The Hygrothermal Performance of Ventilated Stucco Walls Using Spray Polyurethane Foam Insulations and a Smart Vapor Retarder in the Pacific Northwest

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ABSTRACT

Spray polyurethane foam insulations used in residential wood frame buildings have superior thermal performance compared with traditional fiberglass materials. Close-cell foam especially also has low water-vapor transmission property, and at the same time offers good airtightness to building envelope systems. Contrary to common building practice, the application of spray foam to the interior wall cavities requires careful moisture analysis and design to prevent potential moisture related damages in humid climates such as the US Pacific Northwest. This unique climate area has moderate temperatures and high moisture levels caused by precipitation and high relative humidity throughout the year. Recent research on wood framed wall systems with exterior stucco and cavity spray polyurethane foams is being conducted in this climate zone. Two ventilated stucco clad wall systems have been installed side by side in a natural exposure testing facility in the Seattle, Washington area. One wall is insulated with a hybrid insulation system comprised of two-inch spray polyurethane closed cell foam and unfaced fiberglass batts. The other wall is insulated with five and half inches of open cell foam and has a variable vapor resistance smart vapor retarder attached to the interior surfaces of wood studs. The previous study on these walls without ventilation between the stucco and the building paper showed high relative humidity and high moisture content in the exterior sheathing for a long period. The field test data from this study are discussed with respect to the previous results. This paper will describe the hygrothermal performance of these two walls and emphasize the need for clear design guidance for the application of spray polyurethane foam insulation in the wood frame wall systems in the Pacific Northwest.

INTRODUCTION

As spray polyurethane foam (SPF) insulation materials are gaining use in the building industry, the evaluation of the hygrothermal performance of building envelopes adopting SPF as a system becomes critical in many climates. When used in residential wood frame buildings, SPF insulations have superior thermal resistance compared with conventional fiberglass materials. Close cell SPF (CCF) insulation, in particular, has high thermal resistance and low water-vapor transmission rates. When installed in the wall cavities in the Pacific Northwest region, CCF may cause potential moisture related damages. This region is identified as a "Marine Climate" with a unique combination of high precipitation and high relative humidity that creates a challenge to the moisture performance of the building envelope systems. The design of the wall systems with CCF and Open Cell Foam (OCF) requires careful consideration and moisture analysis to avoid long term structural failures.

To accomplish safe insulating with spray foam, system design engineers and architects incorporate hygrothermal modeling into the design process to optimize the building envelope systems under consideration. In this design process, hygrothermal modeling tools such as WUFI (WUFI® 2012) have been extensively used in the building industry for the purpose of building envelop design and performance comparison. As they have been improved substantially over the last decade, these modeling tools can be more easily incorporated into the decision-making process. Also the improved accuracy of the tools has reduced the discrepancy between the modeling results.

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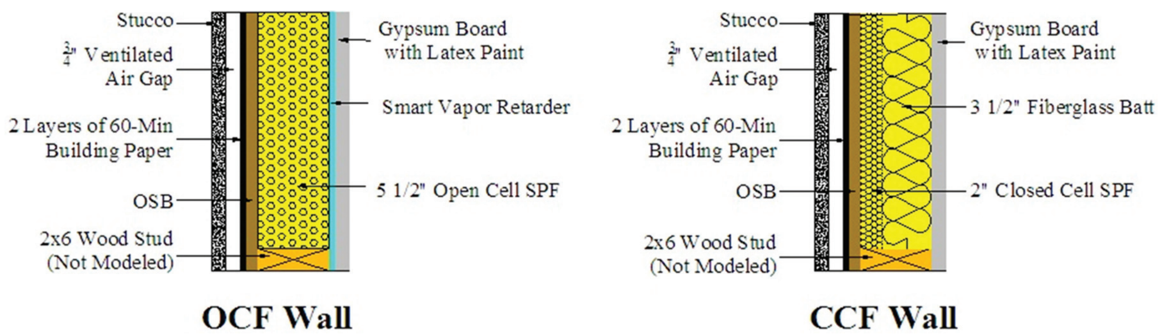

Figure 1 *Cross sections of modeled wall systems (wood studs not modeled).*

One important feature that has been added was the modeling of the ventilated air space behind the cladding material (WUFI® 2012). This feature has been used in the building science community for a few years. Straube and Finch (2009) have shown that the satisfactory agreement between the modeling results and field test data can be achieved with the appropriate use of the air change rate in the ventilated air space behind claddings. Their study also concluded that the determination of the air change rate in the ventilated air space may become complicated for the hourly rate; an estimated annual average rate is sufficient for most modeling purposes. This approach of using an annual average rate is adopted in this study of the SPF insulated walls.

A previous article on this project (Yuan and Karagiozis 2010) presented the hygrothermal modeling and field test results on the SPF insulated walls. The two 2 × 6 wood frame walls had stucco installed on oriented strand board (OSB) sheathing covered with building paper. Two insulation systems were incorporated in the walls: the open-cell SPF and closed-cell SPF with R-13 fiberglass batts. The open-cell SPF wall incorporated a vapor retarding layer on the interior while the closed-cell SPF walls did not have any vapor retarder. The vapor retarding layer used was a smart vapor retarder which has a relative humidity-dependent water vapor permeance (Gatland et al. 2009). Interior 0.5 in. (12.7 mm) thick gypsum wall boards were finished with one coat of primer and one coat of latex paint. Both modeling and field test results showed potential moisture problems with the SPF walls installed in the Seattle, WA climate. The article recommended adding ventilation in the exterior stucco cladding of the walls (Yuan and Karagiozis 2010).

The purpose of this paper is to investigate the hygrothermal performance of the same two residential SPF walls with ventilated stucco in the Pacific Northwest US climate zone. The walls installed in Puyallup, WA were modified with openings at the top and bottom to create ventilated air spaces behind the stucco claddings. These walls were monitored for over a year and the field test data were compared with the modeling results.

HYGROTHERMAL MODELS

Two walls using ventilated stucco cladding, OCF and CCF insulations were modeled. These walls, as shown in Figure 1, consisted of the following layers (from exterior to interior):

- OCF Wall: Stucco, 0.75 in. (19.1 mm) ventilated air gap, 2 layers of 60-minute building paper, 0.5 in. (12.7 mm) OSB sheathing, 2 × 6 wood framing, 5.5 in. (139.7 mm) open-cell SPF, one layer of smart vapor retarder and 0.5 in. (12.7 mm) gypsum plaster board with one layer of primer and one layer of latex paint,
- CCF Wall: Stucco, 0.75 in. (19.1 mm) ventilated air gap, 2 layers of 60-minute building paper, 0.5 in. (12.7 mm) OSB sheathing, 2 × 6 wood framing, 2 in. (50.8 mm) closed cell SPF, 3.5 in. (88.9 mm) fiberglass batt (R-13), and 0.5 in. (12.7 mm) gypsum plaster board with one layer of primer and one layer of latex paint.

One-dimensional hygrothermal modeling was conducted on these four walls for three-year duration beginning January 1, 2011.

Materials Properties

Most material properties used in the models are from the Generic North America Materials Database in the hygrothermal modeling software (WUFI® 2012). The SPF insulation materials are supplied by a major US building insulation manufacturer and their relevant properties are summarized in Table 1 (Yuan and Karagiozis 2010). These materials properties were obtained from the product specification sheets.

A constant annual air exchange rate was imposed in the models for the ventilated air gap behind the stucco cladding according to the recommendations in Straube and Finch (2009). A conservative value of 10 air change per hour (ACH) was applied to a heat and moisture source in the air gap of the models.

The initial and boundary conditions for the models are the default values in the software tool and also listed in (Yuan and Karagiozis 2010). The weather data file in the software for Seattle, WA was imposed on the walls as exterior boundary conditions.

Table 1. OCF and CCF Materials Properties Used in the Modeling

Material Property	OCF (Open-Cell SPF)		CCF (Closed-Cell SPF)	
Density	0.5 pcf	8.0 kg/m^3	2.0 pcf	32.0 kg/m^3
Thermal Conductivity (Aged)	0.278 Btu·in./(h·ft^2·°F)	0.0401 W/(m·K)	0.172 Btu·in./(h·ft^2·°F)	0.0248 W/(m·K)
Thermal Resistivity (Aged)	3.6 h·ft^2·°F/(Btu·in.)	25.0 m·K/W	5.8 h·ft^2·°F/(Btu·in.)	40.2 m·K/W
Water Vapor Permeability (RH$_{mean}$=25 %)	23.8 perm·in.	34.5 ng/(Pa·s·m^2)	1.51 perm·in.	2.19 ng/(Pa·s·m^2)

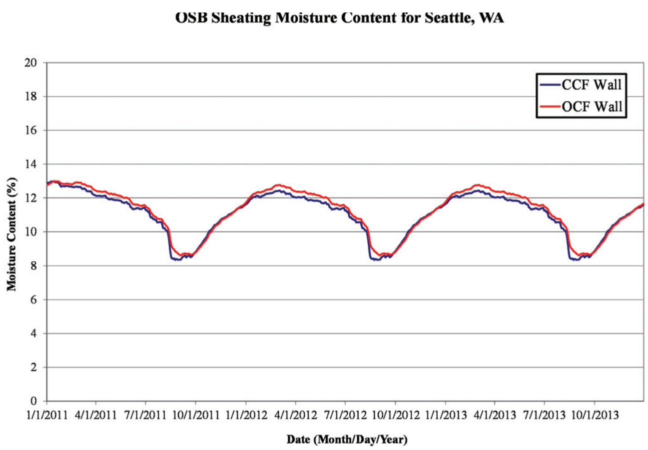

Figure 2 *Modeled OSB Moisture Content For SPF walls in Seattle, WA.*

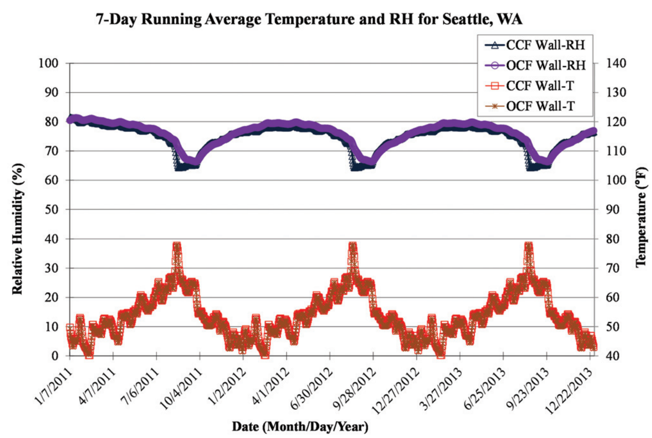

Figure 3 *OSB 7-day running average temperature and RH for Seattle, WA.*

MODELING RESULTS

In the wall systems, wood components are most likely subject to mold growth. Since the wood studs were not modeled, only the OSB sheathing water content is evaluated. Also the surface temperature and relative humidity results for the OSB sheathing are important factors that impact condensation in the wall structure. In this paper, the wall moisture performance evaluation criteria for wood components for avoiding mold growth are as follows (ASHRAE 2009):

1. OSB or wood-stud cavity-moisture content is less than 20% (not referenced in ASHRAE Standard 160 [ASHRAE 2009]);
2. 7-day running average surface RH is less than 98% when the 7-day running average surface temperature is between 40°F (4°C) and 100 ºF (38°C);
3. 30-day running average surface RH is less than 80% when the 30-day running average surface temperature is between 40°F (4°C) and 100°F (38°C).

The modeling results show that the OSB sheathing has less than 13% moisture content for both walls for the entire three-year period. Figure 2 shows the OSB moisture content graphically. In the figure, the OSB moisture contents are very close to each other for both walls, due to the addition of the ventilated stucco cladding. Both walls have high resistance to the moisture flow from indoors reaching the OSB sheathing.

Both SPF walls modeled have highest moisture content and relative humidity levels at the OSB sheathing layer compared with the other components in the same systems. The 7-day and 30-day moving average values of OSB (oriented stranded board) surface temperature and relative humidity (RH) are calculated and plotted in Figures 3 and 4. In Figure 3, the peak RH values for both walls are much less than 90%, while in Figure 4, the RH 30-day running average peak values are reaching 80% but not over 80% when the OSB surface temperatures are within 40°F (4°C) to 100°F (38°C). These results predict no danger of moisture related mold growth problems for the OSB sheathing. Therefore, both walls met the proposed moisture performance criterion for the 7-day and 30-day moving average values of relative humidity.

FIELD TEST

Originally these two walls were constructed in the summer of 2008 in the Washington State University Natural Exposure Testing (NET) facility constructed by Tichy and Murray (2003) through a collaborative research (Dr. Carolyn Roos, WSU investigator) contract with the Oak Ridge National Laboratory (Dr. Karagiozis, Principal investigator). The NET facility is located in Puyallup, WA, approximately 30 miles (48 km) south of Seattle, WA. They were installed on the southern side of the facility. Following the recommendation proposed in Yuan and Karagiozis (2010), the outside claddings were rebuilt to have a 0.75 in. (19.1 mm) ventilated air gap behind the stucco in 2010. Figure 5shows the finished stucco cladding systems with top and bottom air vents. The

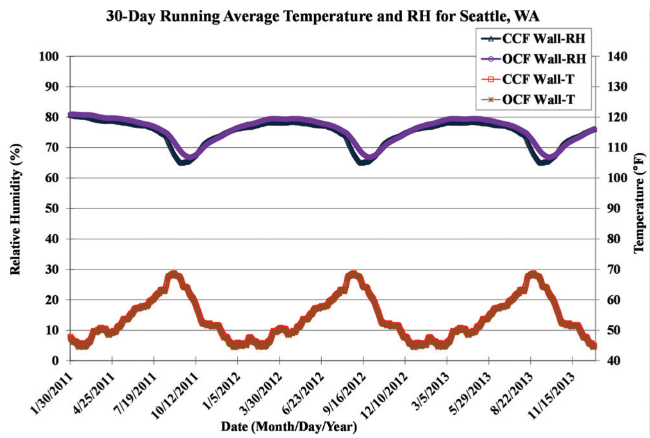

Figure 4 *OSB 30-day running average temperature and RH for Seattle, WA.*

Figure 5 *Photo 1 field test SPF walls in the NET facility (south facing).*

rest of the walls including instrumentations was kept the same as the original walls. The relative humidity in the Net facility was kept constant at 45%, and the temperature was maintained at 68°F (20°C).

FIELD TEST RESULTS

After the modification of the stucco claddings, both walls were monitored for a period of approximately 14 months. Field test data including OSB moisture content, surface temperature and relative humidity (RH) were analyzed for performance determination. The moisture content sensor is physically located approximately 0.125 in. (3 mm) from the exterior of the OSB surface. The hourly moisture content measurements for the OSB are plotted in Figure 8. For both walls, the OSB moisture content never exceeded 16% for the entire 14-month period, indicating no potential mold growth in the OSB. When compared with the OSB moisture contents shown in Figure 2 with the modeling results, the modeling and

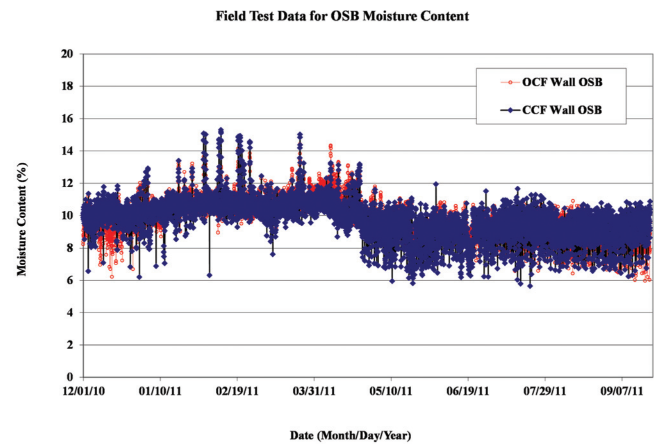

Figure 6 *OSB moisture content field test data for OCF and CCF walls.*

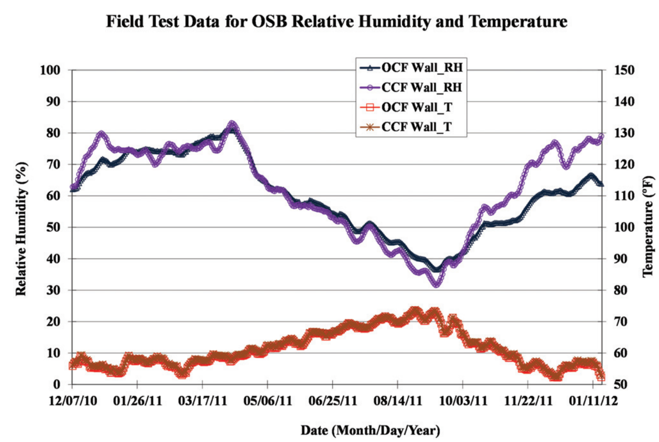

Figure 7 *Field test data of seven-day moving average for OSB relative humidity and temperature for OCF and CCF walls.*

field test data match very well except, for some sporadic high field moisture content readings (15%) in Figure 8.

The 7-day and 30-day moving average test data for the RH and temperature of the OSB are plotted in Figures 6 to 7 for both walls. The data in these figures are obtained from the RH and temperature sensors on the interior side of the OSB sheathing (Yuan and Karagiozis 2010). For the whole field test period recorded, the interior OSB surface for both walls had temperatures between 50°F (10°C) to 75°F (24°C), matching the modeling results as shown in Figures 3 and 4.

The 7-day moving average OSB RH values for both OCF and CCF walls (with the maximum RH being approximately 82%) did not exceed 85% as shown in Figure 8, meeting ASHRAE Standard 160 (ASHRAE 2009). The 30-day moving average of OSB RH values are shown in Figure 8. It shows that the OCF OSB RH reached 80% in April 2011 and dried out to 40% in the middle of September. The CCF OSB RH never reached 80%. Thus both OCF and CCF walls met the

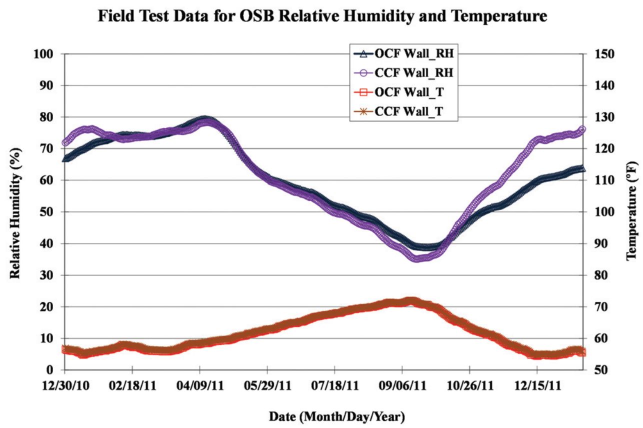

Figure 8 *Field test data of 30-day moving average for OSB relative humidity and temperature for OCF and CCF walls.*

moisture performance evaluation criteria used in this paper following ASHRAE Standard 160 (ASHRAE 2009).

Compared with modeling results, Figures 3 and 4, the field test data showed much lower RH values in Summer 2011. This difference is caused by the application of the conservative 10 ach annual rate in the ventilated air gap behind the stucco claddings in the hygrothermal models. Since low RH values on the OSB interior surface decrease the potential OSB mold growth, this difference between the modeling and the actual field performance does not bring the negative effect on the system design criteria. Thus the models with ventilated stucco cladding predict well the hygrothermal performance of the SPF wall systems.

CONCLUSIONS

Wood frame wall systems insulated with SPF materials may have serious mold growth problems when stucco is applied to the wood sheathing of residential buildings in the Pacific Northwest climates (Yuan and Karagiozis 2010). The design change of ventilating the stucco cladding improves the moisture performance of the wall systems significantly. The two SPF walls described in this paper met all three satisfactory moisture performance criteria for over a 14-month monitoring period after the creation of the ventilated stucco claddings. The field test data showed substantial drying effect on the OSB sheathing interior surface. The ventilated air gap between the stucco and building paper attached to the OSB layer allows moisture flow with air out of the wall instead of penetrating into and accumulating in the OSB and wood studs. This reduces the impact of water penetration through the cladding and also reduces solar driven moisture.

Hygrothermal modeling for building envelopes can quickly predict the actual field performance in specific climate zones. The added feature of the modeling tool that incorporates the sources and sinks for both heat and moisture into the building envelope systems improves the accuracy of such predictions. Using a conservative air change rate in the ventilated air gap behind the stucco cladding for the SPF wall systems tested in the in Seattle, WA area, the modeling results achieved highly reasonable agreement with the field test data. The modeled OSB moisture content results match well the actual field data, while the RH modeling results had agreement on the peak values with the field data. The modeling data did not show the quick drying during summer months as seen in the field data due to the modeled conservative air change rate applied in the ventilated air gap behind the stucco.

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