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HYGROTHERMAL PERFORMANCE OF RH-DEPENDENT VAPOUR RETARDER IN A CANADIAN COASTAL CLIMATE

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ABSTRACT
The hygrothermal performance of wood-frame wall with stucco cladding exposed to the coastal climate of Vancouver, BC, is studied. The primary objective of the study is to compare the moisture management performance of two vapour barriers: the relatively new SmartVapour Retarder (SVR) and commonly used Polyethylene sheet. For a reference purpose a wood-frame wall with no vapour barrier is considered as well. The performances of these three walls, which are exposed to the same indoor and outdoor climatic loads, are compared with respect to their dynamic responses to two simulation variables: interior moisture load (simulated water intrusion in the stud cavity) and paint on the interior gypsum board. The water intrusion is assumed to be through defect areas and the quantity is correlated with the amount of wind-driven rain that the wall is exposed to. The hygrothermal simulation results suggest that adoption of SVR as a vapour barrier yields better moisture management of the sheathing board (OSB) for any conditions considered in this paper including internal moisture load and interior paint. But, in coastal climate, it may have adverse effect on the moisture management of the interior gypsum board, in cases where water leaks into the cavity and the interior gypsum board is painted with low-vapour permeance paint.

RÉSUMÉ
Le rendement hygrothermique de murs à ossature de bois et parement de stucco exposés au climat littoral de Vancouver, CB, est étudié. L’objectif de cette étude est de comparer le rendement en terme de gestion de l’humidité de deux pare-vapeur : le pare-vapeur à perméabilité variable selon l’humidité relative, matériau relativement nouveau, et le polyéthylène, couramment utilisé. Un assemblage de référence sans pare-vapeur est inclus dans l’étude. Le rendement de ces trois assemblages, qui sont exposés aux même conditions intérieures et extérieures, est comparé en fonction de la réponse dynamique à deux variables simulées : la charge d’humidité intérieure (simulant une infiltration d’eau) et le type de peinture sur le gypse intérieur. On prend pour acquis une infiltration de l’eau à travers un défaut de l’enveloppe et la quantité d’eau est correlée à la quantité d’eau de pluie battante arrivant sur le mur. La simulation hygrothermique indique que l’utilisation du pare-vapeur à perméabilité variable résulte en une meilleure gestion de l’humidité pour le parement intermédiaire (OSB) pour toutes les conditions incluses dans cet article. Toutefois, en climat littoral, cette solution peut avoir un résultat contraire pour la gestion de l’humidité relativement au panneau de gypse intérieur, dans les cas où il y a infiltration d’eau dans la cavité isolée et que le gypse est peint avec une peinture à faible perméance à la vapeur.

1. Introduction

Controlling or managing moisture and reducing the risk of moisture-related problems by judicious design, material choice and proper installation is the most practical approach for ensuring adequate long-term performance of wall systems. 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. 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.

Simulation tools are usually applied to assess the hygrothermal performance of building envelope systems and sub-systems in order to prevent moisture damage. 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 vapour retarder (SVR), a humidity controlled vapour retarding film describe in Künzel (1998, 1999) and Künzel and Leimer (2001). Later on, work was done in the USA on this innovative vapour retarder by Karagiozis (2003), Gatland (2005) and Gatland et al. (2007). It consisted of undertaking field measurements and completing computer simulations to compare different vapour diffusion control strategies such as the use of polyethylene sheet and asphalt coated kraft paper (Kraft). Those studies showed the benefit of the use of this product as a vapour retarder but not in excessive relative humidity (RH) conditions such as might be found in enclosures for saunas or swimming pools. To complement this initial work, the National Research Council Canada-Institute for Research in Construction (NRC-IRC) undertook to further investigate the use of this product in buildings assemblies for the Canadian climate (Di Lenardo and Flack 2007; Maref and Tariku 2007; Maref et al. 2008).

In this paper a comparison is made between the moisture performance of 2 by 6-in. wood-frame stucco-clad wall systems subjected to the coastal climate of Vancouver that employ either a polyethylene sheet, a commonly used membrane for vapour diffusion control, or RH-dependent vapour retarder, often referred to as the “Smart Vapour Retarder (SVR)”. The test case wall assemblies considered a vapour control strategy whereby no polyethylene sheet was used but the interior gypsum board finish was painted. The primary simulation variables for comparing the performance of these wall systems were the presence or absence of moisture entry in the stud cavity and the use of paint on the interior gypsum board. The parametric study described in this paper utilizes the NRC-IRC’s advanced hygrothermal model, *hyg*IRC to generate simulation results.

2. Hygrothermal modeling

*hyg*IRC is a two-dimensional transient hygrothermal model capable of predicting heat, air and moisture (HAM) transport in porous building materials. The governing equations for HAM transport that are solved in *hyg*IRC are a set of partial differential equations (PDEs) that account for mass, momentum and energy conservation in a porous media. The PDEs and the numerical scheme employed to solve these equations are documented in Karagiozis and Kumaran (1993), Salonvaara and Karagiozis (1994) and Karagiozis (1997). The model has been validated with well-controlled laboratory experiments (Maref et al. 2002a; 2002b; Kumaran and Wang 2002; Tariku and Kumaran 2002), as well as with a field experiments in which an aerated concrete wall was exposed to real indoor and outdoor climatic conditions (Tariku and Kumaran 2006). The application of the model has been demonstrated in a number of publications, including: Karagiozis et al. (1996), Djebbar et al. (2002), Mukhopadhyaya et al. (2006) and Tariku et al. (2007).

In this paper, the hygrothermal performance of a stucco-clad wall system is subjected to time varying internal and external boundary conditions, and as well, an additional time varying internal moisture source is also investigated. The main input parameters that are required to simulate the dynamic response of the wall system are: the wall configuration, hygrothermal properties and initial conditions of each layer of material that constitute the wall assembly, indoor and outdoor boundary conditions as well as the internal moisture source. These parameters are described below.

2.1 Wall configuration

For this study a 2 by 6-in. (38 by 140-mm) stucco-clad wall system is considered. As shown in FIGURE 1, the wall is comprised of the following layers, in sequence, from exterior to interior: Acrylic stucco (19 mm), Sheathing membrane (asphalt-impregnated building paper, 0.2 mm), Sheathing board (OSB, 12.7 mm), Insulation (Glass fiber, 140 mm), Vapour barrier and Interior finish (Gypsum board, 16 mm). The wall configuration remains the same for all the simulations completed in this study, and only the strategies for the vapour diffusion control are varied. The vapour diffusion control strategies considered include a wall with: (i) no polyethylene sheet; (ii) 4-mil (100 μm) polyethylene sheet as vapour barrier, and; (iii) 2-mil (50 μm) SVR sheet as vapour barrier. In this multilayer system, adjacent layers are assumed to be in a perfect contact and there is no air cavity ventilation as the stucco cladding is directly applied on the sheathing membrane.

The hygrothermal properties of all the materials that make-up the walls are taken from the MEWS and ASHRAE research projects described in Kumaran et al. (2002a, 2002b) and Kumaran (2006). These properties include: density, water vapour permeability, liquid diffusivity, sorption-isotherm and moisture retention, heat capacity, thermal conductivity, and air permeability. In some simulation cases the gypsum board (interior finish) is coated with primer and two coats of acrylic paint. According to the material properties report of Annex 24 (Kumaran 1996) this surface finish has a vapour diffusion thickness of 0.46 m (vapour permeance of 422 $ng.Pa^{-1}.s^{-1}.m^{-2}$). The vapour permeance of the 4-mil Polyethylene sheet is 60 $ng.Pa^{-1}.s^{-1}.m^{-2}$. As shown in FIGURE 2, the vapour permeability of SVR depends on the relative humidity conditions at the boundary of the sheet. As the relative humidity at the boundary increases, the vapour permeability of the SVR also increases, but non-linearly in relation to the RH and following the a power function.

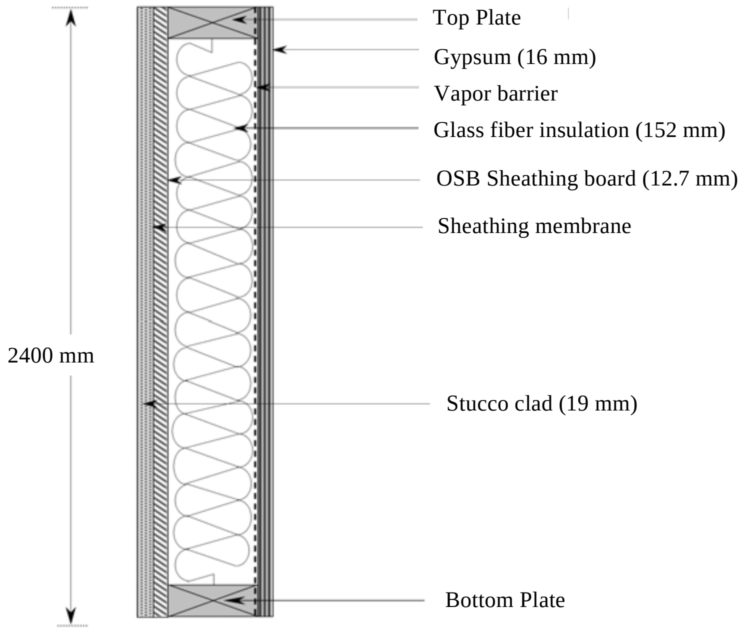

FIGURE 1: SCHEMATIC DIAGRAM OF A STUCCO-CLAD WALL CONSIDERED IN THE STUDY

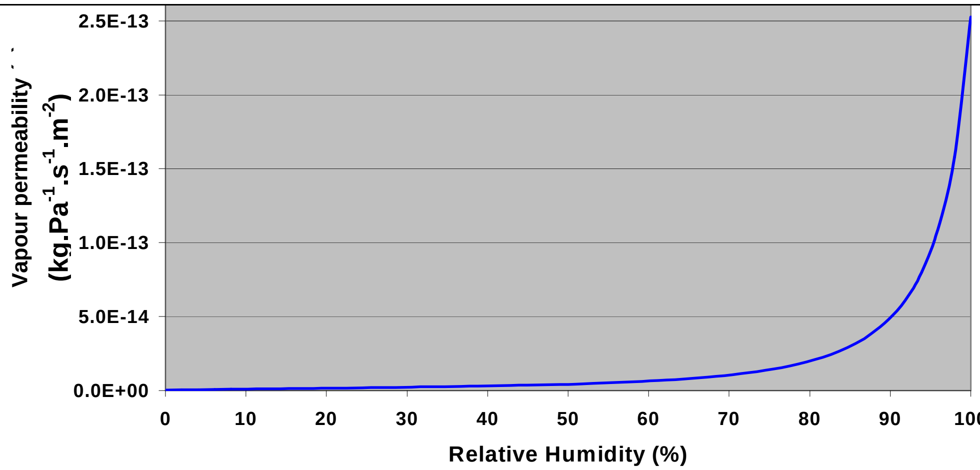

FIGURE 2: THE VAPOR PERMEABILITY CHARACTERISTICS OF SVR

2.2 Boundary and initial conditions

In the hygrothermal simulations carried out in this study, the wall is exposed to “real” weather conditions on the exterior (outside) surface and controlled temperature and relative humidity conditions on the interior (indoor) surface. The wall systems are considered to be exposed to the coastal Canadian climate of Vancouver (British Columbia). According to Cornick et al. (2001), Vancouver has a moisture index (MI) value of 1.09 in terms of the North America climatic classification index and is considered to be a region with high moisture loading. MI is a function of two terms: the potential for wetting (based on annual rainfall) and the potential for drying (based on annual evaporation potential). The higher the value of MI, the more severe the moisture loading is. Currently, the moisture index (MI) is adopted for use in the National Building Code Canada (2005).

In each simulation case, the dynamic response of the stucco wall system is simulated over a period of three years. This approach is similar to that used in the MEWS project for which additional information can be found in (Beaulieu et al., 2002). The three years are selected from the available weather data for the location based on the annual wind-driven rain load. The selected years are assembled in "average-wet-wet" year sequence for the simulation. The first year is used to condition the wall, and the final two years are used as a basis for analysing the hygrothermal response of the wall assembly. The hourly weather data that comprises temperature, relative humidity, wind speed, wind direction, global radiation, diffuse radiation, reflected radiation, rain and cloud index of the location of interest are taken from IRC's existing climate database.

The indoor temperature and relative humidity are set, respectively, to 21^{o}C and 50% during the winter and 24^{o}C and 65% in the summer. These settings represent the worst-case scenario (Maref and Tariku 2007) in which the high indoor humidity has significant effect on the moisture performance of a wall assembly. The heat and moisture fluxes to which the internal boundary surface is subjected are calculated using constant values of heat and mass transfer coefficients of 8 W/m^{2}K and 5.8E-8 s/m, respectively. The heat and moisture fluxes applied to the exterior surface of the wall are calculated using variable heat and mass surface transfer coefficients. The heat transfer coefficient is a function of wind speed, and the mass transfer coefficient is deduced from the heat transfer coefficient using the Lewis relation (ASHRAE 2005). The initial conditions for all layers of the wall are assumed to be at 20^{o}C and 50% relative humidity.

3.0 Internal cavity moisture load

Water penetration has the most critical influence on the moisture management of wall systems. Neither vapour diffusion nor air leakage causes comparable magnitude of moisture condensation. The effect of water penetration may be several orders of magnitude greater than that which simply occurs by vapour or even liquid diffusion. The presence of wall penetrations such as windows and joints amplifies the local hygrothermal influences, as water loads become many times greater than in walls without penetrations (i.e. opaque portions of exterior wall).

The internal moisture load, which simulates wind-driven rain intrusion into the wall through defects, was determined by considering the local climate, topography, building geometry and orientation. The predefined water penetration, which is expressed as the amount of water in kilograms in a unit volumetric space, is assumed to be uniformly deposited on top of the bottom plate in the stud cavity. The quantity of water deposited on the bottom plate is related to the percentage of wind-driven rain that impinges the wall (estimated based on Straube and Burnett (2000) simplified method), and calculated on an hourly basis from the assembled weather data. In this paper, 1% wind-driven rain entry is assumed as per the ASHRAE Standard 160P (2008). The hourly internal moisture loads that are considered during the three years of simulation period are shown in FIGURE 3.

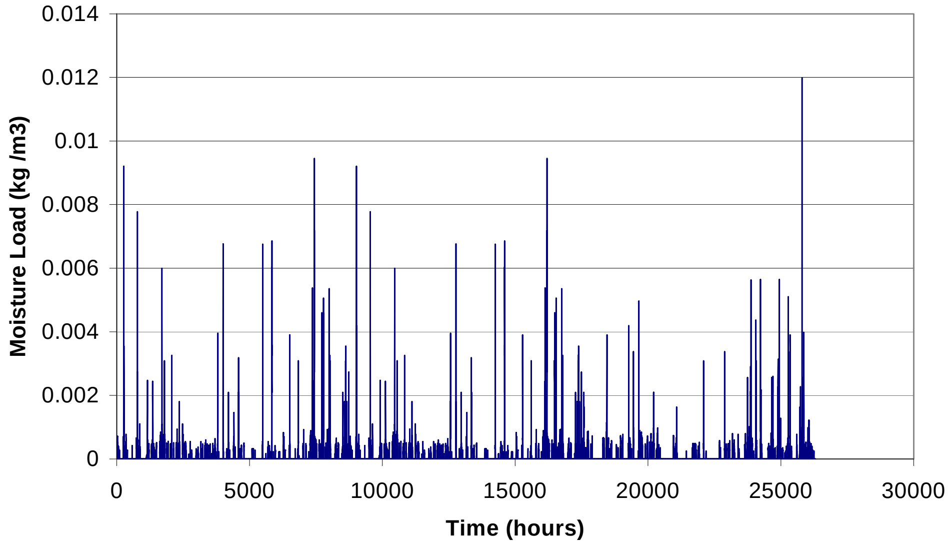

FIGURE 3: INTERNAL MOISTURE LOAD IN THE STUD CAVITY DURING THE THREE YEARS OF SIMULATION PERIOD

4.0 Simulation Results and Discussion

Outputs derived from the simulation software include transient states of moisture content, temperature and airflow distribution in the calculation domain for the applied time-varying boundary and prescribed initial conditions. Within this section, results regarding the change in moisture content of the OSB sheathing board (exterior sheathing board) and interior gypsum board are examined in relation to different vapour control strategy. Moreover, the effects that the internal moisture loads and surface finish have on the moisture performance of the wall are discussed. 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. All simulations start on January 1st.

4.1 Case with no internal cavity moisture load

FIGURE 4 shows the transient moisture condition of the sheathing board, OSB, in the case where there is no additional moisture load due to wind-driven rain penetration. Generally, the moisture content of the OSB varies over the years based on weather conditions. It accumulates relatively more moisture in the winter and dries out in the summer period. In the case with no polyethylene sheet, the drying and wetting potential of the OSB are significantly higher than the walls with polyethylene or SVR vapour barriers. The SVR allows reduced moisture accumulation in the winter compared to the case with no polyethylene sheet while promoting faster drying to the interior during summer. In the case of the wall with a polyethylene sheet, the drying potential of the OSB to the interior is retarded by the lower vapour permeance of the polyethylene. In all the three simulation cases (FIGURE 5), the moisture accumulations in the gypsum board (interior finish layer), show step-functions following the indoor climatic condition profiles. A slightly variable pattern is noticed in the case with no polyethylene sheet as it allows the relatively moist OSB to dry out to the interior.

FIGURE 6 shows the relative-humidity profiles of a control volume at the back of a painted gypsum board. The relative humidity of the location fluctuates highly (40 to 80%) in the case where there is no polyethylene sheet. Whereas, in the case of the wall with polyethylene sheet the RH of the location is relatively stable showing 52 and 68% RH during the winter and summer time respectively. In the case of a wall with SVR sheet the moisture condition of the location is affected by the moisture conditions in the exterior part of the wall such as the OSB. Consequently, the RH of the location has a slightly larger band (upper minus lower values) compared with the wall with the polyethylene sheet; with the polyethylene sheet the moisture movement in the gypsum board is almost isolated from the exterior part of the wall.

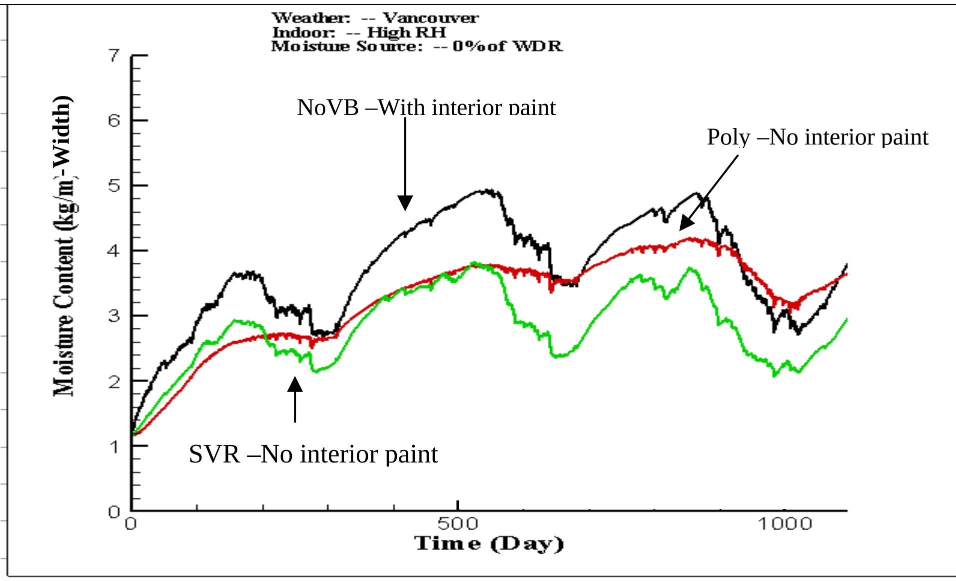

FIGURE 4: TRANSIENT MOISTURE PROFILES OF OSB IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 0% WDR.

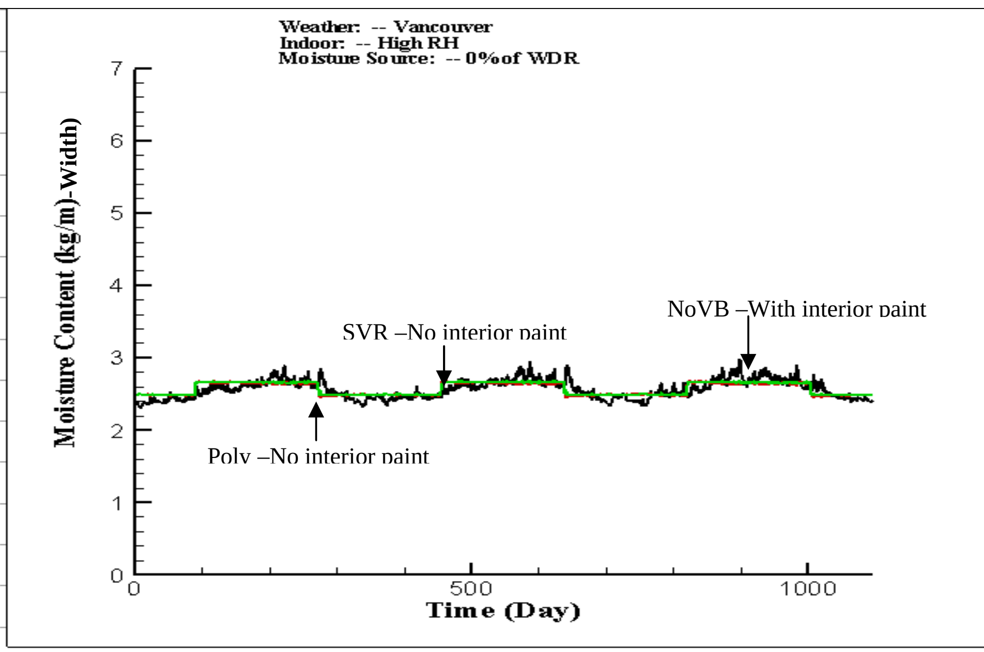

FIGURE 5: TRANSIENT MOISTURE PROFILES OF GYPSUM BOARD IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 0% WDR.

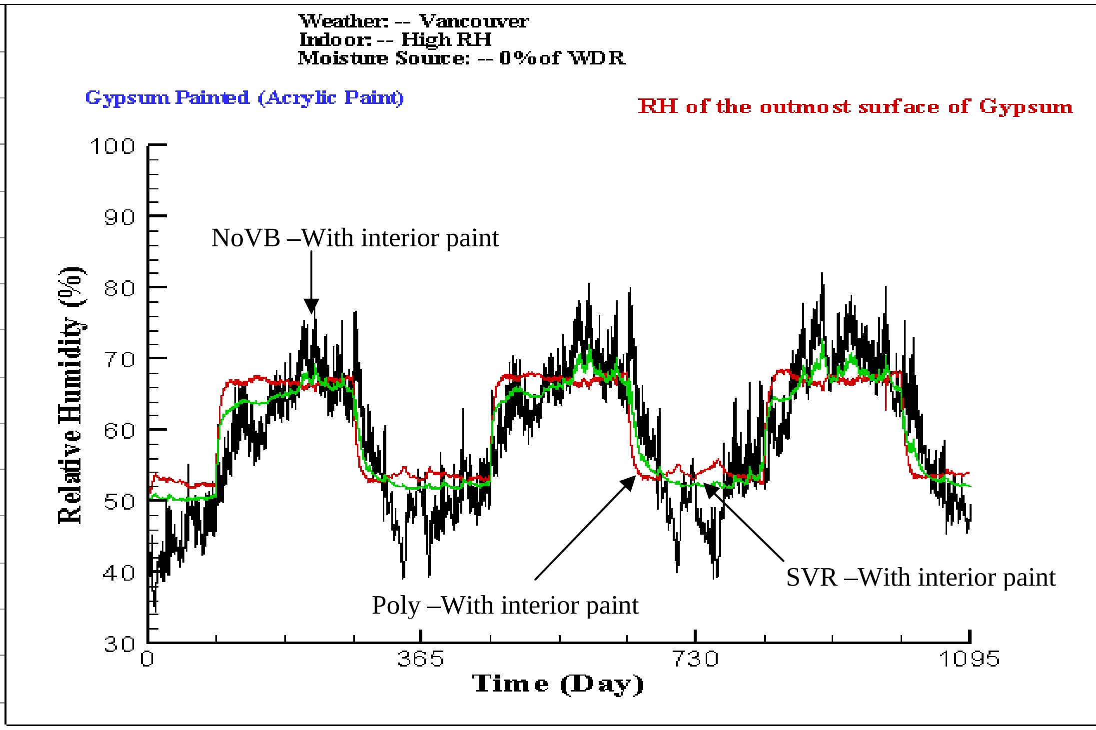

FIGURE 6 TRANSIENT RELATIVE HUMDITY PROFILES OF A PONT AT THE BACK OF INTERIOR GYPSUM BOARD IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 0% WDR.

4.2 Case with interior cavity moisture load

As presented above, in cases where there is no internal moisture load associated with wind-driven rain penetration, the wood frame wall with SVR performed better than that of walls with or without polyethylene sheet as vapour barrier with unpainted gypsum board. The SVR sheet provides good wall system performance giving lower moisture accumulation in the OSB and making the gypsum board more responsive to the dynamic moisture conditions of the exterior part of the wall. In this section, results from simulation of the same wall configuration and boundary conditions are provided that also include an internal moisture load in the stud cavity. In the case of the wall with polyethylene sheet the drying potential of the wall is almost exclusively to the exterior since the low vapour permeance of the polyethylene hinders drying into the indoor space. Consequently, as shown in FIGURE 7, the OSB accumulates higher moisture content throughout the simulation period as compared to the cases with no polyethylene sheet or the use of an SVR sheet. Although the case with no polyethylene sheet promotes maximum drying to the indoor space it also allows high moisture movement from the interior (high vapour pressure) to the exterior (low vapour pressure) during the winter period; this results in higher moisture accumulation in the OSB over this period. The wall with the SVR sheet allows moderate moisture transfer to/from the interior from/to exterior part of the wall as opposed to nearly closed (polyethylene) or fully open (no vapour barrier) cases and results in moderate moisture accumulation in the OSB. The total moisture content profile of the gypsum board (FIGURE 5) is similar to the cases with no internal moisture load.

In cases where, however, the interior gypsum board is painted with acrylic paint, as shown in FIGURE 8, the total moisture accumulation on the gypsum board is highest in the case of the wall with SVR compared to the case of walls either having or not having polyethylene sheet. This is due to the fact that the drying potential of the gypsum is reduced due to the presence of surface finish paint on one side and the SVR sheet on the other side. Consequently, the moisture that the

SVR sheet allows into the gypsum during the drying process of the intruded water builds up due to the resistance of the paint. The walls having or not having polyethylene show better moisture conditions on the gypsum board as compared to SVR for different reasons. The polyethylene won't allow moisture movement from the moist section of the wall (cavity) to the gypsum board in the first place. In the case of the wall with no-vapour barrier, the gypsum board has a potential of receiving more moisture than the case with SVR but it also has a higher drying potential towards the exterior, as there is no retarding media. This means that the gypsum can dry both to the interior and exterior depending on the moisture balance conditions.
FIGURE 9 shows the moisture condition (relative humidity) of a control volume at the outermost surface of the gypsum board in simulation cases with internal cavity moisture load and painted interior finish. In the case of the wall with polyethylene sheet, the relative humidity of the point of interest fluctuates between 55 and 70%. Whereas in the case of the wall with SVR, the same point of interest sustains relatively high relative humidity (>95%) for an extended period of time during the second and third year of simulation. In the case of the wall with no- polyethylene sheet, the relative humidity of the point of interest is also high but does include some drying patterns.
The results from the parametric study carried out and described in this paper generally suggest that use of the SVR sheet helps maintain acceptable moisture levels on the OSB sheathing for all conditions evaluated in the study. However, in instances where the gypsum board is painted with a low water vapour permeance coating, its use may increase moisture accumulation on the gypsum board in the presence of an internal cavity moisture load. Given that homeowners customarily paint the interior of their homes for aesthetic reasons, and there may be accidental rain penetration over the period of use, it is recommended that for the coastal climates considered in this study, the SVR sheet be used in conjunction with paints that have high water vapour permeance.

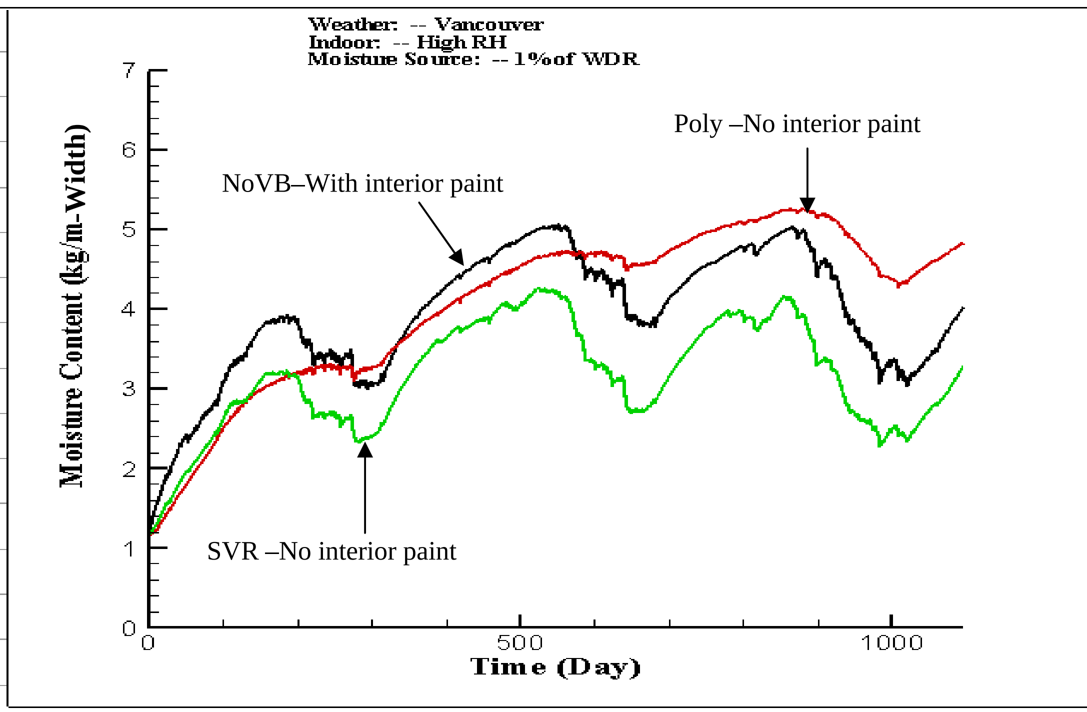

FIGURE 7: TRANSIENT MOISTURE PROFILES OF OSB IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 1% WDR.

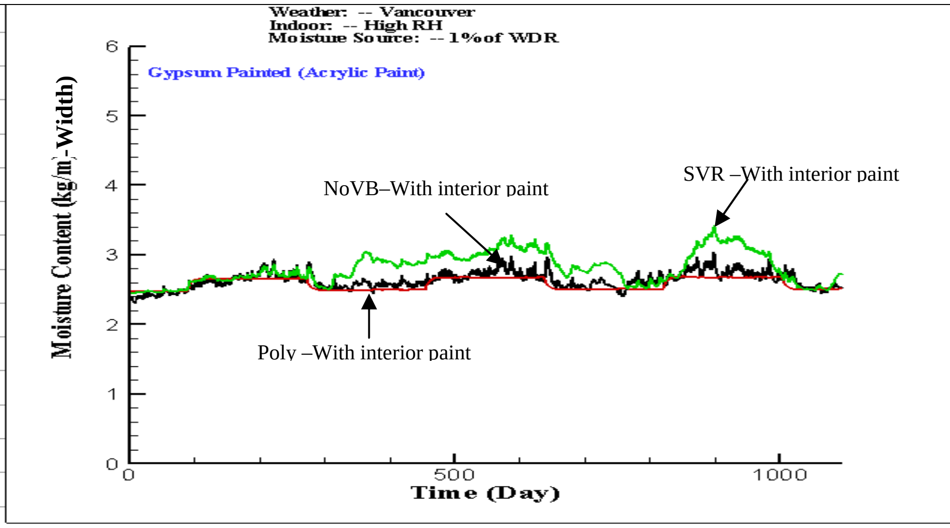

FIGURE 8: TRANSIENT MOISTURE PROFILES OF GYPSUM BOARD IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 1% WDR.

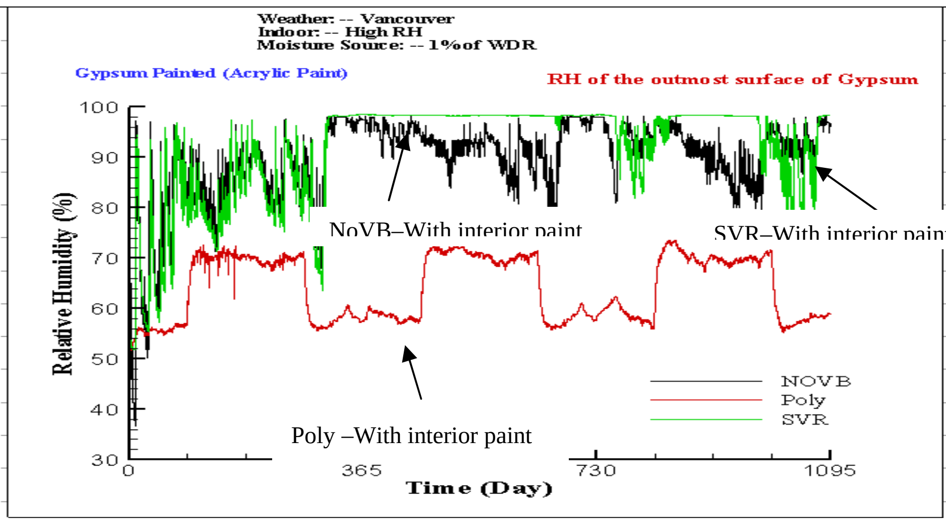

FIGURE 9: TRANSIENT RELATIVE HUMDITY PROFILES OF A POINT AT THE BACK OF INTERIOR GYPSUM BOARD IN DIFFERENT VAPOUR CONTROL STRATEGIES WITH SIMULATION CASES OF 1% WDR.

CONCLUSIONS

In this paper a comparison is made between the moisture performances of 2 by 6-in. wood-frame stucco-clad wall systems subjected to the coastal climate of Vancouver that employ either a polyethylene sheet, a commonly used membrane for vapour diffusion control, or the RH-dependent vapour retarder, often referred to as the "Smart Vapour Retarder (SVR)". The primary simulation variables for comparing the performances of these wall systems were the presence or absence of moisture entry in the stud cavity and paint on the interior surface of the gypsum board. Analysis of the hygrothermal simulation results suggests that in the cases where there is no water entry, the wall systems that employ SVR showed the best hygrothermal performance compared to the ones that have either a polyethylene sheet or no polyethylene sheet. Moreover, the yearly moisture accumulation on the exterior sheathing (OSB) is less in the case of the wall with SVR compared to the two other wall systems regardless of the surface finish of the interior gypsum board (with or without paint). In all three simulation cases with no rain penetration within the cavity, the moisture accumulations in the gypsum board (interior layer) show step-functions that follow the response profile of indoor climatic conditions.

In the case where an assembly has no paint on the interior gypsum board but water is deposited in the stud cavity due to rain penetration, the SVR helps to manage the moisture accumulation in the OSB to an acceptable level. For the same simulation scenarios, a wall system with a polyethylene sheet results in the highest yearly moisture accumulation on the sheathing board. For the particular wall and climatic conditions considered in this study, the worst-case scenario for the wall assembly incorporating a SVR occurs when the interior gypsum board is painted and rain penetration in the stud cavity is assumed. In this scenario, the moisture accumulation in the OSB is still much less than the wall assemblies incorporating polyethylene or wall assemblies having no polyethylene; however the moisture accumulation in the interior gypsum board is found to be excessive compared to the other two wall systems.

Generally, use of SVR as a vapour barrier yields a better moisture management of sheathing board (OSB) for any of the conditions considered in this study including the condition where an internal cavity moisture load is simulated together with the use of paint on the interior finish. But it may nonetheless have adverse effects on the moisture management of the interior gypsum board in cases where the wall is subjected to an internal cavity moisture load and the interior gypsum board is painted with a low water-vapour permeance paint. Although the modeling results indicate that low permeance paint is likely results high moisture accumulation on the interior finish, this outcome would have to be validated by experiment. Until such experiments are carried out, the authors recommend a conservative approach be adopted in coastal areas in which either no or a high vapour permeance paint is used on the interior finish.

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