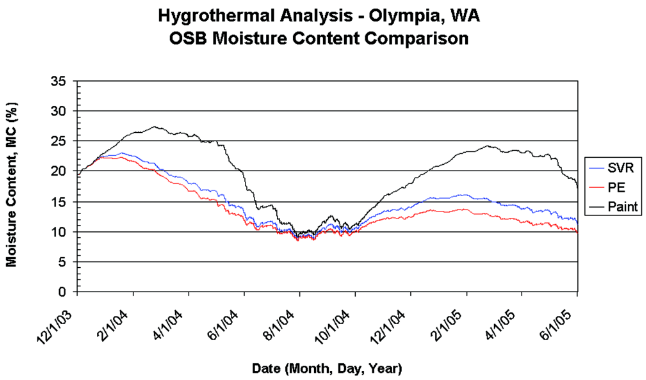

Figure 18 *Eighteen-month simulated OSB panel siding moisture content—Olympia, Washington.*

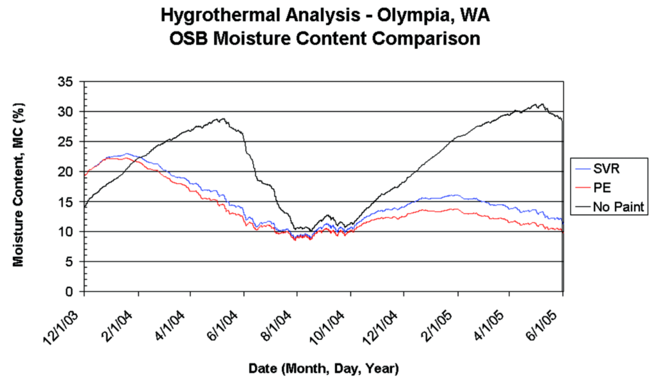

Figure 19 *Eighteen-month simulated OSB panel siding moisture content (no paint)—Olympia, WA.*

In addition, all materials started the simulation with an equivalent equilibrium moisture content at 80% RH.

The moisture content estimates of the OSB panel siding for the Paint wall system closely match the measured results given in Figure 18 with exception of magnitude during the first winter. Significant moisture accumulation occurs during the winter period. Figure 19 indicates that additional moisture accumulation will occur in the OSB panel siding when the interior gypsum board surface is not painted, which is consistent with the measure results. The SVR and PE wall systems maintain safe moisture content levels in the OSB panel siding over the course of 18 months.

The differences between measured and simulated results in the rate of OSB wetting and drying may be due to the use of historical data rather than measured weather data, as well as due to differences in material properties, specifically the liquid transport coefficient of the painted OSB panel siding material. Differences due to possible moisture intrusion or air leakage should have been minimized, since the assemblies were constructed under controlled conditions and assembled to be airtight.

CONCLUSION

The experimental results and hygrothermal modeling indicate that both traditional and dynamic water vapor control strategies perform well at reducing wintertime condensation in two common wood-framed wall assemblies in the Seattle, Washington, area. A 2 mil (50 μm) polyamide film used as an interior vapor retarder will enhance a wall system's ability to dry more quickly and maintain lower cavity RH levels during the warmer months of the year. Smart vapor retarders can increase a building envelope's moisture tolerance and potentially reduce moisture-related risk. Low permeance vapor retarders, such as polyethylene, can increase a building envelope's moisture-related risk by creating surface RHs on adjacent wood surfaces greater than 80% for extended periods of time during the warmer months.

Additionally, interior gypsum board finished with a single coat of polyvinyl acetate primer and a single coat of latex paint is not considered an acceptable vapor control strategy in common wood-framed wall assemblies located in the Pacific Northwest. Results from both research projects contributed to the most recent building code requirement for an interior vapor retarder in the marine climate (Zone 4C) (ICC 2003).

Table 1 summarizes the peak surface RH and moisture content results for each assembly at both test facility locations for the winter (December through March) and summer (June through September) months. Peak OSB panel siding moisture content and cavity-side surface RH occurs during the winter season. Peak vapor retarder or gypsum board cavity-side surface RH occurs during the summer season.

Computer modeling conducted in accordance with Proposed BSR/ASHRAE Standard 160 (ASHRAE 2006) without a 1% moisture intrusion rate can predict transient hygrothermal performance of well-constructed, airtight building envelope systems using historical weather conditions. Care must be taken to use the most accurate and current material property data available. Incorporating moisture intrusion and air leakage rate capabilities into professionally available hygrothermal analysis software will create more accurate results consistent with real-world applications.

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Table 1. Summary of Peak Seasonal Moisture Content and Cavity-Side Surface RH Results

Construction Type	Peak OSB Panel Siding Moisture Content, %	Peak OSB Panel Siding Surface RH, %	Peak OSB Panel Siding Surface RH, %
Multi-Family Wall	**Winter Months**	**Winter Months**	**Summer Months**
SVR	16	97	65
PE	12	91	90
Paint	39	100	54
Residential Wall			
SVR	18	99	62
PE	19	98	99
Paint	29	100	62

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