HYGROTHERMAL PERFORMANCE ASSESSMENT OF BRICK VENEER WALL SYSTEMS WITH WATER REPELLENT COATING: AN EXPERIMENTAL STUDY

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ABSTRACT

The climate in southern British Columbia (BC) is characterized by mild temperature and a wet climate. In this type of a climate, wind-driven rain is the major source of moisture load on building envelope systems. The mild temperature and the relative moist outdoor air reduce the drying potential of these systems. The combination of high wetting and low drying potentials of building envelope systems in the coastal climate calls for building envelope designs that mitigate these unbalanced potentials. One of the proposed design solutions, and now part of the BC Building Code, is the adoption of rain screen wall design to improve the moisture management performance of wall systems, especially with water absorptive cladding such as brick and stucco. In this paper, the hygrothermal performances of four full-scale brick veneer wood-frame wall systems are examined for over a period of nine months in a field experiment test setting. The effect of surface coating and cavity ventilation on the hygrothermal performance of brick veneer wall systems are studied. The moisture responses of the moisture sensitive layer (wood based sheathing board) to the indoor and outdoor 'real' weather exposure are analyzed and presented.

KEYWORDS: rain screen wall, moisture content of sheathing, ventilation, air gap, water repellent.

INTRODUCTION

The climate in southern British Columbia (BC) is characterized by mild temperature and a wet climate from the late fall to early spring. Wind-driven rain is the major source of moisture load on building envelope systems. The mild temperature and the relative moist outdoor air reduce the drying potential of these systems. The combination of high wetting and low drying potentials of building envelope systems in the coastal climate calls for building envelope designs that mitigate these unbalanced potentials. One proposed design solution, and now part of the BC Building Code, is the adoption of rain screen wall design to improve the moisture management performance of wall systems, especially with water absorptive cladding such as brick and stucco. In evaluating the drying potential of air gap ventilation for various wall systems, extensive fields and laboratories testings and computer modelling has been done [1] to [4]. The parameters studied include types of cladding from brick, stucco, wood siding, vinyl to metal; air gap geometry including depth of gaps and sizes of vents; initial moisture loading of wet cladding and wet sheathing and moisture response under different climatic conditions and seasons [5]. The overall conclusions are that ventilation drying is helpful for wet sheathing and for solar-driven inward vapour diffusion while drying of sheathing in winter is minimal [6] [7]. Although it is generally accepted to have weep holes at the bottom of brick veneer cladding for drainage purpose, the advantage of having vents at the top for ventilation drying hasn't been conclusive. Simpson [5] and Straube et al. [8] concluded that brick veneer walls with open top vents provided higher drying potential by air gap ventilation. However, Hens and Fatin [9] found that having top vents did not reduce significant moisture content (MC) due to small ventilation rates and high capacity of moisture storage in brick veneer. In addition to cavity ventilation strategy that aims to remove out the moisture that is stored in the brick and sheathing board, a strategy that reduces moisture absorption by the brick as a first step along with cavity ventilation to help the drying process may be a viable alternative in a climate like Vancouver where the wetting potential is relatively high compared to the drying potential of building envelope components. To investigate the hygrothermal performance of such wall systems, two brick veneer walls with water repellent coating and another two walls with no coating are considered for the study. The field-experimental study is carried out using BCIT's two-storey Building Envelope Test Facility (BETF). The facility has the capability of assessing multiple wall systems independently, and more information can be found at http://commons.bcit.ca/bsce/facilities.html#envelope. The hygrothermal responses of these wall systems are monitored for over a period of nine months (from February 23, 2010 to December 2, 2010) using moisture pins, thermocouple and relative humidity and temperature sensors that are mounted at different layers of the walls. The hygrothermal responses of the moisture sensitive layer (wood based sheathing board) of the four wall systems are presented and discussed in the sections below.

EXPERIMENT SET-UP

The relative location and the respective labels of the four brick veneer rain screen test panels that are considered in this study are shown in Figure 1. All test wall panels are 4' (1.22m) wide. Two walls (BW1 and BW2) are 16' (4.88m) high while the other two walls (BW3 and BW4) are 8' (2.44m) high The test panels are oriented in the same orientation (Southeast) for similar climatic exposure on the outside surface. The indoor surfaces of the test panels are also exposed to similar stable indoor temperature and humidity conditions delivered by the BETF's mechanical system. The local weather conditions including temperature, relative humidity, wind speed and direction, solar radiation, and rain (on horizontal surface) and wind-driven rain (on vertical surfaces) are measured and recorded every minute along with the indoor temperature and humidity conditions for the entire experimental period. The set points of indoor temperature and relative humidity are 21°C and 35%. Although the BETF's mechanical system is able to achieve the indoor temperature set point thought-out the year, the humidity during the summer time is usually above the set point, which is due to the fact that the mechanical system integrates a humidifier but not a dehumidifier.

Figure 2 shows the cross-section of a typical test panel. The test panels are made of 2" x 6" (38mm x 140mm) wood-frame and have the following layersfrom exterior to interior: Brick veneer, air gap, Tyvek house wrap, spun bonded polyolefin sheathing membrane, 1/2" (12.7 mm) plywood as a sheathing board, R20 batt fiberglass insulation filled in 2 x 6 wood frame, 6-mil polyethylene film, and 1/2" (12.5mm) gypsum board as interior finish. The full course of brick veneer is separated from the wood-frame panel by a 1" (25.4mm) air gap.

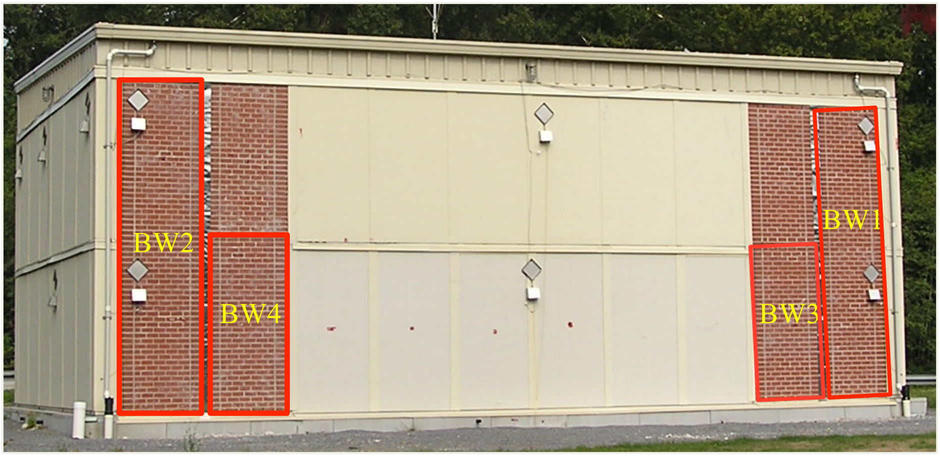
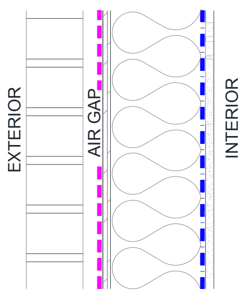


Figure 1: Four Brick Wall Locations on Southeast Façade of BETF.



Interior
1/2" (12.5mm) gypsum board interior finish
6 mil polyethylene film (vapour barrier)
2 x 6 (38mm x 140mm) wood frame @ 16" (600mm) o.c.
- filling with R20 fibreglass batt insulation
1/2" (12.7mm) plywood sheathing
spun bonded polyolefine (SBP) sheathing membrane (air barrier)
1" (25mm) air gap
3-1/2" (90mm) red clay brick veneer
Exterior

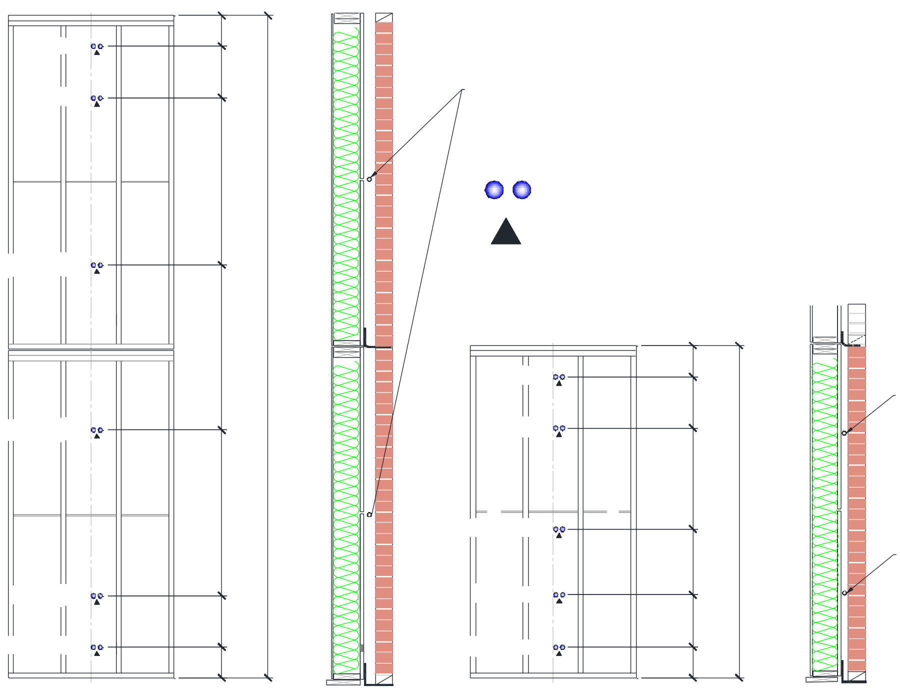
Figure 2: Cross-section of the Brick Veneer Rain Screen wall system

The test variables including the locations, number and sizes of top and bottom vents and application of water repellent coating are summarized in Table 1. Test panel BW1 and BW2 have a continuous air gap throughout the entire height of the two storey high test panel. Whereas in the other two test panels the air gap is limited to one storey high. BW1 and BW4 have a water repellent coating on the exterior surface of the brick veneer. The vents on the brick veneers for all the test walls are discrete type, i.e. weep holes, between brick courses. No flashing cover the top vents for all the test walls.

Table 1: Test Variables

Results / Specimen	Locations, Numbers and sizes of Vents		Water repellent
	Top	Bottom	
BW1	without	2-12mm x 78mm with insect screen	Yes
BW2	2-12mm x 65mm with insect screen	2-12mm x 78mm	No
BW3	6-12mm x 65mm	6-12mm x 78mm	No
BW4	2-12mm x 65mm with insect screen	2-12mm x 78mm	Yes

Figure 3 shows the vertical view of a typical test panel along with the corresponding sensors to measure moisture content of the plywood sheathing and air conditions in the air cavity. To measure the MC of the plywood at different heights, five pairs of moisture pins are installed from the inside along its center line at the top, upper, middle, lower, and bottom positions for all the 8' (2.44m) high walls. A total of six pairs of moisture pins are installed on the 16" (4.88m) high walls, one pair of moisture pins added at the middle part of the wall. A thermocouple is also installed with each pair of moisture pins to continuously measure temperature of the plywood. This measurement is also used for conversion of the electrical resistance measurements of moisture pins to MC in plywood. In addition, RH-T sensors are installed in the air gap between the sheathing membrane and brick veneer for each wall to monitor air moisture and temperature response to boundary conditions. BW1 and BW2, the two- floor high walls, have two RH-T sensors in the upper and lower part of air gaps, 4' (2.44m) away from both the top and bottom of the wall panels. BW3 also has two RH-T sensors and at the positions of 2' (1.22m) away from both top and bottom of the wall. BW4, the wall on the first floor like BW3, has one RH-T sensor at the upper part and 2' (1.22m) away from the top of the air gap. The accuracy of moisture pins in the moisture content range of 6% to 26% is 2%. The temperature measurements are accurate to ±0.5°C of readings. The RH-T sensors are accurate to ±3% RH readings in the range of 0 to 90% and 5% in a range of 90% to 98% RH. The detailed descriptions of the manufacturing and instrumentation of the 2" x 6" wood-frame test panels can be found in Simpson [5].



a) b)

Figure 3: Typical Sensor Positions in Plywood Sheathing and Air Gap: a) BW1 and BW2 and b) BW3 and BW4

TEST RESULTS AND DISCUSSIONS

The mechanism of driving forces for moisture changes in the moisture sensitive wood-based sheathing board (plywood sheathing) in a coastal climate of BC is the combination of indoor/outdoor vapour pressure difference, wind-driven rain and solar radiation. In this section, the moisture content profiles of the sheathing board during the monitoring period (February 23, 2010 to December 2, 2010) are presented in Figure 4 to Figure 7. In these figures, the moisture content profiles of the plywood at different vertical positions (Figure 3) are presented along with the corresponding hourly rain and global horizontal solar radiation measurements. As shown in the figures, the moisture content profiles of the plywood sheathings in the four test panels have similar trends, having relatively higher moisture content during the winter period followed by substantial drying during the spring period (8 to 9% MC) and further drying to 6 to 7% during the summer period before starting to increase in the fall period. The moisture response of the walls corresponds to the rainfall events and solar radiation amounts. During the winter and fall seasons, rain events are frequent and the amounts of solar radiation are relatively low, decreasing the drying and increasing the wetting potential of the walls. Although there are rain events during the spring period, the solar radiation amount increases significantly, especially during the second half of the spring period, which resulted in net drying. In the summer the solar gains of the walls are significant compared to the wetting by rain events, which contributed to further drying of the sheathing boards.

As shown in Figure 4, the top and the upper as well as the middle sections of the two storey brick wall (BW1) have a moisture content between 15% to 16%, whereas the lower section (Lower and Bottom) have a moisture content about 10% at the time of the water repellent coating application. During the same time, the moisture content at the top, middle and lower sections of BW2, Figure 6, are about 15-16%, 14% and 10-12%, respectively. Thus, the moisture conditions of the plywood sheathing at the start of this experiment can be assumed to be equivalent. At the end of the experiment (December 2, 2010), the moisture content at the upper and lower sections of the sheathing board in BW1 are fairly close (within a 2% difference) compared to BW2 (about a 4% difference).

BW3 is characterized by a relatively large number of vents at both bottom and top positions on brick veneer, which is likely responsible for the uniform moisture content distributions along the height of the sheathing board as shown in Figure 6. At the start of this experiment, the plywood in BW4 has a similar moisture content to the lower walls of BW1 and BW2. The upper section is about 15% and the middle and lower sections have a moisture content about 12% and show similar profiles of drying during the spring period and wetting in fall seasons. In general, the difference in the moisture content of the sheathing board along the height narrows in the spring and almost becomes identical during the summer. The steep moisture content rises at the top sections of BW3 and BW4 sheathing boards on November 23 must have been due to wind-driven rain penetration through their respective top vents. This suggestion is based on the fact that such a large moisture content increase in just one day cannot otherwise be justified. Thus, it is imperative to have flashing over vents with the exception of the bottom vents to avert wind-driven rain penetration and wetting of moisture sensitive layers. Further investigation of rain run-off and penetration through the vents is required.

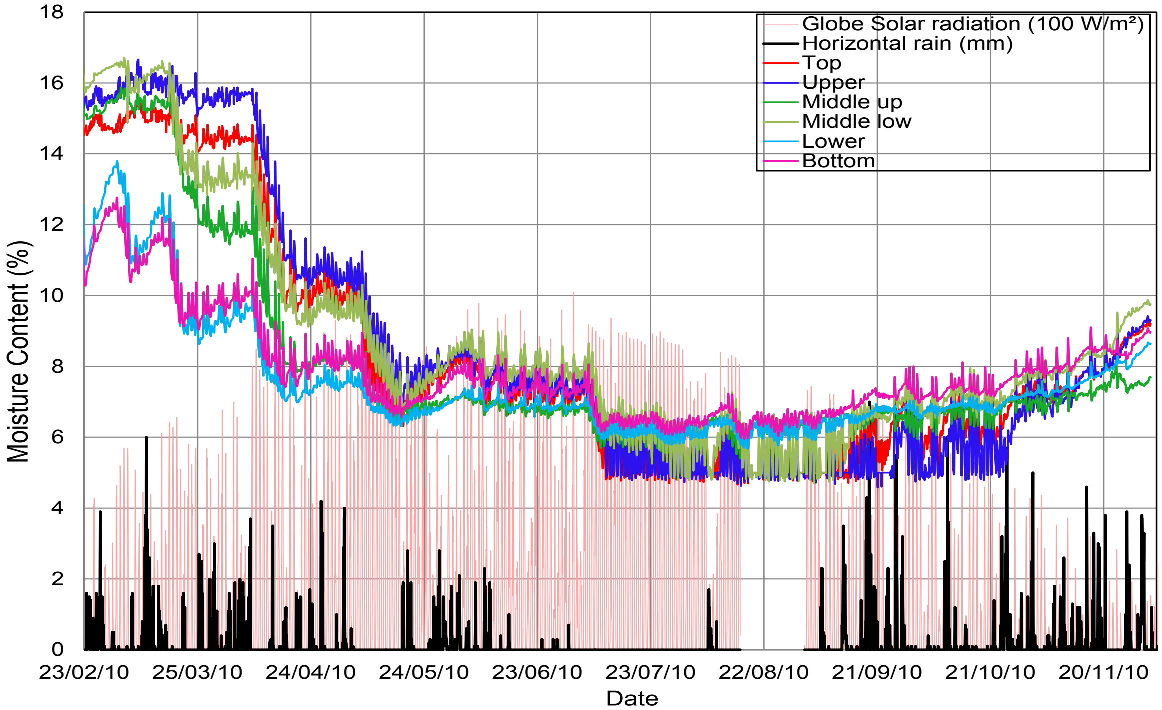


Figure 4: Moisture content of plywood sheathing board in Brick Wall BW1 (at different heights) and relevant indoor and outdoor climatic conditions.

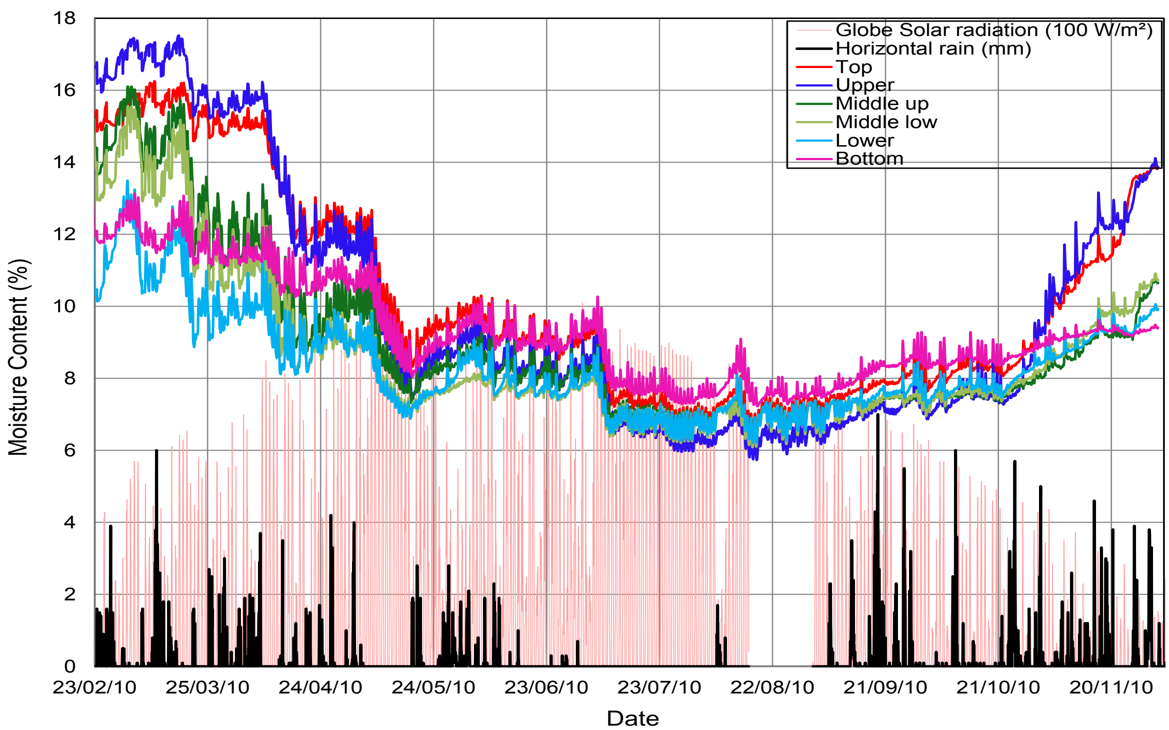


Figure 5: Moisture content of plywood sheathing board in Brick Wall BW2 (at different heights) and relevant indoor and outdoor climatic conditions.

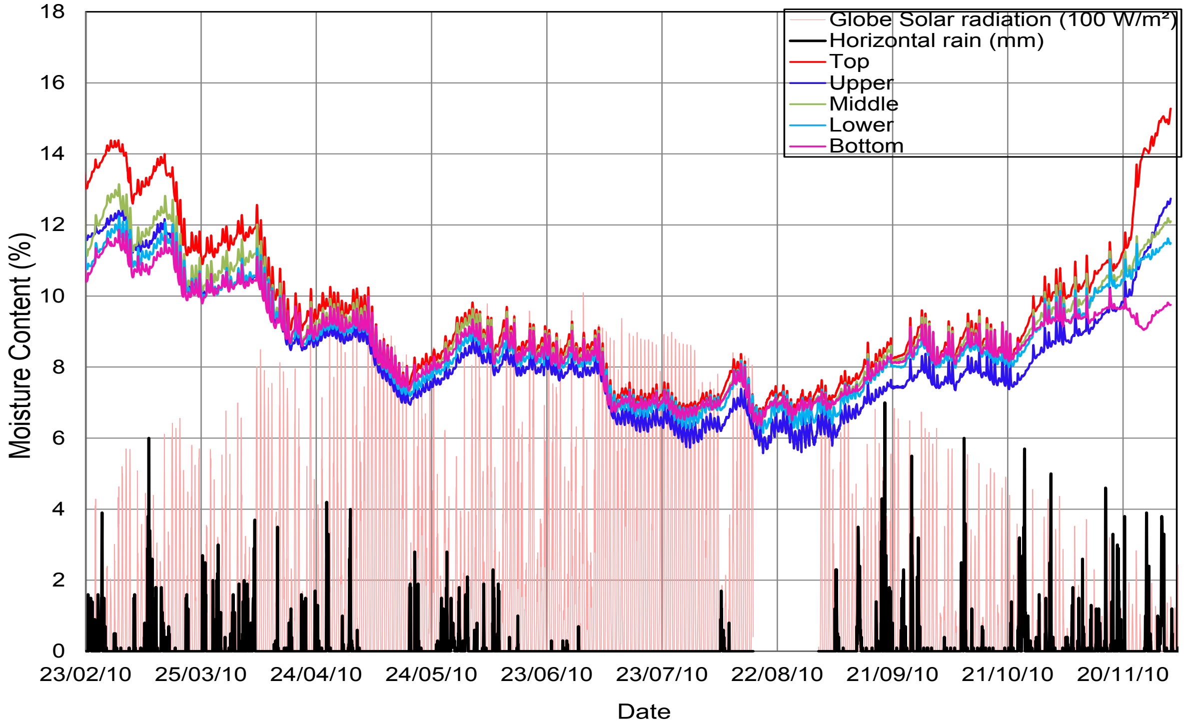


Figure 6: Moisture content of plywood sheathing board in Brick Wall BW3 (at different heights) and relevant indoor and outdoor climatic conditions.

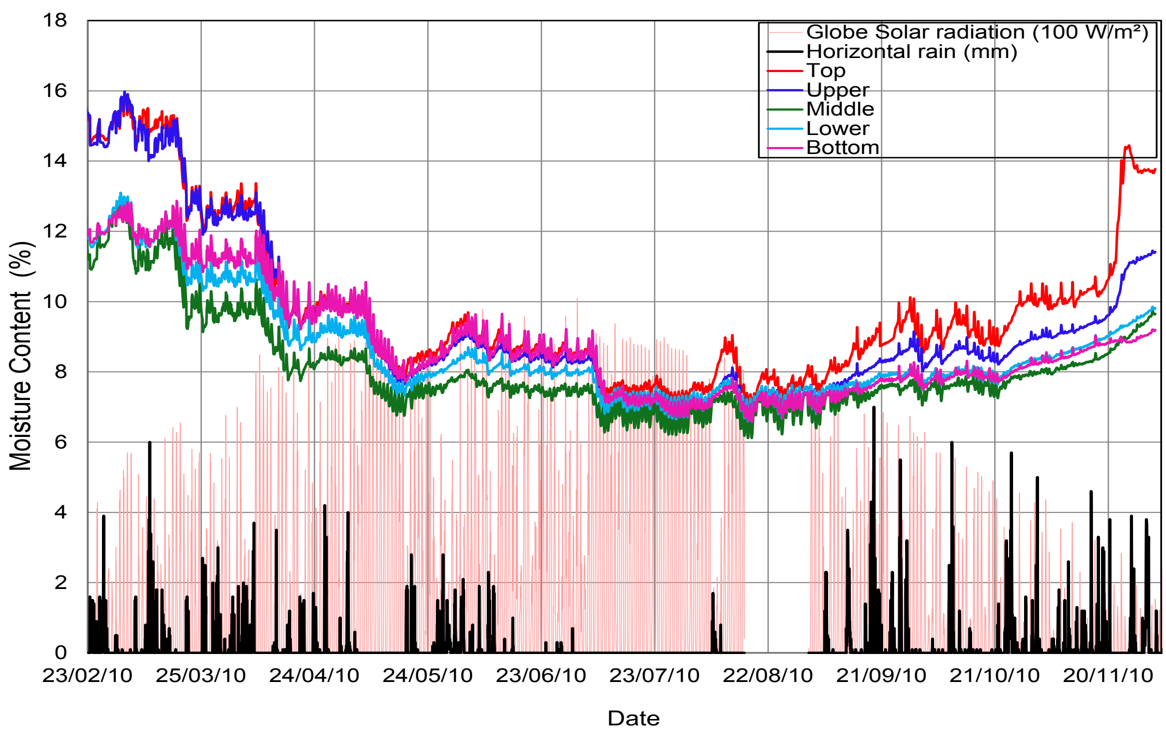


Figure 7: Moisture content of plywood sheathing board in Brick Wall BW4 (at different heights) and relevant indoor and outdoor climatic conditions.

Figure 8 shows the moisture content profiles of the plywood at the upper and lower positions of the BW1 and BW2 wall systems for comparison. Despite the difference in vent configurations in these walls (BW1—vent opening with insect screen (drainage) only at the bottom and BW2—vent opening at the bottom and at the top with insect screen), prior measurements indicated that the moisture content of the respective walls' sheathing boards are nearly identical during the wetting and drying processes. Thus, the difference in the top vent configurations and their impact on the walls' moisture performance can be ignored. During the spring period, when the major drying process takes place, minor differences between the two walls is noticed when rain events are followed by increased solar radiation exposure. In such instances solar driven vapour diffusion to the inside will be dominant. The level of moisture flow to the inside depends on the amount of rain water absorbed by the brick veneer. As can be seen in the figure (April 22 to May 7), the upper and lower sections of BW1 have a slightly lower moisture content compared to BW2 (wall with no water repellent coating). This slight decrease in moisture content in BW1 sheathing must be due to the relatively low rain water absorption as a result of the presence of water repellent coating. The moisture performance difference of the two walls increased during the fall season, especially in October and November. This period is characterized by high rainfall and low solar radiation. As shown in the figure, the moisture content in BW1's plywood gently increases while the moisture content in BW2's plywood increases significantly. At the end of the monitoring period, the moisture content differences between the two walls are 1.5% and 4.7% at the upper and lower sections, respectively. In this particular set of experiment, the application of water repellent coating on the brick veneer does not impact the drying potential of the BW1 system as its moisture content is consistently lower than that of BW2 during the whole drying period.

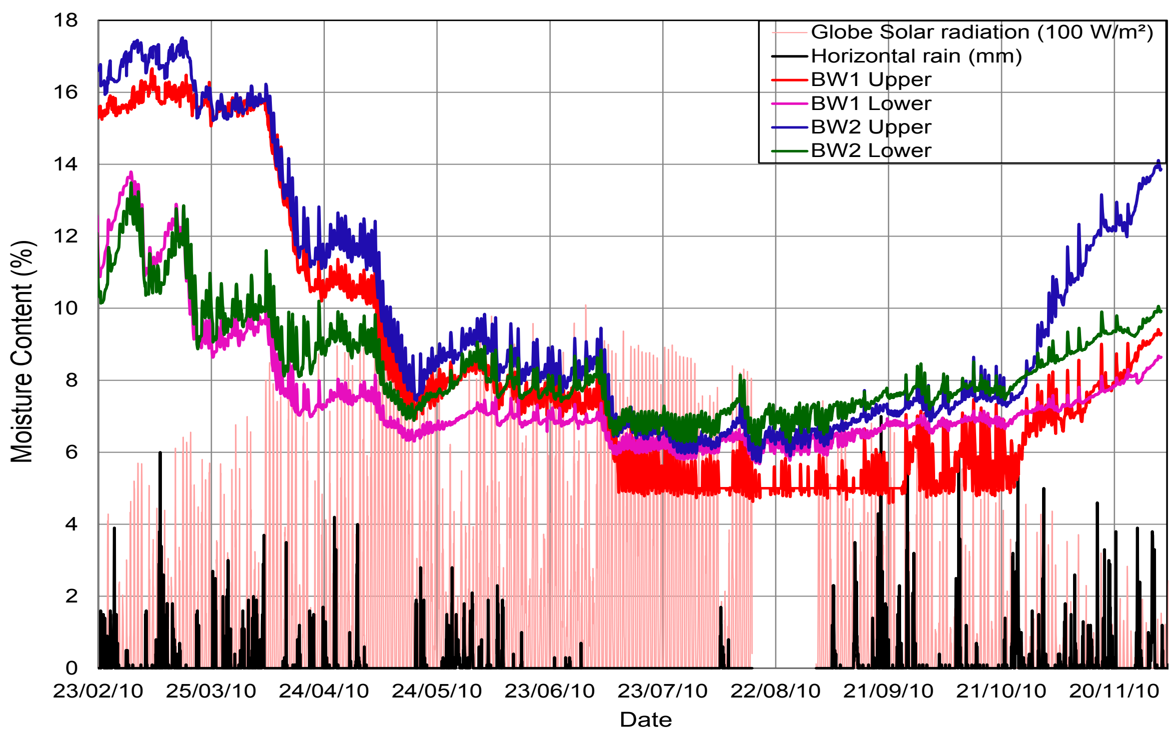


Figure 8: Comparison of MC in Plywood Sheathing between BW1 and BW2, two-floor high with little ventilation in air gaps and applying water repellent on BW1.

Figure 9 shows the moisture content profiles of the sheathing board at the middle position of the BW3 and BW4 wall systems. BW3 is characterized as a wall with high cavity ventilation (six 12mm x 65mm vents at the bottom and a similar number and size of vents at the top) and with no water repellent coating. BW4 is characterized as a wall with limited cavity ventilation, and exterior coating to minimize rain absorption by the brick veneer. This wall has two 12mm x 65mm vent openings at the bottom, and two top vent openings of a similar size but with an insect screen which further restricts airflow.

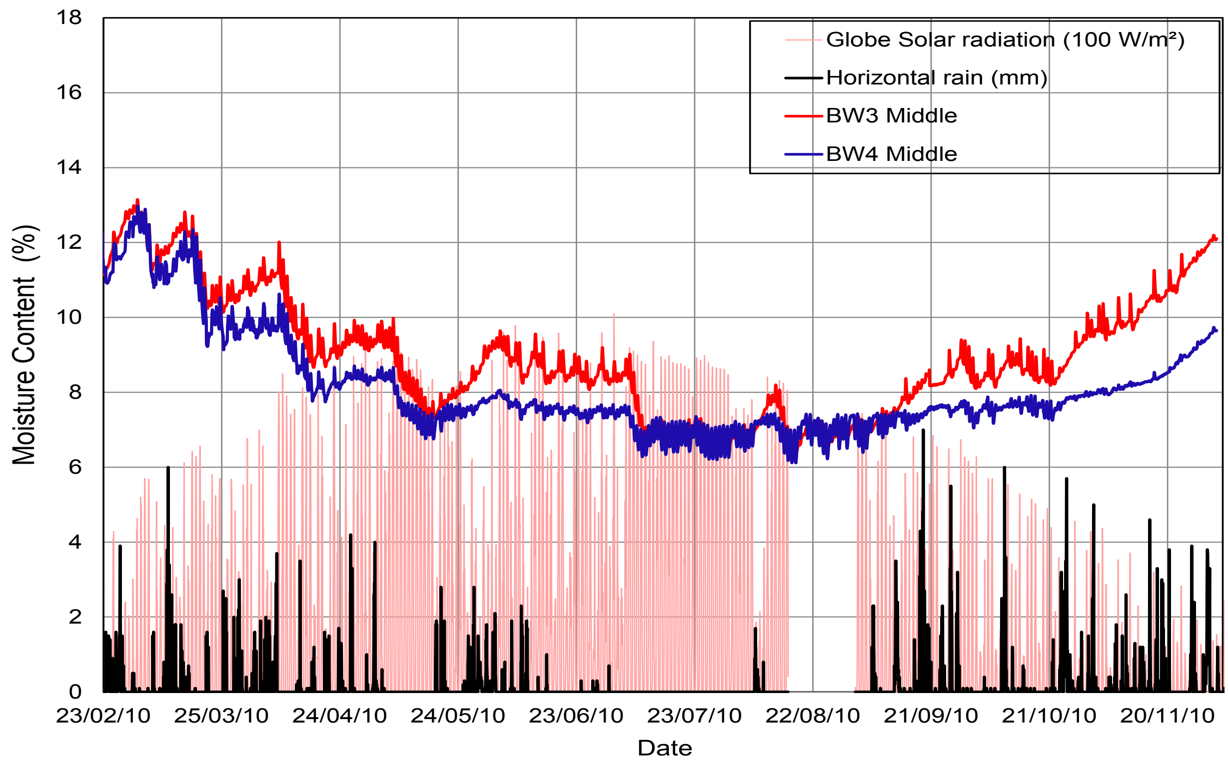


Figure 9: Comparison of MC in Plywood Sheathing between BW3 and BW5 at Lower Floor, one-floor high, BW5 with water repellent applied.

The advantage of applying a water repellent coating on the exterior surface of brick veneer is clearly seen in Figure 9 in both prominent drying and wetting periods in the spring and fall seasons, respectively. The sheathing board in the wall with no water repellent coating (BW3) seems to be more sensitive to solar driven vapour flow, rain events followed by solar radiation exposure, than BW4 as shown in the figure (March 23 to April 7 and May 17 to May 31). The responses of the wall for the short rain event and high solar radiation on August 8 also confirm that brick veneer walls with no water repellent coating will absorb more rain water and transfer more moisture to the sheathing board compared to the one with water repellent coating. In October and November when there is substantial rainfall, the moisture content in BW4 modestly increases to 9.5% whereas the sheathing in BW3 increases markedly to 12%. The application of water repellent on the exterior surface of BW4 helped to shade the rain water and minimize the moisture transfer to the inside of the wall. For the wall system studied here, having a water repellent coating on the exterior of brick veneer is more advantageous in terms of moisture performance than relying on cavity ventilation for drying—as it is demonstrated here with wall (BW3) that has a provision that can deliver high possible cavity ventilation.

CONCLUSION

The hygrothermal responses of four brick veneer rain screen wall panels, with different exterior surface treatment and vent configurations, are monitored for over nine months. In this field-experimental study, the panels are exposed to stable indoor climate conditions and the mild and wet coastal climate of British Columbia. The results show that, in general, moisture content on the sheathing board increases with height. In this particular experimental setup and boundary conditions, the sheathing boards in test panels with no water repellent coating seem to be more sensitive to solar driven vapour flow, rain events followed by solar radiation exposure, compared to that of the test panels with water repellent coating. The application of water repellent on the exterior surface of brick veneer helps to shade the rain water and minimize the moisture transfer to the inside of the wall. Moisture content measurement data during the drying period indicates that the rate of drying of the sheathing boards, in the test panels with and without water repellent coating, are not significantly different, which implies that the particular coating used in this experiment does not have a significant effect on the drying potential of the walls. For the wall system studied here, having a water repellent coating on the exterior of brick veneer is found to be more advantageous in terms of the moisture performance of the walls than relying on cavity ventilation for drying. Relatively high moisture content measurements are observed on the top sections of the sheathing boards of the single storey high test panels, BD3 and BD4, which is believed to be the result of wind-driven rain penetration through unprotected top vents. Building upon the work presented in this paper; the need of top vents, effects of different water repellent coatings and the level of cavity ventilation on brick veneer wall systems' hygrothermal performance warrants further investigation on a larger scale.

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