Hygrothermal Performance Assessment of Vented and Ventilated Wall Systems: An Experimental Study

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ABSTRACT

Based on analysis of the drying and wetting potentials of a particular local climate, designers choose wall systems with or without an air gap between a sheathing membrane and a cladding layer. In addition to the capillary break that the air gap provides, thereby reducing the moisture transfer from wet cladding to the interior of the wall, the airspace will add the thermal resistance of the wall system and reduce the heat flow across the wall system. These moisture and thermal performances are straightforward to understand if the air in the air cavity is assumed to be a "still air." In this paper, an experimental study is undertaken to understand the impact of airflow through an air cavity on the moisture and thermal performance of wall systems. To achieve this objective three test panels are instrumented and monitored in the field-experimental setting: one with no air gap, another one with an air gap but restricted airflow, and the third one with an air gap and open for airflow. The second and third wall systems have the same air gap width but different top flashing designs creating vented and ventilated wall systems. For the wall systems' orientation and boundary conditions considered in this study, the wall with no air gap accumulates relatively high moisture content on the sheathing board, stud, and bottom plate and also has high moisture content changes in a year cycle when compared to the vented and ventilated wall systems. In general, the hygrothermal performances of vented and ventilated wall systems are comparable. During the winter period when relatively high moisture accumulation occurs, the upper section of the ventilated wall system shows slightly lower moisture content compared to that of the vented wall system. The temperature readings of the sheathing boards in the vented and ventilated wall systems are slightly warmer than that of the wall with no air gap for 85.5% and 73% of the time (based on hourly data of a year), respectively. For the balance of a period of time, the sheathing boards in the walls with an air cavity are slightly cooler than that of the wall with an air gap. Although the low temperature on the sheathing board, which is caused by solar radiation-induced airflow, is beneficial during a cooling season, the air gap and the associated airflow may reduce the heat gain that may be obtained from solar radiation during the heating season. The implications of air cavity and flashing design (airflow rate) on the heating and cooling load calculations of different orientations, wall configurations, and climate require further investigation.

INTRODUCTION

New materials and building envelope designs are continuously being introduced in the construction industry with the objective of increasing the energy efficiency, durability, and safety of buildings. It is crucial to evaluate the performance of the new approaches in relation to the performance of existing building code accepted solution. One of the three ways of investigation of newly proposed solutions is through a field experimental study, where the other two are computer modeling and laboratory evaluation. Field experiment has the advantage of assessing performance in real operating conditions as it enables the capture of a range of hygrothermal loads and wall systems' responses to real environmental exposures. In wet climatic regions where a wind-driven rain load is significant, a water absorbing exterior layer holds and transfers moisture to moisture sensitive layers such as wood based sheathing boards

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and frames. If the moisture accumulation on these sensitive materials is significant and lasts for an extended period of time, the durability of the materials will be compromised, and subsequently, the building will fail (Morrison Hershfield 1998; Rousseau and Dalgliesh 2004). To reduce the moisture transfer from the exterior to the interior part of a wall, the National Building Code of Canada (2005) prescribes a mandatory 10 mm (3/8 in.) air gap requirement between cladding and sheathing membrane materials. The air gap will act as a capillary break and eliminates liquid moisture transfer. In this type of wall design, which is referred to as a *rain-screen* wall design, the moisture transfer from the exterior to the interior part of the wall is limited to the maximum moisture storage capacity of the air in the air gap, and the moisture transfer mechanism is limited to vapour flow by diffusion and convection. Although the function and advantage of the air gap as a capillary break is demonstrated in a number of publications (Hazleden and Morris 2002; Straube et al. 2004; Shi and Burnett 2006; Bassett and McNeil 2005; Tariku and Ge 2010; Simpson 2010), the amount and effectiveness of cavity airflow on the moisture management potential of wall systems are active research topics. It has been shown in a laboratory setting (Burnett et al. 2004) and parametric analysis (Onysko 2004) that as the airflow in the cavity increases the drying potential of the wall system increases. In this paper, the effect of promoting cavity airflow in a mild and wet climate is investigated in a field experiment setting. To achieve this objective three test panels (one with no air gap, another one with an air gap but restricted airflow, and the third with an air gap and open for airflow) are instrumented and monitored in a field exposure test facility for fifteen months. The second and third wall systems have the same air gap width but different top flashing designs creating a vented and ventilated wall system. The hygrothermal responses of the various layers of the three wood-frame wall systems are presented and discussed in the sections below.

FIELD EXPERIMENT

The first objective of this experimental study is to understand the hygrothermal impact of an air gap between the sheathing membrane and cladding, and the associated top flashing designs that lead to vented and ventilated wall designs in a coastal climate; and the second objective is to gather experimental data of such wall system performance in "real" operating conditions for benchmarking of hygrothermal models. To achieve these objectives one conventional wall system (Figure 1a), a wall with nonair gap between the sheathing board and cladding, and another two wall systems with similar air gap width but different top flashing designs are considered (Figure 1). The flashing designs are intended to create a ventilated (Figure 1b) and a vented (Figure 1c) wall system. In the ventilated wall system, the clearance between the cladding exterior surface and the flashing is 12.7 mm (1/2 in.), which essentially results in a wall system which is open at both bottom and top and allows air movement through the air cavity. Whereas in the vented wall system, the clearance is only 1.0 mm (1/16 in.) and the airflow through the air cavity is expected to be insignificant, thus in this paper this wall system is referred to as a vented wall system (open at the bottom but nearly closed at the top).

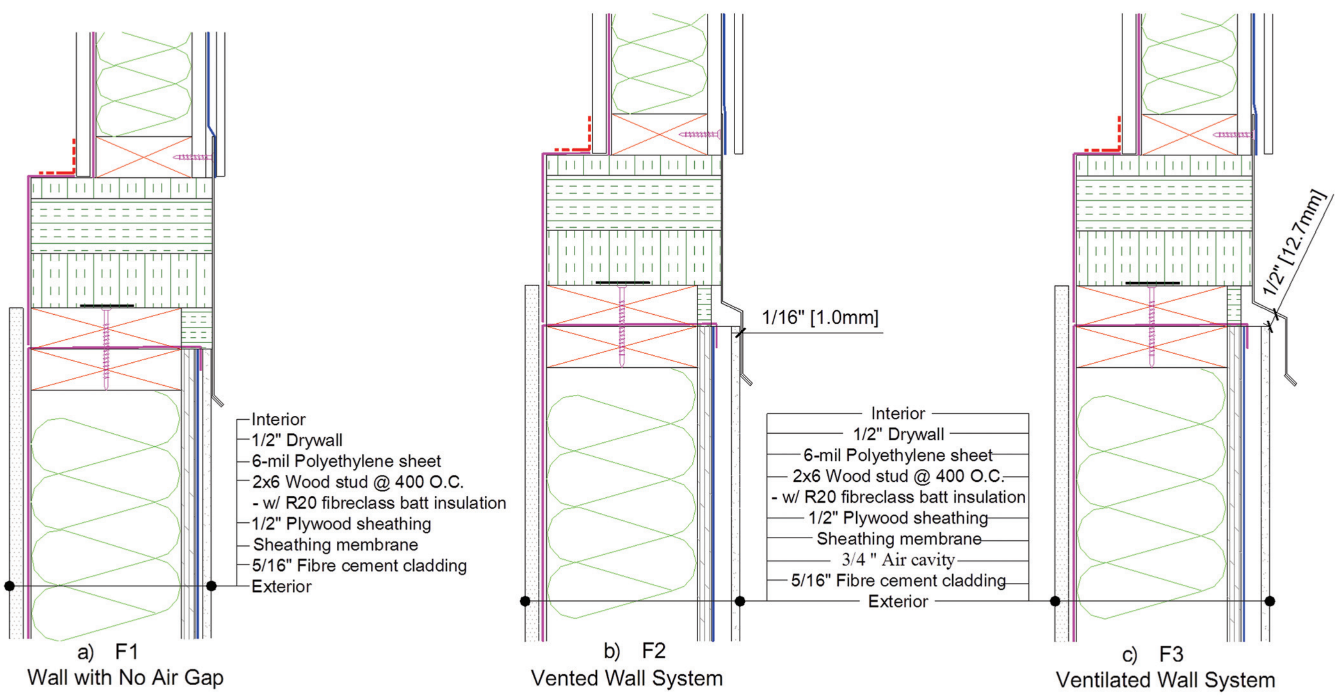

Figure 1 *Top flashing configurations and descriptions of wall assemblies for test walls F1 (no air gap), F2 (vented), and F3 (ventilated).*

The walls are instrumented with thermocouples, humidity probes, and moisture pins to measure the temperature, relative humidity, and moisture at various layers of the test panels. The three test panels are installed side by side on the southeast orientation of BCIT's Building Envelope Test Facility (BETF), a direction where the local wind-driven rain load is predominant, to ensure similar indoor and outdoor climatic loads on both the interior and the exterior sides of the test panels. The BETF is a 13.4 by 8.5 m (44 by 28 ft) two-storey facility, Figure 2, positioned in a relatively open site to allow higher wind-driven rain and solar radiation exposures. The outdoor climatic conditions, including temperature, relative humidity, wind speed and direction, and global horizontal solar radiation are measured with a weather station that is mounted on the roof of the facility. The actual wind-driven rain load and solar radiation that the samples are subjected to are measured from the wall mounted wind-driven rain gauge and pyranometer as shown in Figure 2. The indoor environmental conditions, namely temperature and relative humidity, are controlled and maintained with forced-air heating/cooling and humidification systems. Dehumidification of the indoor air is relayed on the air-conditioning system. The indoor temperature is controlled by a thermostat, which is set at 21°C. Humidistat works with the humidification system to maintain the indoor relative humidity at 35%.

Test Panels Description

The test panels are built as a regular 2 × 6 (38 by 140 mm [1.5 by 5.5 in.]) wood-frame wall system. Each test panel is 2235 mm (88 in.) high, 1219 mm (48 in.) wide, and has three cavity spaces between four studs. The center and side cavity spaces are 368 and 349 mm (14 1/2 and 13 3/4 in.) wide, respectively. The configuration and materials used to construct the test panels are shown in Figure 1. Fiber cement board is used as an exterior layer (cladding), pressure treated plywood strip (19 mm [3/4 in.] thick and 51 mm [2 in.] wide) as furring, spun bonded olefin as a sheathing membrane, plywood as a sheathing board, 6 mil polyethylene sheet as a vapour and air barrier material, and gypsum board as an interior finishing layer. The wood frame is made of spruce, and the stud cavity is filled with R-20 (RSI-3.5) fiberglass insulation. The conventional wall system is built in the same way as that as shown in Figure 1 except that there is no furring and air cavity between the sheathing membrane and cladding (Figure 1).

Sensor Layout and Installation

The layouts of moisture pins, thermocouples, and relative humidity sensors are shown in Figure 3. To assess the moisture and temperature variations along the length of the sheathing board, three pairs of moisture pins are inserted into the mid-thickness of the plywood sheathing and thermocouple sensors are installed in the interior surface of the plywood at lower, middle, and upper sections (305, 1118, and 1930 mm [12 in., 44 in., and 76 in.] from the bottom plate respectively). To avoid edge effects on the measurement, sensors are installed in the middle bay along the symmetry line. Just 127 mm (5 in.) above the location of the moisture pins, two 51 mm (2 in.) long strips of moisture detection tapes are installed in both interior and exterior surfaces of the plywood. The detection tapes are intended to alarm unintended

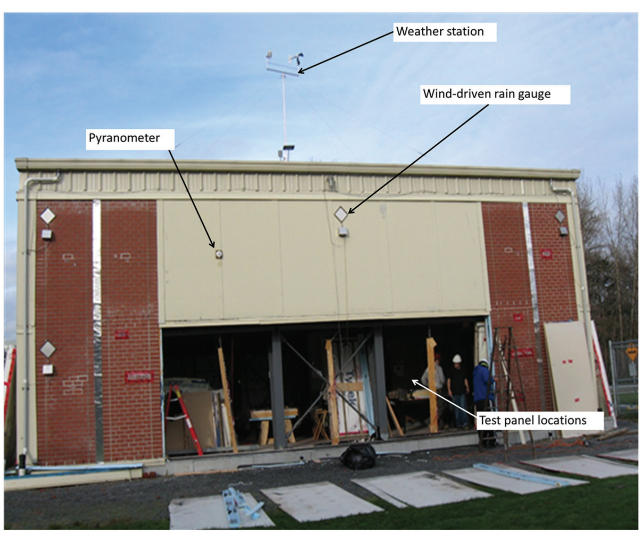

Figure 2 *Weather station on the roof of BETF with a pyranometer and five wind-driven rain gauges on the south east façade.*

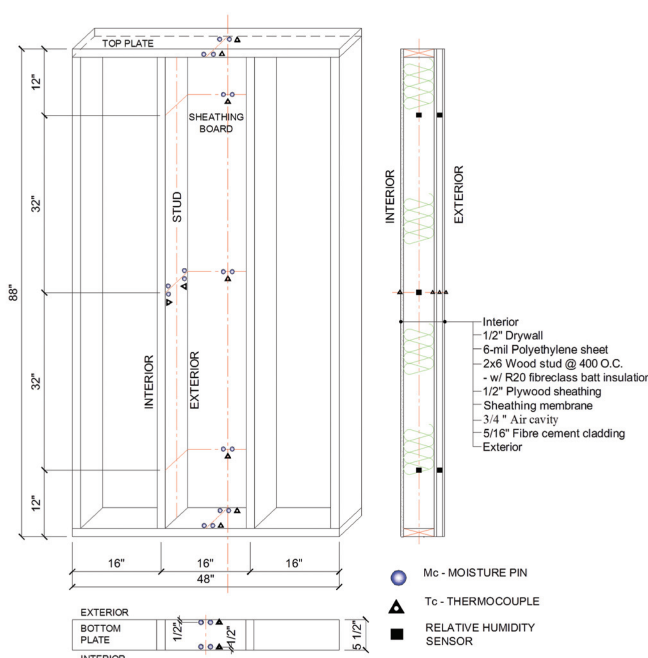

Figure 3 *Sensor locations and test panel configuration.*

water leakage to the test panels. The moisture pins are manufactured from 6 mm (1/4 in.) diameter stainless steel wire. The wire is coated with electrical insulating paint except for the tip area, which enables the measurement of moisture content at a desired depth. Here, the moisture content of the plywood at mid-thickness is sought, and therefore, the pins are inserted 6 mm (1/4 in.) from the interior surface of the plywood. To restrict possible water seepage into the plywood through the pin-plywood contact area, epoxy is applied around the moisture pin and plywood surface. In addition, the moisture pin tip surface area, which is soldered with instrumentation wire, is coated with epoxy to avoid possible short circuiting between the two pin heads through the insulation material in the event that the insulation near the moisture pin heads get wet. The moisture pins are inserted 25 mm (1 in.) apart and the wires are connected to 5M Ohm resistor in series. The electrical resistance between the end surfaces of the two pins is measured and translated to moisture content using a moisture pin calibration curve. The calibration curve is developed in house by measuring the equilibrium moisture contents of wood samples (plywood and spruce) at 30%, 50%, 70%, and 90% relative humidity and the corresponding electrical resistance. The temperatures at various locations of the test panels are measured using Type T (copper and constantan) thermocouple wires. The temperature readings are accurate to ±0.3°C as per the calibration done using an isothermal bath, which has an accuracy of ±0.1°C. The temperature and moisture content inside each wall insulation space are measured using three Vaisala HMP50 RHT sensors that are located at the same height as the lower, middle, and upper moisture pins. Like the moisture pins, the RHT sensors are located in the center plane of the middle bay and 70 mm (2 3/4 in.) deep from the interior surface of the insulation. The RHT sensors are newly acquired and have an accuracy of ±3% within the manufacturer's calibration range of 0%–90% and ±5% between 90% and 98%. Using an Agilent 34980A data-acquisition unit, the moisture content, temperature, and relative humidity measurements are collected every five minutes, whereas the indoor and outdoor climatic conditions are recorded every minute using a Campbell Scientific CR10X data-acquisition unit.

Test Panel Fabrication and Installation

The test panels are fabricated and instrumented in the lab before installing them on the field exposure test facility for monitoring. All the materials are newly acquired and kept inside the test facility for about 30 days. The exposure of these materials to the nearly constant indoor temperature of 21°C and 35% relative humidity helps to attain uniform distribution of initial moisture content in the wood-based materials (spruce and plywood), cladding, and drywall.

The construction and instrumentation series are as follows: first, the wood frames are constructed and the plywood is attached. Since the temperature, moisture, and air pressure gradients normal to the test panel will be higher than in the lateral directions during testing, the instrumentation wires are routed from the center bay to the side of the test panels through two 25 mm (1 in.) diameter holes on the studs and connected to the terminal block. As recommended in Straube et al. (2002), the locations on the studs where the strands of wires pass through are sealed with polyurethane foam to restrict air, vapour, and heat movement across the wire routing openings. The sheathing membrane is cut to the same dimension as the sheathing board plane area and stapled on the exterior surface of the sheathing board with 305 mm (12 in.) spacing. The test panel is flipped, and the three stud spaces are filled with R-20 (RSI-3.5) fiber glass insulation. Then, a polyethylene sheet is placed on top of the insulation and wrapped around the side studs and top and bottom plates and overlapped 25 mm (1 in.) on the sheathing membrane at the back of the test panel. The polyethylene sheet edge is taped onto the sheathing membrane using tuck tape, which forms a test panel with controlled test areas and no moisture and airflow along the lateral directions. The polyethylene sheet is stapled to the studs and plates with approximately 305 mm (12 in.) spacing. After the four 51 × 19 mm (2 × 3/4 in.) pressure-treated wood straps are placed on top of the sheathing membrane and nailed onto the studs with 305 mm (12 in.) spacing, the test panels are installed side by side in the southeast orientation of the BETF. As the polyethylene sheet wraps around the side of the test panels to avoid lateral air and moisture transfer between the panels, 51 mm (2 in.) rigid insulation (extruded polystyrene) is installed between the test panels to thermally isolate them. Finally, the test panels' interior and exterior are closed with gypsum boards and fiber cement claddings, respectively.

EXPERIMENTAL RESULTS AND DISCUSSION

In this paper, the results from fifteen and a half months of monitoring starting July 1, 2011 to November 15, 2012 are presented and discussed. The period prior to July 1, 2011 is considered as a conditioning period. At the time of installation, the moisture contents of the sheathing boards (plywood) in all three test walls are 9%, whereas the moisture contents in the wood-frames (studs and top and bottom plates) are 12%. In this section, the wall system with no air cavity is referred to as *F1*, the vented wall system as *F2*, and the ventilated wall system as *F3*. The hygrothermal responses of the respective wall layers, including sheathing board, wood-stud, bottom plate, and cladding are discussed. The transient moisture content profiles of the sheathing boards in the walls F1, F2, and F3 are shown in Figures 4, 5, and 6, respectively. The measured wind-driven rain and solar radiation loads on the cladding surfaces are superimposed on the moisture content plots of the respective figures. Figure 4 shows the moisture content of the plywood in the F1 wall system at the lower, middle, and upper locations. The wind-driven load on the cladding is more frequent during the period from October to May, a period which can be characterized as a wet period. During this period the solar radiation is also relatively low. The months between July and September can be characterized as a dry period as the solar radiation is relatively high while the wind-driven rain events are relatively low. The moisture content in the plywood increases to the highest level in the fourth week of March, 2012 and the lowest level at the end of August. The continued drying of the sheathing board in April to June in spite of substantial rain events occurring shows that during this period, the drying potential of the outdoor climatic condition (solar radiation and temperature) is higher than its wetting potential (rain).

In general, the moisture content variation across the height of the sheathing board is minimal, as can be seen in the figure. Compared to the middle and upper sections, the bottom section of the plywood seems to have slightly higher drying and wetting rates during the corresponding drying and wetting periods. The relatively higher drying rate leads the lower section to have moisture content (MC) of 6% moisture content while the middle and the upper sections have 8% MC. Following the drying period, the lower section also shows steep moisture uptake during the fall season and attains about the same moisture content as the upper and middle sections of the plywood. For this conventional wall system, the highest moisture content that is measured on the sheathing board during the monitoring period is 18.5% MC, which is close to the upper limit of the Canadian Building Code requirement (i.e., 19% MC).

Figure 5 shows the moisture content profiles of the lower, middle, and upper sections of the sheathing board of the vented rain screen wall system (F2). As the figure shows, the moisture content across the height of the sheathing board is about the same. In this wall system, the moisture content on the plywood varies from about 6% MC (first week of September 2012) to the highest value of about 14% MC (first week of February 2012). The moisture profile on the sheathing board in the ventilated wall system (F3) is shown in Figure 6. The moisture content on the sheathing board varies from 6% MC in the first week of September to the highest moisture content of 13% MC in the first week of February. The lowest and the highest moisture content measurements are made at the middle and lower sections of the sheathing board, respectively. Like F1, in this wall system the upper and middle sections of the sheathing board have very similar moisture content, but the lower section of the sheathing board has slightly higher moisture content in comparison to the other two sections, which is a reverse situation to wall F1. During the high moisture accumulation period (February and March) the moisture content difference between the lower section and the upper and middle sections is about 2%. The moisture content difference in these sections reduces below 1% during the drying periods.

To compare the hygrothermal performance of the three wall systems, the moisture content of the lower, middle, and upper sections of the respective sheathing boards are plotted in Figure 7 to Figure 9. As it can be seen in Figure 7 (lower section), approximately from the beginning of November 2011 to the end of April 2012, the sheathing board in F1 has a relatively high moisture content when compared to that of F2 and F3 wall systems. During this period, the moisture content difference between F1 and the other two walls (F2 and F3) can be as high as 7%. In the other six-month period

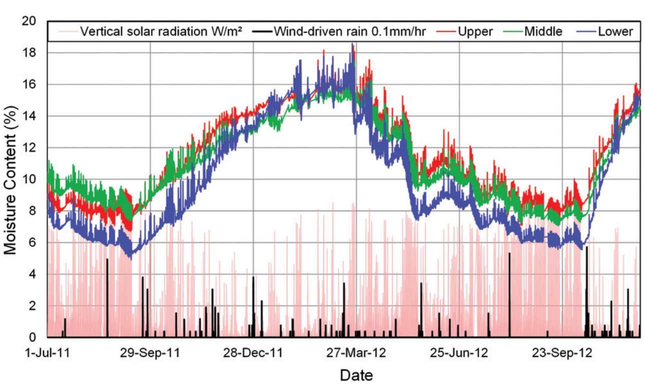

Figure 4 *Hourly average moisture content in plywood sheathing of F1, a wall with no air gap.*

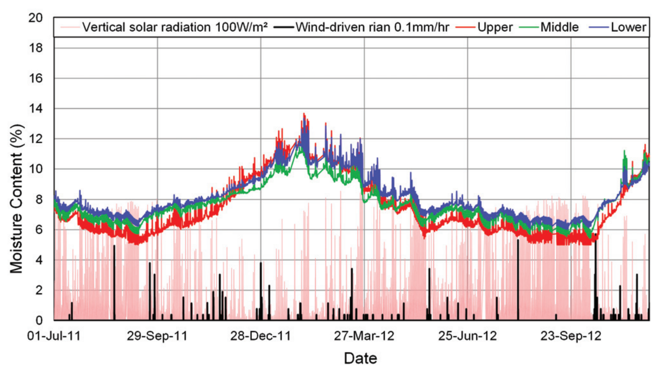

Figure 5 *Hourly average moisture content in plywood sheathing of F2, a vented wall.*

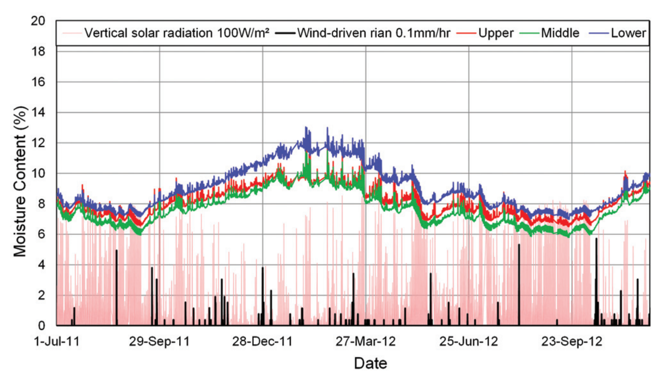

Figure 6 *Hourly average moisture content in plywood sheathing of F3, a ventilated wall.*

(May to October), the moisture contents in the sheathing boards are comparable and are within a 2% MC difference. Within a year cycle, the amplitude of moisture content change in F1 is 13% whereas in F2 and F3 they are 7% and 6%, respectively. Given that the three walls are exposed to similar indoor and outdoor climatic conditions and significant moisture content differences on the sheathing boards are observed while the frequencies of rain events are higher (October to April), the substantial hygrothermal performance difference between the wall systems must be associated with the presence (F2 and F3) and absence (F1) of an air gap and the role it plays as a capillary break.

In comparison to F2 and F3, the rate of moisture accumulation after the drying period is higher in F1, Figure 7. While its moisture content continues to increase for the third week of March before it starts drying, the sheathing board moisture contents in F2 and F3 reach to their maximum level in the first week of February (six weeks prior to F1's peak time) and maintain about the same level of moisture content before start drying at the end of March. The relatively stable moisture content readings observed on the F2 and F3 sheathing boards in February and March, in spite of the rain events and winter cold temperature, is believed to be the result of moisture removal from the sheathing board and cladding by the airflow through the air gap. The airflow is believed to be induced by the increases in solar radiation in February and March (compared to November to January).

As shown in Figure 8 and Figure 9, the moisture content at the middle and upper sections in F1 are consistently higher than that of the corresponding F2 and F3 wall systems. In the middle section, Figure 8, the amplitudes of sheathing board moisture content change in a year cycle (difference of maximum minus minimum values) are about 10% MC, 7% MC, and 5.5% for the wall systems of F1, F2, and F3, respectively. In the upper section, Figure 9, the moisture content changes in a year cycle in F3 is relatively low (5%: varies from 6.5% to 11.5%) compared to F2 (8.3%: varies from 5.3% to 13.6%) and F1 (12%: varies from 6.5% to 18.5%).

In general, the hygrothermal performance of vented (F2) and ventilated wall (F3) systems are comparable. The moisture content of the lower section of the ventilated wall system (F3) seems to be higher by 1% compared to the vented wall system, Figure 7, which may be attributed to the enhanced airflow in F3 that brings in moist outdoor air into the air cavity. In the two wall systems the moisture contents at the middle section of the respective sheathing boards are nearly the same during most of the monitoring period, Figure 8. Like the lower section of the sheathing board, the upper section of F3 has a slightly (about 1%) higher moisture content during the spring and summer periods, Figure 9. However, during the winter period when relatively high moisture accumulation occurred, the upper section of F3 shows slightly lower (1% to 2%) moisture content compared to that of the vented wall system (F2), Figure 9, which leads to a moisture content profile with relatively low amplitude

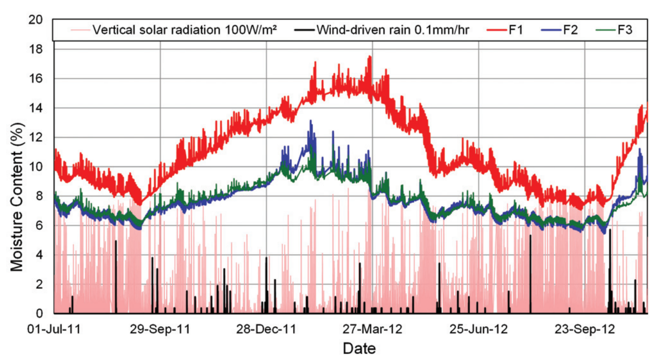

Figure 8 *Comparison of hourly average moisture content at middle part of plywood sheathing between walls: F1, wall with no air gap; F2, vented wall; and F3, ventilated wall.*

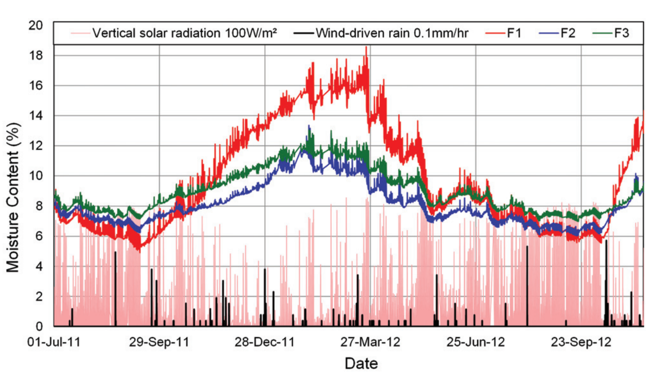

Figure 7 *Comparison of hourly average moisture content at lower part of plywood sheathing between walls: F1, wall with no air gap; F2, vented wall; and F3, ventilated wall.*

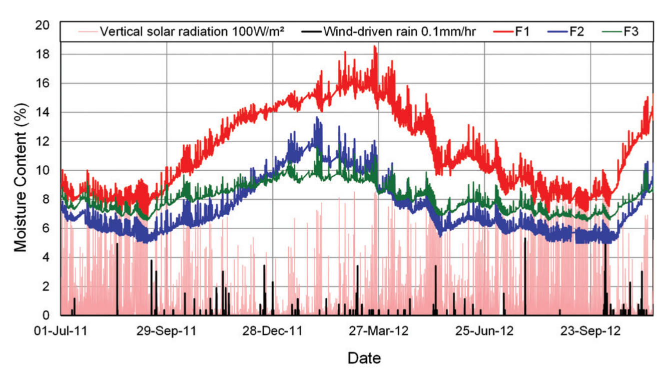

Figure 9 *Comparison of hourly average moisture content at upper part of plywood sheathing between walls: F1, wall with no air gap; F2, vented wall and F3, ventilated wall.*

between the dry and wet instances. The enhanced moisture management potential of F3 at the critical time when the high moisture accumulation occurs is believed to be the result of solar radiation-induced airflow in the wall F3 air cavity enhanced by the open flashing design. For the entire monitoring period, the sheathing boards in both wall systems are under 14% moisture content and under 12% for most of the monitoring period.

The moisture contents in the studs of the three wall systems at the mid height and 12.7 mm (1/2 in.) from the outside surface of the studs are shown in Figure 10. As the sheathing board, the moisture content of the stud on the wall with no air cavity shows higher moisture accumulation compared to that of vented and ventilated wall systems. The maximum moisture contents of the respective wall systems are about 16% (F1) and 12% (F2 and F3). The moisture content magnitudes and profiles of F2 and F3 studs are similar. The difference in moisture content between walls with and without an air gap is lower during the summer period and increases during the fall and winter periods to about 4% difference in the third week of March. The moisture content profiles at the middle and interior locations of the studs are nearly stable at about 10% MC during the majority of the monitoring period (figure not shown here because of space limitation). It is also observed that when solar radiation is significant in the spring and summer periods, the interior part of the stud seems to show a slight increase in moisture content, which is believed to be a consequence of moisture release from the sheathing board to the interior cavity and moisture drives from the exterior to the interior part of the studs as they are going through a drying process.

Similar to the interior part of the stud, the moisture contents at the interior parts of the top and bottom plates are stable (about 10%) for the majority of the time and show a slight increase in moisture content when solar radiation is high. Figure 11 shows the moisture content profiles of the bottom plates of the three walls at a location 12.7 mm (1/2 in.) from the outside surface of the plate. As it can be seen in the figure, the moisture content at the bottom plate of the vented wall (F2) is lower (by about 1%) when compared with that of the ventilated wall (F3). The difference is consistent throughout the monitoring period (wet and dry seasons). During the moisture uptake period, the moisture content of the bottom plate of the wall with no air gap (F1) increases from about 8.5% to 14% while that of F2 increases from 8.5% to only 10.5%. During the drying period, the bottom plate in F1, however, manages to dry fast and reach to the same level of moisture content as that of F2 (8%) in the fourth week of September, which is a decrease of 5.5% for F1 and 2.5% for F2 from their respective peak moisture contents. In general, the moisture accumulation and drying processes of the bottom plate in the wall with no air cavity (F1) seem to be faster in the respective wet and dry seasons.

Figure 12 shows the inside surface temperatures of the sheathing boards at the mid-height of the respective three wall systems. The lowest and the highest temperature read-

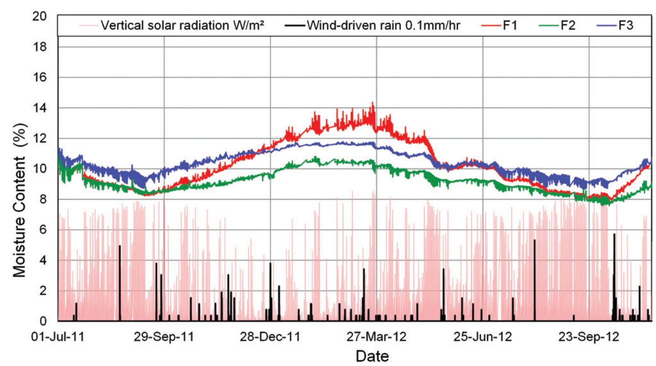

Figure 11 *Comparison of hourly average moisture content in bottom plates, 12.7 mm (1/2 in.) near exterior edge, between walls: F1, wall with no air gap; F2, vented wall; and F3, ventilated wall.*

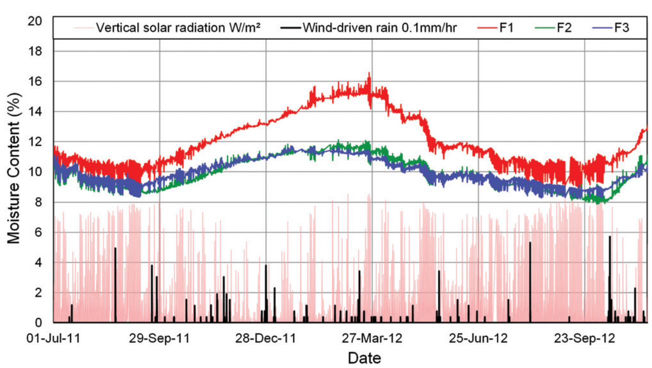

Figure 10 *Comparison of hourly average moisture content at the middle height of stud, 12.7 mm (1/2 in.) near the exterior edge, between walls: F1, wall with no air gap; F2, vented wall; and F3, ventilated wall.*

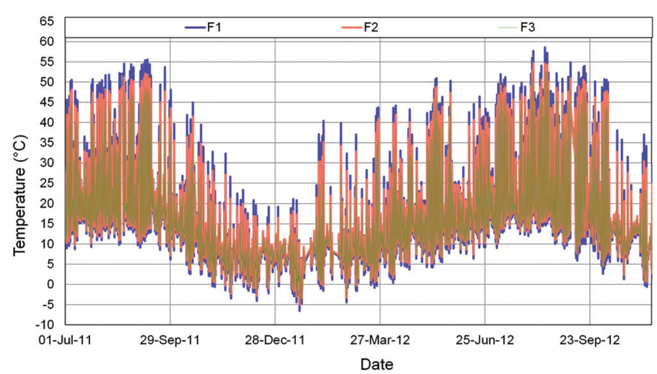

Figure 12 *Comparison of hourly average temperature at the middle part of the sheathing board, inside surface, between walls: F1, wall with no air gap; F2, vented wall; and F3, ventilated wall.*

ings on the sheathing board, which are –6.3°C on January 17, 2012 and 58.5°C on August 15, 2012, are made on the wall with no air gap (F1). Although the temperature profiles of the three walls' sheathing boards are similar, noticeable differences are observed during the entire monitoring period. It seems that the sheathing board temperature in F1 rises slightly above F2's and F3's when the solar radiation is present, otherwise its temperature is slightly lower than the other two. Figure 13 shows the cumulative probability distribution of the temperature difference between the sheathing boards using the wall with no air gap (F1) sheathing board temperature as a reference. Positive values in the *x*-axis indicate that the sheathing board in the wall with no air gap is warmer in comparison to that of vented and ventilated wall systems, and the negative values indicate the opposite. The temperature difference between F1 and F2 sheathing boards can vary from –3°C to 7°C, whereas the difference between F1 and F3 can range from –2°C to 13.5°C. The sheathing board in the wall with no air gap is warmer than the vented and ventilated wall systems for about 14.5% and 27% of the time (hourly data of a year). These temperature differences can be as high as 7°C in the case of the vented wall system and 13.5°C in the case of the ventilated wall system. Based on the measured solar radiation data, the 14.5 and 27 percentiles solar radiation corresponds to 150 W/m^2 and 50 W/m^2, respectively. This suggests that a stronger solar radiation (above 150 W/m^2) is required to have air movement in the vented cavity, whereas in the ventilated cavity just 50 W/m^2 may start air movement. At times when the solar radiation is between 0 to 50 W/m^2, which is about 85% of the time, the presence of the air gap in F2 and F3 leads to a slightly warmer sheathing board (to the maximum of 2°C to 3°C) as compared to wall F1.

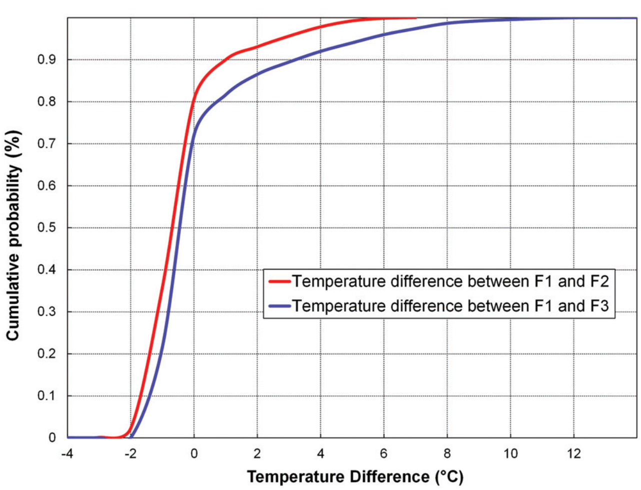

Figure 13 *Cumulative probability distribution of temperature differences between the sheathing boards, using the sheathing board temperature of F1 (the wall with no air gap) as a reference.*

The temperature difference within the three wall systems can be explained as follows: the solar radiation heats the cladding and then the air in the F2 and F3 cavities, which creates a situation where fresh air will be drawn into the air cavity and the warm air leaves the cavity, cooling the sheathing board and cladding, a phenomena which won't happen in F1. The temperature differences in the sheathing boards of the vented and ventilated wall systems are related to the amount of airflow through the air cavity, which depends on the type of top flashing configuration. The more open the flashing design, the higher solar radiation induced airflow through an air cavity. The air movement through the air cavity at nighttime or when solar radiation is minimal is expected to be none or significantly less than the solar driven airflow rate. During these times, the sheathing boards in the walls with an air cavity seem to have a slightly higher temperature, which is because of the added thermal resistance obtained from the air in the cavity without being short-circuited by cross airflow (a situation near still air condition).

In addition to the sheathing board, the airflow through the air cavity in walls F2 and F3 has an impact on the temperature of the fiber cement cladding. The cladding temperature difference between the wall with no air gap and the vented wall ranges from –3°C to 6°C, whereas between the wall with no air gap and the ventilated wall system the difference is –4°C to 9.5°C. For over 95% of the time the cladding on the wall with no air gap has a higher temperature than either of the other wall systems' cladding. For 20% of the time, the temperature difference is greater than 1°C.

CONCLUSION

Here, the hygrothermal performances of ventilated and vented wall systems are evaluated in comparison with a wall system with no air gap between sheathing membrane and cladding. The three test panels are simultaneously tested in a field experimental setting. The test panels are exposed to the same environmental loads on both interior and exterior sides of the test panels. For the wall systems, orientation, and boundary conditions considered in this study, the wall with no air gap accumulates relatively high moisture content on the sheathing board, stud, and bottom plate and also has high moisture content changes in a year cycle compared to the vented and ventilated wall systems. In this experiment, the moisture content of the sheathing boards in the vented and ventilated wall systems are under 14%, while the moisture content of the sheathing board in the wall with no air gap reaches to 18.5%. The air gap creates a capillary break and reduces the rate as well as the amount of moisture accumulations on the sheathing board. In general, the hygrothermal performance of vented and ventilated wall systems are comparable, but with some slight differences. The upper and bottom sections of the sheathing board in the ventilated wall system seem to have slightly higher moisture content than that of the corresponding sections of the vented wall system. However, during the winter period when relatively high moisture accumulation occurs, the upper section of the ventilated wall system shows slightly lower (1% to 2%) moisture content compared to that of the vented wall system. The better moisture management potential of the ventilated wall system at the critical time when the high moisture accumulation occurs is related to the enhanced (solar radiation induced) airflow that resulted from the open flashing design.

The air gap in the vented and ventilated wall systems adds additional thermal resistance and keeps the respective sheathing boards slightly warmer than that of the wall with no air gap for 85.5% and 73% of the time (based on hourly data of a year), respectively. The temperature difference can be as high as 2°C to 3°C. For the balance of a period of time, the sheathing boards in the walls with an air cavity are slightly cooler than that of the wall with an air gap. The temperature difference can be as high as 7°C and 13.5°C. Although the low sheathing board temperature, which is caused by solar radiation-induced airflow, is beneficiary during the cooling season, the air gap and the associated airflow may reduce the heat gain that may be obtained from solar radiation during the heating season. The implications of air cavity and flashing design (airflow rate) on the heating and cooling load calculations of different orientations, wall configurations, and climate require further investigation.

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