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Hygrothermal Performance of Exterior Wall Systems Using an Innovative Vapour Barrier In Canadian Climate

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ABSTRACT: Controlling or managing the accumulation of moisture and reducing the risk of moisture-related problems by judicious design, material choice and proper installation is one of the most practical approaches for ensuring adequate long-term performance of exterior wall systems. An innovative vapour barrier with relative humidity-dependent water vapour permeance made of a proprietary 2 mil (50 μm) thick, nylon-6 film was tested and evaluated. The film is intended to replace the base 4-mil-thick (100 μm) conventional polyethylene vapour barrier that is required by the 2005 National Building Code Canada (NBC). This product is to be installed behind painted regular gypsum board or any other interior finish and it is intended to provide drying potential towards the interior when high relative humidity may be present in the wall cavity. This paper provides highlights of the research work carried out at the National Research Council Canada, Institute for Research in Construction on assessing the hygrothermal performance of wall systems that included this innovative vapour retarder (Note: *Vapour Barrier in Canadian terminology is equivalent to Vapor retarder in US terminology*). The performance of walls was assessed when subjected to eastern coastal climate conditions of Halifax, one of the four Canadian climatic locations used in this study. A wood-framed stucco clad wall was the reference assembly. Results from different cases based on the variation of vapour control strategies and their effect on the hygrothermal performance of the wall systems are analysed. The results for the Halifax climate location indicate that the installation of a humidity controlled, innovative vapour retarder is a recommendable solution for the envelope design of residential buildings of these locations with moderate or high water vapour permeance of the interior paint. In this study, the advanced hygrothermal tool, *hyg*IRC, was used to perform the hygrothermal performance analysis of the wall systems.

1 INTRODUCTION

As moisture damage has become one of the main causes of building envelope deterioration, the demand for methods to assess the moisture behaviour of building components has increased.

In the design of modern engineered buildings it is customary to use a variety of mathematical models to simulate the performance of the structural system and the service systems. Structural, mechanical and electrical engineers use various mathematical models to analyze the response of the modeled system or subsystem and then improve, adjust, or redesign the system as needed until a final design is arrived at. Analysis, even repeated analysis and, perhaps, with more than one model, is necessary to design a new facility or subsystem as well as to assess an existing building or part thereof.

Assessing the performance of new building materials, components or systems typically requires extensive laboratory testing or, in some instances, elaborate and time-consuming field trials. Thorough analyses of the hygrothermal behaviour of wall systems in response to different climatic loads are not usually part of the assessment process. Whereas laboratory and field experiments are often too selective and time consuming, a practical means of assessing the response of wall systems to changing environmental loads is accessible through the use of hygrothermal simulation models. As well, rapidly changing technologies such as those in materials and interior building environments, combined with higher expectations of performance for both the enclosure and the building, have created a very real need for the development and use of practical hygrothermal analysis methods. As with structural design, computerized models help make quantitative analysis easier, and thus permit an understanding of the complex response of walls to climatic loads.

Simulation models can accommodate a variety of changing boundary conditions and as well, result in much faster analysis, given the recent advances in computer technology that have permitted ready access to enhanced computing performance. This in turn has brought about an increased emphasis on the use of numerical methods to solve the fundamental hygrothermal equations that form the basis for many of the mathematical models developed over the past decade. Depending upon the complexity of the problem under consideration, such models can be based on very simple, one-dimensional, steady state methods or on more complex, two and three-dimensional, transient methods.

Simulation tools are usually applied to assess the hygrothermal performance of building envelope systems and sub-systems in order to prevent moisture damage. Also, they may also be used to create new and innovative envelope components or building materials by running parametric studies with virtual assemblies or material layers. One such example is the development in Germany of the smart retarder, a humidity controlled vapor retarding polyamide (PA)-film describe in Künzel (1998, 1999 and 2001). Later on, work was done in the USA on this innovative vapor retarder (Karagiozis& al. 2003, Gatland 2005 and Gatland & al. 2007). It consisted of field measurements and computer simulation in order to compare different vapor diffusion control strategies such as the use of polyethylene (PE) and asphalt coated Kraft paper. Those studies showed the benefit of this product as a vapor retarder although the advantage was not evident for situations of excessive RH such as might occur in enclosures of saunas or swimming pools. To complement this work, research was carried out in Canada led by the National Research Council Canada-Institute for Research in Construction (NRC-IRC) to investigate the use of this product in the Canadian climate (Di Lenardo & al., 2007 and Maref & al., 2007 and 2008 & Mukopadhyaya et. al. 2007).

This document highlights the research work carried out at the NRC-IRC on modeling the hygrothermal performance of wall systems. It provides a study of the performance of the new vapor barrier component known as a Smart Vapour Retarder (SVR) used in a wood-framed stucco wall system exposed to the simulated climate of one Canadian location. The study provides a quantitative performance characterization of the transient heat and moisture transport across the SVR component and compares this vapour diffusion control strategy to those currently used employing 4-mil PE sheet or in a wall system having no polyethylene vapour barrier. As well, importance of applying, or not applying, paints on the interior wall finish (gypsum wallboard) and their effects on the overall hygrothermal performance of the wall system was investigated when using a 4-mil PE sheet or the SVR. This parametric study was completed using *hyg*IRC, an advanced hygrothermal tool developed at the NRC-IRC. This paper focuses on the use of this SVR in a wall system located in Halifax (Nova Scotia), an eastern coastal area of Canada

2 THE HYGROTHERMAL MODEL *hyg*IRC

2.1 *Description of hyg*IRC

The development and applications of NRC-IRC's advanced hygrothermal model hygIRC have been reported in earlier publications (Maref et al. 2002 (a) and (b)). To this was added the most recent knowledge related to quantifying wind-driven rain on building facades that permitted predicting liquid water moisture loads on exterior wall surfaces (Tariku & al., 2007). Extensive laboratory benchmarking exercises of the model hygIRC were completed at the system level (Maref et al. 2002 (a), (b), (c) and (d)) as well as a field benchmarking exercise (Tariku & al., 2006).

2.2 *Inputs for hygIRC 2D*

2.2.1 *Wall Configuration*

In this study, residential wood-frame direct-applied stucco cladding was considered to represent a "worse case scenario" in the evaluation of the SVR. The basic details of the construction of the wood-frame stucco wall are shown in Figure 1. The wall remains the same for all the simulations completed in this study, and only the strategies for vapour diffusion control are varied by either changing the vapour barrier or applying paint on the gypsum board.

Figure 1 shows the base case that, from exterior to interior components, consisted of:

- 19 mm cement-based stucco
- Sheathing membrane (asphalt-impregnated building paper (0.2 mm))
- 12.7 mm Oriented Strand Board (OSB) as a sheathing board
- 2x6 (38 by 138 mm) wood-framed wall (Spruce)
- 2x6 wood-frame cavity filled with glass fibre insulation (11 kg/m^3 density)
- 100 μm (4-mil) PE sheet (base case) or 50 μm (2-mil) SVR or no vapour retarder
- 16 mm gypsum wallboard either painted with latex paint or not painted.

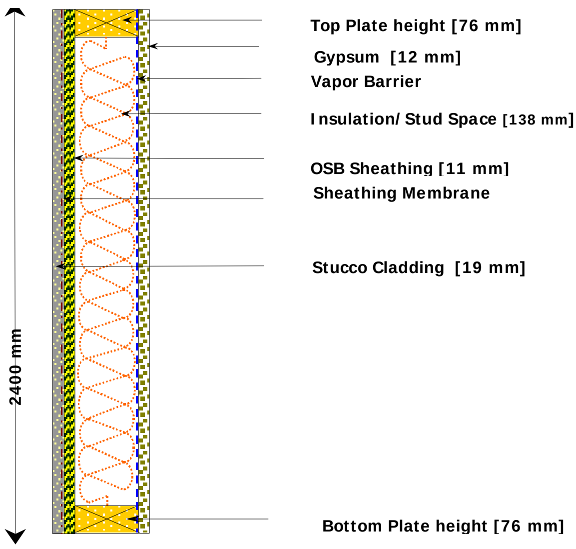

Figure 1 – Wall Configuration

2.2.2 *Material Properties*

The physical and transport properties of the materials used are very critical as input values for hygrothermal modeling and, hence, the need to carefully determine these properties cannot be overemphasized. In this study, the basic material properties required for the *hygIRC* input file are taken from the material database available at the National Research Council Canada (NRC-IRC). Great care was taken in generating these values and each followed standard test procedures.

Three (3) vapor control strategies are considered:

1- 4-mil polyethylene or (60 ng/Pa• s• m^2, minimum NBC 2005 requirement)
2. Smart Vapor Retarder
3. Paint as a vapour barrier

Two (2) configurations of gypsum wallboard were used, including:

1. Wallboard and Latex paint (High Vapor Permeance WVP = 1140 ng/Pa.s.m^2)
2. No paint

2.3 *Boundary Conditions and Geographical Location*

2.3.1 *Exterior Conditions*

The exterior climatic conditions required for *hygIRC-2D* simulations have seven major weather components (i.e., temperature, relative humidity, wind velocity, wind direction, rain fall, solar radiation and cloud index) recorded on an hourly basis. In this paper, Halifax (Shearwater) was considered based on the drying and wetting potentials expressed by a moisture index (MI) (*Cornick et al. 2002*).

The total exposure period or duration of the simulation is three (3) years (Wet, Wet, and Average years, see below). The first year is simply to permit the wall components to reach equilibrium and thereafter, the analysis is carried out on the response of the wall and its components to the last two years of simulation. All simulations start on January 1st. The *wet* year for a city is defined as the year with highest wind-driven rain, and the *average* year as the year closest to the mean wind-driven rain. The moisture management strategy for a wall system is climate specific. Halifax (NS) is used for this study and was selected on the basis of moisture load characteristics. The moisture load characteristic of any geographic location is expressed in terms of the moisture index, or MI, and is derived from an analysis of recorded weather data for 30 or more years (*Cornick et al. 2002*). The MI describes the climatic moisture load and is a function of two terms, the potential for wetting (i.e. Wetting Index (WI)) and the potential for drying (i.e. Drying Index (DI)). The higher the value of MI, the more severe the moisture loading is. The WI is based on annual rainfall whereas the DI is based on annual evaporation potential. The MI is independent of wall characteristics and design strategies that might be used to manage moisture loading. To assign rankings on the basis of climate analysis at any location in North America, the following definition is used (*Cornick et al. 2002*):

$$MI = \sqrt{WI^2_{normalized} + \left(1 - DI_{normalized}\right)^2} \qquad (1)$$

The details of the normalization procedure are given in *Cornick et al. 2002*. The MI value for Halifax is shown in Table 1.

Table 1: Moisture Index for Halifax (NS)

Location: Shearwater (NS)	**MI**	**Classification w.r.t Moisture Loading**
	1.15	High
Orientation	**Wet year**	**Average year**
East	1962	1980

For each simulation, the wall was oriented in the direction where the wind-driven rain was dominant for the location. In the case of Shearwater, this orientation was East.

2.3.2 *Interior Conditions*

The hourly interior climatic conditions (i.e., temperature and relative humidity) are considered as a subject of parametric variation. Since a worse case scenario is of interest in this study, a high indoor relative humidity (RH) was chosen, for which the following were selected for summer and winter conditions:

- 50% RH (constant) and 21°C temperature for winter,

- 65% RH (constant) and 24ºC temperature for summer.

2.4 *Initial Moisture Content and Moisture Load*

2.4.1 *Initial Moisture Content*

In any hygrothermal simulation, the user defines the initial moisture content of each wall component at the beginning of the simulation period. In this study it is assumed that the initial moisture content of each wall component is equivalent to a corresponding relative humidity of 50%, derived from the sorption isotherm of the respective materials. Similarly, the initial temperature across the entire cross section of the wall is assumed to be 20°C.

2.4.2 *Moisture Load*

A moisture source in the wall cavity is assumed since in reality, over the service life of the wall system, defects will likely occur that would result in water (liquid moisture load) being deposited in the stud cavity due to the effects of wind driven rain impinging on the surface of the wall cladding. The magnitude of this moisture load is estimated to be 1 % of the wind driven rain that is deposited on the wall (ASHRAE 2005 Standard 160P).

3 *hyg*IRC SIMULATION

For the exterior conditions *hyg*IRC uses rain and wind data to calculate the amount of rain that is deposited on the vertical surface and uses radiation and cloud index data to calculate radiant heat transfer between the wall and the surrounding sky.

The following assumptions were made for all hygIRC simulations:

- Air tightness of the house,
- Other than water penetration, no deficiencies were incorporated in the wall system,
- No air cavity ventilation was included; the stucco cladding was applied directly to the sheathing membrane,
- The contact between the membrane and the OSB sheathing was assumed to be perfect (no interstitial airspace).

4 SIMULATION RESULTS AND ANALYSIS

Within this section, results regarding the change in moisture content of the OSB sheathing board (exterior sheathing board) are first examined in relation to different approaches to treating the interior finish (e.g. no paint or painted with latex paint). Thereafter, and within the same section, changes to the bulk moisture content of the interior gypsum wallboard are discussed in relation to the same modes of treating the interior finish. Results of the effect of moisture load inside the stud cavity are also presented.

These simulation results reflect the response of three stucco-clad wall assemblies respectively employing three different vapour control strategies. As a means of comparing the response of different walls when subjected to the same boundary conditions, the results obtained from simulation of the three walls are presented in the same graph.

4.1 *Moisture Content (MC) of OSB*

4.1.1 *Gypsum Board painted with Latex Paint*

Figure 2 & 3 show output curves of the moisture absorbed into the exterior sheathing OSB (2.4 m high per m width) of the three wall systems with latex paint on the face of the gypsum. Figure 2 shows that when there is no direct water penetration into the stud cavity, the moisture content varies over the year based on the weather conditions. The moisture is mainly transported into the wall either by diffusion, capillary suction or air movement through materials.

The results plotted in Figure 3 clearly show the hygrothermal performance of the wall system with SVR compared to the two other wall systems. Even with water penetration, the wall employing SVR performs better. The graph shows the net accumulation of moisture in the OSB layer with some drying potential to the outside in the case of walls having a PE sheet (Figures 2 & 3).

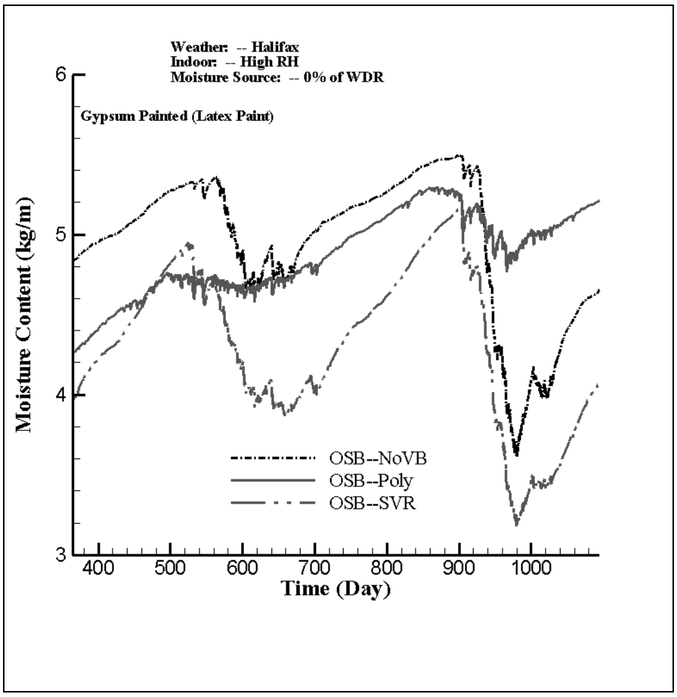

Figure 2 – Bulk Moisture Content (kg/m) of OSB versus time (day) for simulations on wall assemblies hav-

ing different vapour control strategies with 0% WDR and interior finish painted with latex paint

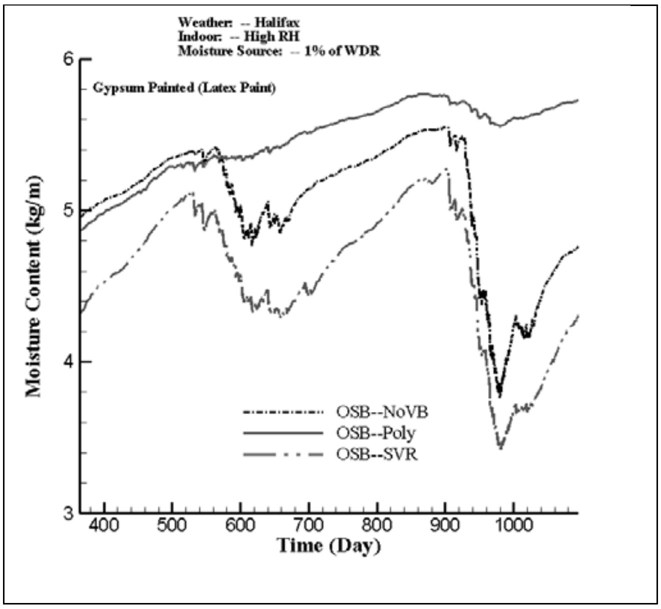

Figure 3 – Bulk Moisture Content (kg/m) of OSB versus time (day) for simulations on wall assemblies having different vapour control strategies with 1 % WDR and interior finish painted with latex paint

4.1.2 *Unpainted Gypsum Board*

Figure 4 and 5 show the total moisture content in the OSB layer as function of time, with no paint on the face of the gypsum board in the case of wall system employing SVR and with PE as a vapour diffusion control element. The first case with no water entry is shown in Figure 4 and with water entry in Figure 5. In both figures it is evident that the SVR provides better performance in terms of the comparatively lower moisture retention by the OSB for wall systems with SVR as compared to those having painted gypsum as vapour barrier or with a polyethylene as barrier.

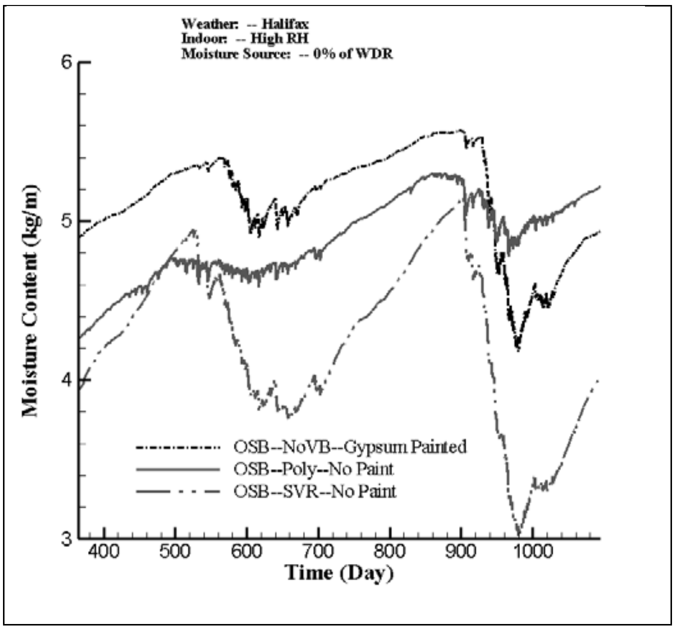

Figure 4 – Bulk Moisture Content (kg/m) of OSB versus time (day) for simulations on wall assemblies having different vapour control strategies with. 0 % WDR and interior finish unpainted or painted with latex paint in the case of No VB.

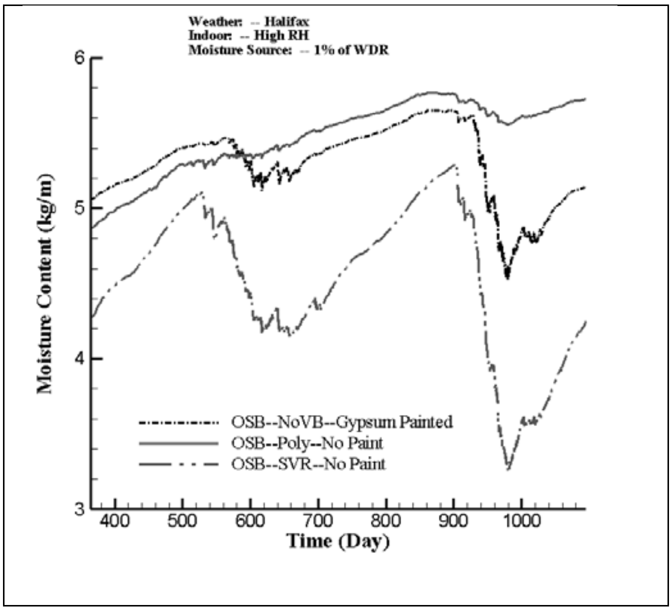

Figure 5 – Bulk Moisture Content (kg/m) of OSB versus time (day) for simulations on wall assemblies having different vapour control strategies a with 1 % WDR and interior finish unpainted or painted with acrylic paint in the case of No VB.

4.2 *Results for Moisture Content (MC) of Gypsum Board*

To obtain a measure of the overall hygrothermal performance of the three wall systems and to assess the different vapour diffusion control strategies, results on the changes in MC of the gypsum board are presented.

4.2.1 *Gypsum Board with Latex Paint*

Figure 6 & 7 show the moisture content of the gypsum board as function of time for the three wall systems having latex paint. Figure 6 shows the results with no water penetration; Figure 7 with water penetration.

In the case of no deficiency (Figure 6) the three wall systems behave in the same way and have nominally the same moisture content, ranging between 9.2% and 11.2% (i.e. between 50% RH and 84%) depending whether it is in the summer or winter conditions. In the case of the system with a polyethylene, it is clear that the change in MC of the gypsum board follows the pattern of change in interior relative humidity.

Figure 7 shows the moisture content of the interior finish gypsum board as function of time (Day) with water penetration into the stud cavity (1% moisture load). In the case of a wall system with PE, it is evident that the gypsum board will not respond to changes in moisture load to the stud cavity (1% moisture load or 0%) as the PE sheet acts as barrier to vapour flow. In the case where latex paint is used as interior finish, the presence of water inside the stud cavity did not have an effect on the bulk moisture content in the gypsum board for the wall systems having the SVR and the other with no PE; . In this case, the high vapour permeance of the paint clearly affects the degree of vapour diffusion control in the wall system. The system with high vapour permeance allows drying towards both sides of the gypsum (to the inside and the outside).

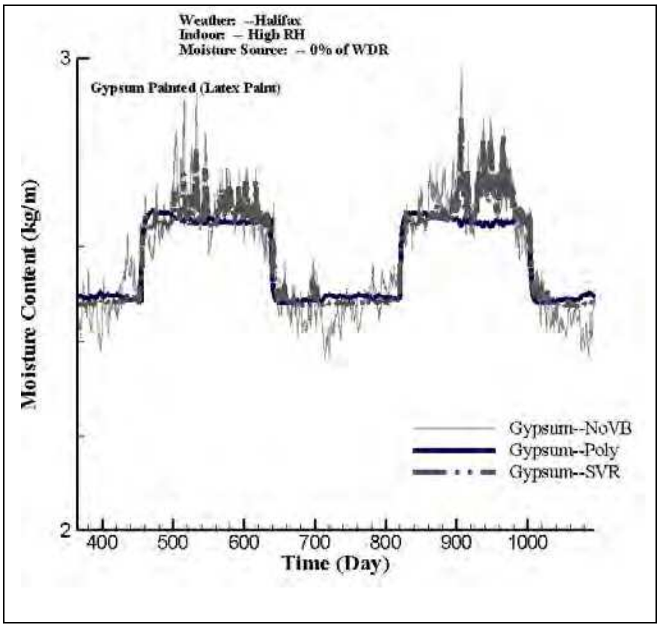

Figure 6 – Bulk Moisture content (kg/m) of interior gypsum board in relation to time (day) for simulations on wall assemblies having different vapour control strategies with 0% WDR and interior finish painted with latex paint.

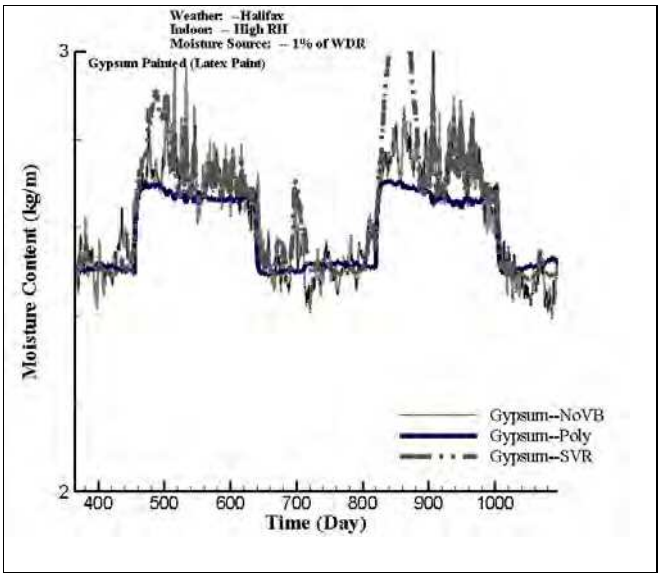

Figure 7 – Bulk Moisture content (kg/m) of interior gypsum board in relation to time (day) for simulations on wall assemblies having different vapour control strategies with 1% WDR and interior finish painted with latex paint.

4.2.2 *Unpainted Gypsum Board*

Figure 8 & 9 show the moisture content of the interior finish gypsum board as a function of time for the three wall systems without latex finish paint. Figure 8 shows the results with no water penetration and Figure 9 with water penetration.

In the case of no water penetration (Figure 8) the three wall systems behave in the same way; both these wall systems nominally had the same moisture content that ranged between 9.2% and 11.2% (i.e. between 50% RH and 84%), depending whether it is was summer or winter conditions. For the case of the system with a SVR and PE sheet it is clear that since the gypsum is not painted, the gypsum board behaves in the same way as the variation in indoor relative humidity.

Figure 8 shows the moisture content of the interior finish gypsum board as function of time (Day) with water penetration into the stud cavity (1% moisture load). In the case of a system incorporating PE, it is expected that the gypsum board would not show any response to changes in moisture load (1% moisture load or 0%) given the location of the vapour barrier in relation to the board. In the case of a system using a SVR, the wall system performs as well as the system having a PE barrier; the back of the gypsum board is not affected by water entry into the cavity and additionally, it permits drying on both sides, whilst nominally maintaining the same conditions as the indoor environment. Whereas, in the case of a wall system having unpainted gypsum board, the wall system having a SVR shows better hygrothermal performance as compared to a system with no PE and performs as well as one with a PE barrier.

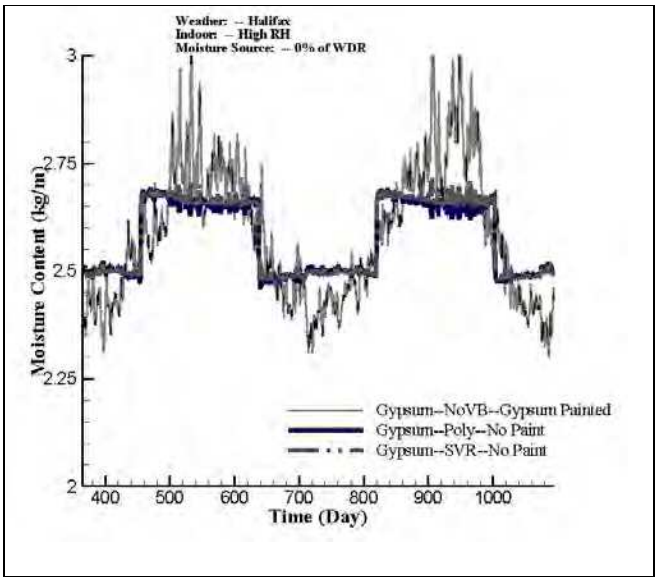

Figure 8 – Moisture content (kg/m) of interior gypsum board in relation to time (day) for simulations on wall assemblies having different vapour control strategies with 0% WDR and interior finish unpainted.

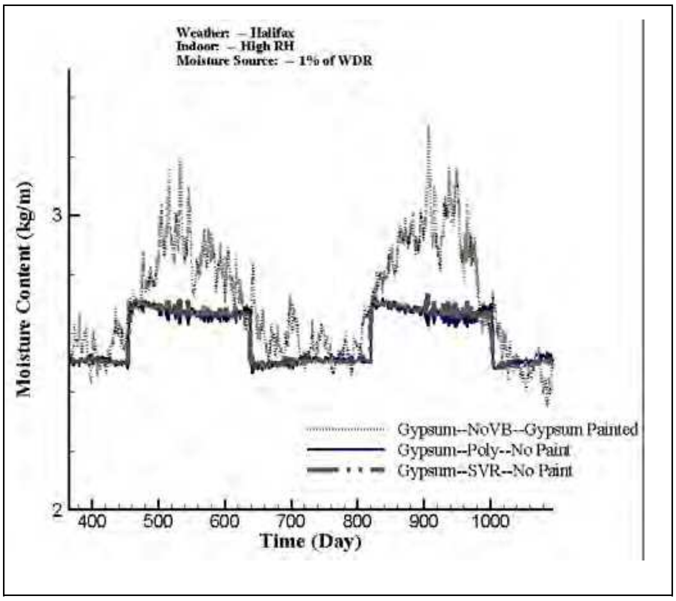

Figure 9 – Moisture content (kg/m) of interior gypsum board in relation to time (day) for simulations on wall assemblies having different vapour control strategies with 1% WDR and interior finish unpainted

CONCLUSION

Note that in all simulated cases there is:

- Direct application of the stucco on the sheathing membrane.
- All extreme conditions chosen for the study are to simulate the worse case scenario for that location.

Continuous polyethylene-films have been used for interior vapor diffusion and air leakage control in Canada. This hygrothermal modeling study using the advanced hygrothermal model *hyg*IRC concluded that wall systems employing an innovative Vapor Retarder perform well in a coastal area such as Halifax. Also, data show that latex-painted interior board systems when subjected to moderate interior cavity moisture loads may be suitable for use in those coastal locations.

Finally, the hygrothermal performance of a stucco wall has demonstrated the benefits of having a bi-directional vapour retarder-drying ability with relative humidity dependence when the vapour permeance of the interior paint is relatively high. The SVR allows moisture vapour flow to occur when the load becomes critical and has higher tolerance to moisture accumulation due to the ability for increased drying. The installation of a humidity controlled, variable-perm vapor retarder is a recommendable solution for the envelope design of residential buildings in coastal areas such as Halifax (Canada) with moderate or high water vapour permeance of the interior paint.

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