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A Field Monitoring Investigation of the Effect of Adding Different Exterior Thermal Insulation Materials on the Hygrothermal Response of Wood-Frame Walls in a Cold Climate

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ABSTRACT
As energy costs and demands for environmental sustainability increase, the building industry seeks effective and durable strategies for improving the energy performance of the building envelope. Adding thermal insulation on the exterior of the existing shell can increase the overall R-value and the airtightness of the wall assembly, as well as reduce thermal bridging due to structural elements, while causing minimal disruption to the occupants and their living space. However, the effect of the heat, air and vapour flow control properties (e.g. air and vapour permeance) of the selected thermal insulation on the moisture accumulation into the wood-frame cavity due to wintertime condensation can be of concern. These properties can affect the potential of the wall assemblies to get wet by condensation (in wintertime) and to dry out (in spring and summertime), hence having the potential to affect negatively the durability of the assembly.

NRC-IRC researchers investigated the hygrothermal response of two wood-frame wall assemblies, each retrofitted with one type of exterior insulation (XPS or semi-rigid mineral fibre insulation) in comparison with a non-retrofitted wall assembly. In NRC-IRC Field Exposure of Walls facility (FEWF) the authors conducted experiments whereby the energy retrofitted test specimens (with and without deficiencies in the air/vapour barrier) were challenged with exposure to a series of varying levels of relative humidity and pressure on the indoor side, while being exposed to naturally occurring weather conditions on the exterior side. Continuous monitoring of temperature, relative humidity, pressure and surface liquid detection was conducted on critical layers of the wall assemblies from January till June 2008.

This paper will present and discuss monitoring results of this study, comparing the hygrothermal response of the 3 side-by-side test wall assemblies. The results showed that adding some thermal insulation on the exterior of an insulated stud cavity can contribute to reducing the duration of the potential for interstitial condensation but events of condensation can still take place during the coldest period of winter in a climate such as Ottawa (when other essential contributing factors are in place). Results indicated that the air and vapour permeance of the exterior insulation materials not only affected the flow of moisture to the outside during wintertime periods of air exfiltration but also affected moisture inwards flow during humid early summer conditions.

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Keywords: Condensation, cold climate, field monitoring, exterior insulation, energy, retrofit, exterior walls, housing, durability, moisture accumulation, wood-frame construction, air leakage.

INTRODUCTION

As energy costs and demands for environmental sustainability increase, the building industry seeks effective and durable strategies for improving the energy performance of the building envelope. For existing construction, options for building envelope improvement are limited based on cost effectiveness, more so than in new construction. Adding thermal insulation on the exterior of the existing shell of the building is a viable retrofit option with a few advantages including: minimal disruption to the occupants and their living spaces; and the ability to minimize costs, particularly if the energy retrofit measures are coordinated with other façade rehabilitation work. Adding thermal insulation on the exterior of the existing shell can increase the overall R-value and the airtightness of the wall assembly, as well as reduce thermal bridging due to structural elements. This results in higher energy efficiency and thermal comfort, and lower operation costs. However, the effect of the heat, air and vapour flow control properties of the selected thermal insulation on the moisture accumulation into the wood-frame cavity due to wintertime condensation can be of concern. A variety of thermal insulation materials can be used on the exterior of existing shells, and their hygrothermal properties vary: some exhibit low vapour and air permeance, while others have higher air and vapour permeance. These properties can affect the ability of the wall assemblies to get wet by condensation (in wintertime) and to dry out (in spring and summertime), hence having the potential to affect negatively the durability of the assembly. Research to compare the hygrothermal response of such energy retrofitted wall assemblies can yield valuable information about critical elements of wall assembly design for satisfactory performance and service life.

In 2007 NRC-IRC initiated the project "Evaluating the effects of two strategies of energy retrofit for housing on the wetting and drying potential of the wall assemblies-2007-08". Partnership and funding from NRCan (Housing and Buildings /Sustainable Building and Communities CANMET / Group) and CMHC (Sustainable Housing Policy and Research Group) was obtained.

OBJECTIVE

The objective of the study was to test the hypotheses that 1) the properties of the thermal insulation installed on the exterior of the wood-frame wall cavity will affect the temperature, vapour and air pressure gradients, and will consequently affect the wetting and drying potential of the assembly 2) air leakage through an assembly is a potent factor in transporting moisture to and from enclosed cavities 3) increases in indoor relative humidity levels can result in higher potential for wetting of stud wall cavity elements 4) walls with exterior insulation are less prone to interstitial condensation than similar walls without such exterior thermal lining.

METHODOLOGY

General Approach

The study was designed to compare the heat, air and moisture response of two exterior insulated retrofitted wood-frame walls with different air and vapour permeance, when subjected to air leakage under naturally occurring outdoor conditions, and controlled challenging indoor conditions. A traditional R20 2X6 wall assembly acted as reference.

During the winter of 2007-2008, NRC-IRC researchers investigated the effects of exterior energy retrofit strategies on moisture accumulation, and temperature and air pressure distribution in typical housing construction (38 X140 mm (2x6) wood studs with glass fibre batt insulation and poly air/vapour barrier for air, heat and moisture control). A test protocol was developed to challenge two wall assemblies with varying indoor relative humidity and air exfiltration levels.

To gather data to verify the research hypotheses, three wall assemblies (W1, W2 & W3) of different composition were placed side-by-side in the test bay of the NRC-IRC Field Exposure of Walls facility (FEWF). W1 specimen was built using a traditional wood-frame method, with glass fiber insulation batts between studs, while W2 included an exterior insulation material with lower air and vapour permeance, and W3 included an exterior insulation with higher air and vapour permeance. See the next section for a full description of the test specimens.

The test walls were instrumented during construction to collect data on the temperature (T), relative humidity (RH), air pressure (P) at most layers in the assemblies, as well as water deposition on surfaces and moisture content of wood-based materials in critical layers. The 3 wall test specimens were installed side-by-side in the test bay of FEWF. The test walls were monitored from Fall 2007 until Summer 2008. Two of the three test specimens were subjected to challenging indoor conditions of moisture and air pressure from February to April 2008, while an air leakage path was in place, in order to investigate the effect of the exfiltration/infiltration on the wintertime wetting and spring drying potential of these assemblies.

W1 test specimen was exposed to naturally occurring weather conditions outdoors and the uncontrolled indoor conditions of the adjacent room (about 20% RH- dry wintertime level). No deficiency in the air/vapour barrier polyethylene membrane was introduced in W1. W2 and W3 test specimens were subjected to naturally occurring weather conditions outside, and to a variety of indoor relative humidity (30-50%) and air pressure (up to 10 Pa above room air pressure) as introduced in the indoor climatic chamber. In wintertime indoor relative humidity levels in the indoor climatic chamber were controlled to represent low, average and high indoor RH conditions. Indoor air pressure levels resulted in a low level of pressurization under calm wind conditions. The two energy retrofitted test specimens were subjected to air leakage (infiltration or exfiltration depending on wind pressure) when a path for airflow was introduced at the poly air/vapour barrier and drywall indoors, and at the wood-based sheathing board (a 6 mm (1/4 in) gap at mid-height of the test specimen, simulating an open joint between two boards installed horizontally).

Description of Test Specimens

In fall 2006 and winter 2007 for the first year of study, three essentially identical test wall assemblies (W1, W2 & W3) each measuring 1727 mm x 1219 mm (5 ft 8in x 4 ft) were built and tested side-by-side in the FEWF (Figure 1). These wall assemblies were conventional glass fiber batt insulated 2X6 stud cavity wood-frame construction [1 and 2]. The polyethylene plastic membrane behind the interior finish was intended to act as the air/vapour barrier. For the second year of operation and the project described herein, the exterior layers of two of the three original test specimens (W2 and W3) were modified: thermal insulation was added on the exterior to replicate an exterior energy retrofit. In a procedure similar to what a homeowner would do to retrofit the exterior, the team removed the siding from the original W2 and W3 test specimens and made the necessary changes to accommodate 50 to 63.5 mm of additional thermal insulation on the exterior of the existing sheathing membrane of W2 and W3. As construction and retrofit work took place, the instrumentation was laid at their specified locations layer by layer. W1 specimen was used as the reference wall, and was not altered.

W2 included one layer of a low vapour and air permeance insulation layer, a rigid extruded polystyrene (XPS) board 50 mm (2 in) thick (RSI 1.76 or R10), installed on the exterior of the existing wood-based board and sheathing membrane. Three XPS boards were installed horizontally and the joints (square edges) were not sealed. W3 test specimen included three layers of a higher air and vapour permeance insulation, a semi-rigid mineral fibre insulation totalling 63.5 mm (2 ½ in) in thickness (RSI 1.76 or R10), placed on the exterior of the existing wood-based sheathing and sheathing membrane.

To provide adequate support for the attachment of the vinyl lap siding the construction of W2 and W3 differed. For W2, the siding was attached to the wood studs directly through the 50 mm XPS rigid insulation; no sheathing membrane was placed on the exterior of the XPS foam board. For W3, a sheathing membrane was placed over the semi-rigid mineral fibre insulation. Due to the flexibility and thickness of the mineral fibre insulation, furring strips were installed to facilitate the fastening of the vinyl siding. Vertical furring strips were installed vis-à-vis the wood studs, with the first 38 mm (1½ in) thick layer of the insulation left between the stud and furring strip in order to reduce thermal bridging. Figure 2, Figure 3 and Figure 4 as well as Table 1 described the layout and composition of the test specimens.

Figure 1: Field Exposure of walls facility and exterior view of the three test specimens

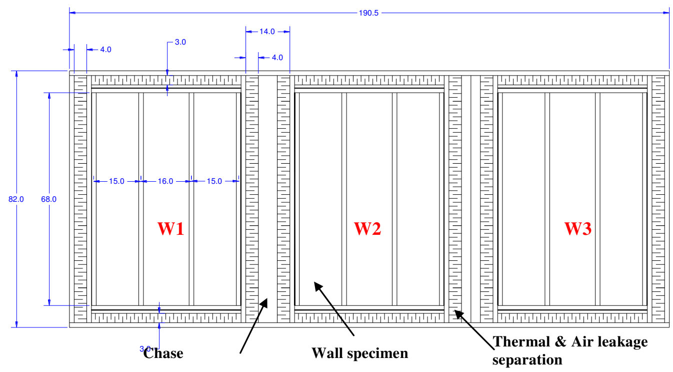

Figure 2: Elevation view from indoors of the 3 test specimens and the separating chases

All dimensions are in inches.

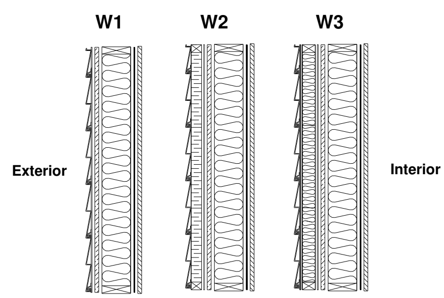

Figure 3: Vertical cross-section of the three wall specimens

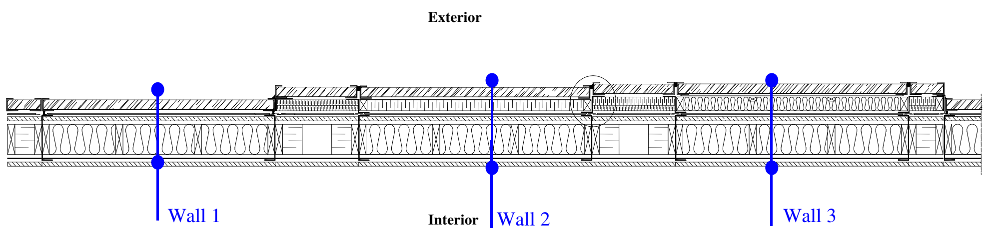

Figure 4: Horizontal cross section of the three wall specimens

Table 1: Composition of test specimens

W1 38mm X 140mm (2x6) insulated wood-frame with no exterior insulating sheathing	W2 Lower Air & Vapour Permeance Insulating Sheathing	W3 Higher Air & Vapour Permeance Insulating Sheathing
• Vinyl siding • Sheathing membrane (spun-bonded olefin) • 11mm OSB wood-sheathing (with a 6 mm horizontal gap at mid-height) • 38mmx140mm (2X6) nominal stud cavity with RSI 3,5 (R20) glass fiber insulation batts • Plastic air/vapour barrier • Painted drywall	• Vinyl siding • 50mm (2 in.) XPS rigid foam insulation, 609mm (24 in.) wide sections installed horizontally, square edge • Sheathing membrane (spun bonded olefin) • 11 mm OSB wood-sheathing (with a 6 mm horizontal gap at mid-height) • 38mmx140 mm (2X6) nominal stud cavity with RSI 3.5 (R20) glass fiber insulation batts • Plastic air/vapour barrier • Painted drywall	• Vinyl siding • Sheathing membrane (spun-bonded olefin “SPBO”) • 19 mm x 38 mm (¾ x 1½ in.) vertical strapping @ 400 mm (15¾ in.) o.c. mounted on blocks • 63.5 mm (2½in) semi-rigid mineral fibre insulation boards installed horizontally • Sheathing membrane (SPBO • 11 mm OSB wood-sheathing (with a 6 mm horizontal gap at mid-eight) • 38mmx140 mm (2X6) nominal stud cavity with RSI 3.5 glass fiber insulation batts • Plastic air/vapour barrier • Painted drywall

Testing Protocol

The objective of the test protocol was to investigate the effects of changes in indoor relative humidity (RH) and pressure (P) levels on the wetting and drying of two energy retrofitted wall assemblies. The experimental work was divided into 3 phases (Table 2):

Table 2: Description of the 3 phases of the test protocol

Phase	Date Start	Date Finish	Opening in Air Barrier (mm)	Indoor RH (%)	ΔP (Pa) (Indoor climatic chamber pressure – Indoor pressure)
1	November 2007	11-Jan-2008	0	Uncontrolled	0
2	11-Feb-2008	24-Feb-08	3 x 320	Uncontrolled	
A2	24-Feb-08 00 :00	29-Feb-08 16 :00	3 x 320	30%	0
B2	29-Feb-08 16:00	18-Mar-08 12:00	3 x 320	50%	0
C2	18-Mar-08 12 :00	21-Mar-08 11 :30	3 x 320	30%	5
D2	21-Mar-08 11 :30	27-Mar-08 11 :30	3 x 320	≈50%variable	5
E2	27-Mar-08 11 :30	09-Apr-08 14 :30	3 x 320	≈50% variable	10
F2	09-Apr-08 14: 30	30-Apr-08 00 :00	3 x 320	50%	0
3	30-Apr-08	03-July-08	3 x 320	Uncontrolled	0

Opening, RH and pressure conditions described in the table apply to W2 and W3 only. W1 was exposed to uncontrolled dry interior conditions throughout all phases.

Phase 1: No challenging indoor RH and P and no deficiency in the Air Barrier Systems (ABS) of test specimens

During this phase, the test specimens were left to acclimatize to naturally occurring environmental conditions. As the wall specimens did not include deficiencies into the air/vapour barrier, very little changes in moisture response within the wall specimens were expected.

Phase 2 *Challenging Indoor RH and P and a deficiency in the Air Barrier System (ABS) of W2 and W3 test specimens*

The objective of Phase 2 was to challenge W2 and W3 test walls in several ways in order to increase the wintertime condensation potential in the wall cavities and layers of the assemblies, and to characterize the effects on the surface wetting and the moisture content of wood-based materials within the wall assemblies. Conditions for mild air exfiltration of indoor humid air through the test specimens W2 and W3 were induced. An opening was made in the interior poly air/vapour barrier and the drywall to create an air leakage path (there was also a similar opening into the wood-based exterior sheathing) (Figure 5). The indoor climatic chamber was constructed and installed against W2 and W3, which allowed for the control of indoor relative humidity and air pressure (Figure 6).

W2 and W3 were subjected to conditions including two levels of indoor RH (30 and 50%) and a slight pressurization (5 to 10 Pa) of the indoor climatic chamber above room air. The humidity and pressure conditions in the chamber were designed to challenge W2 and W3 test specimens during the six steps of this Phase of the testing program. Measurements of the relative humidity in the room and in the chamber, and the applied pressure in the chamber are plotted in Figure 7. The temperature in the room, in the chamber and outdoors are plotted in Figure 8. The full test schedule is described in Table 2. W1 remained unchanged, i.e. without opening in the air/vapour barrier, and was not exposed to challenging indoor conditions of relative humidity and pressure, as the indoor climatic chamber did not enclose it. In the wintertime, the research house was operated at low RH (about 20%), and the room air temperature was generally cooler than the air in the indoor chamber.

Figure 5: Air leakage openings A - Horizontal opening in the polyethylene membrane of 320 x 3mm. B- A 6 mm horizontal opening in the wood-based sheathing representing an open horizontal joint between panels

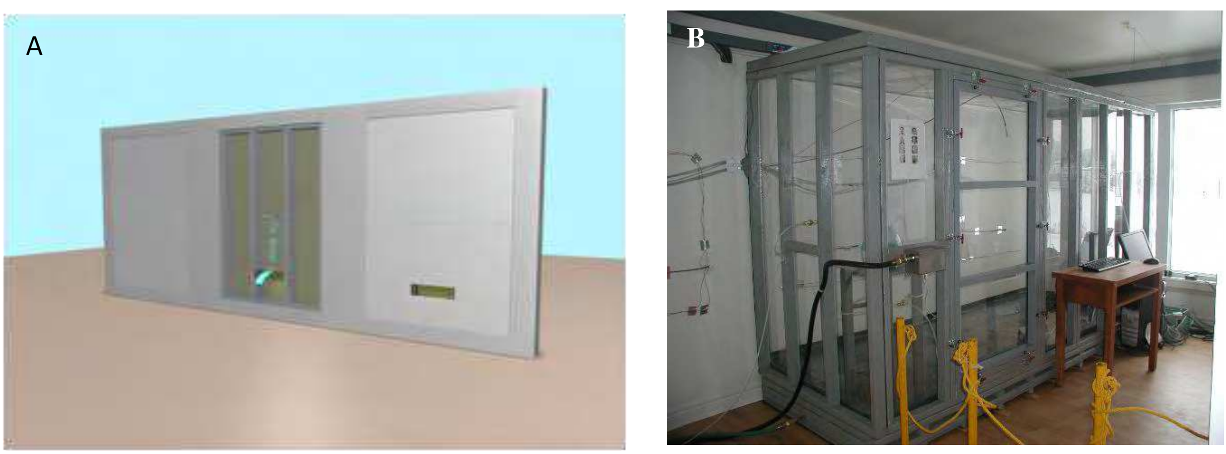

Figure 6: Air leakage path and indoor climatic chamber

A - Schematic showing an indoor view of the three test specimens. The figure shows the air leakage path created via gaps in the air/vapour barrier and in the wood-sheathing board, in the middle test specimen W2 and W3.

B- Indoor climatic chamber subjecting W2 and W3 test specimens to controlled temperature, relative humidity and air pressure. W1 did not have an opening in the air/vapour barrier, and was not connected to the indoor climatic chamber.

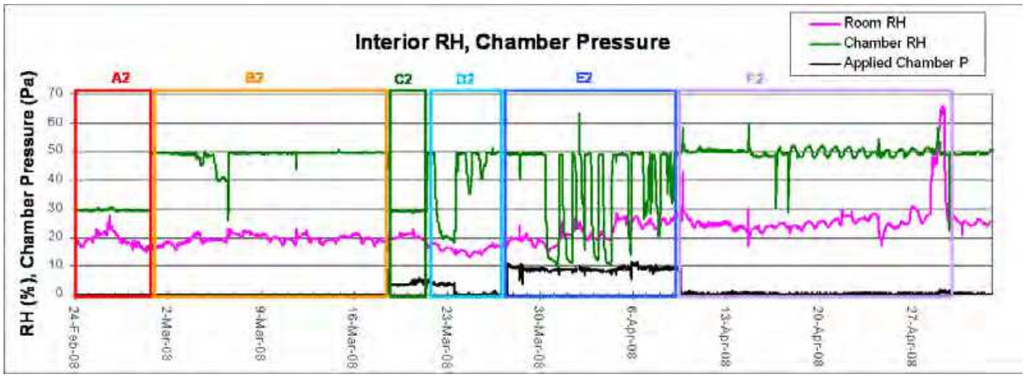

Figure 7 The six steps of the Phase 2 test program with corresponding indoor room and indoor chamber relative humidity and applied pressure (relative to room air)

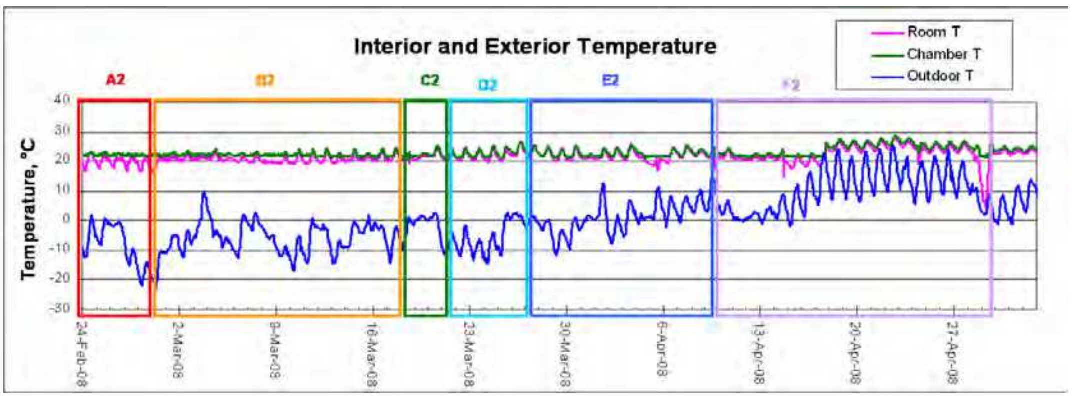

Figure 8-The six steps of the Phase 2 test program with corresponding indoor room, chamber temperature and outdoor temperature.

Phase 3: Constant 50% Relative Humidity, followed by 40% after the chamber was dismantled %), no pressure applied and a deficiency in the ABS

After Phase 2 was complete, the specimens were subjected to uncontrolled naturally occurring conditions indoors and outdoors, from April until July 2008. The indoor and outdoor climates were expected to promote the drying of the specimens. In July a section of the test specimens was opened up to observe the condition of the bottom of the stud cavity.

RESULTS AND DISCUSSION

The results of the field monitoring and the exposure of the test specimens to challenging indoor conditions are presented below in sequential order of the implementation of the test protocol (Table 2). The discussion of results will concentrate on Phase 2 conditions A2 and E2.

Phase 2- Configuration A2: Constant 30% Relative Humidity, No pressure applied, a deficiency in the ABS

This configuration was selected to investigate the test specimen responses when exposed to an indoor RH level which can be considered average and when natural air infiltration/air exfiltration patterns take place. During this 5-day period, hourly mean outdoor temperature fluctuated between 0ºC and –25ºC. The conditions in the indoor climatic chamber were stable.

Moisture Effects

Based on the moisture detection strips and the moisture pins readings, no condensation occurred in the test walls. The RH and T measurements taken at each interface of the test wall assemblies also supported this statement, as these measurements showed that the air at every interface was maintained at an RH level below saturation, even on the coldest day of the whole test period recorded -Feb. 29th 08 (Figure 9, Figure 10 and Figure 11). The absence of interstitial condensation in W2 and W3 (which included an air leakage path) can be explained by the observation that the test walls were almost always subjected to air infiltration: the pressure at the exterior of the wall assembly was higher than the pressure in the chamber (Figure 12). Even though there was a 3 mm by 320 mm opening through the air barrier system and drywall, and temperatures in the stud cavity dropped below the dew point of the indoor chamber air (Figure 13 and Figure 14), indoor moisture was not driven into the stud cavity for either W2 or W3. The three test specimens showed similar response in terms of measured humidity ratios at the different layers within their assemblies (Figure 15). Considering that W1 did not have an air leakage opening and was not subjected to increased indoor RH, and the measured humidity ratio was similar at interstitial layers in the three walls, it could be inferred for W2 and W3 that there was very little air and moisture transfer taking place across these specimens as well. Comparing the effect of the indoor RH on the dew point location within the test assemblies, Figure 13 and Figure 14 showed that in mild winter conditions (-5ºC), the W2 and W3 test specimens maintained the wood-based exterior sheathing above the dew point of room air (~15% RH), while W1 did not. However, the exterior sheathing of all three walls was at or below the dew point of chamber air (30% RH). During the episode of extreme cold weather (-25ºC) (Figure 14), again W2 and W3 test specimens were at an advantage over W1 composition as their exterior wood-based sheathing was slightly above the dew point of room air. But at the higher chamber RH of 30%, the dew point would be located within the glass fiber insulation in the stud cavity for W1, W2 and W3. This indicates that in very cold weather the presence of the RSI 1.76 (R10) exterior insulating sheathing on the exterior of the RSI 3.5 (R20) stud cavity did not have much effect on the location of the dew point, compared to the test specimen W1 which had no exterior insulating sheathing. In the three test specimens, the wood-based sheathing could be susceptible to condensation formation when other required conditions are present (e.g. moisture entering the cavity). One difference between walls with and without exterior insulations would reside in the duration of condensation. In the A2 test conditions, indoor moisture did not enter the stud cavity, and no condensation resulted, even though the cavity materials were cold enough to be below the dew point of chamber air. This can be explained by the absence of a driving force (i.e. a positive air pressure difference) to move indoor humid air into the stud cavity. Wind pressures were such that the wall assemblies were subjected to air infiltration at that time.

Temperature Effects

W2 and W3 test specimens exhibited similar temperature gradients across their assemblies, for average as well as extreme outdoor temperature exposure (Figure 13 and Figure 14). This was expected, as the RSI value of the two assemblies was very similar. W1, which did not include an exterior insulating sheathing, exhibited a different thermal response and the single major temperature drop was across the glass fibre insulation in the stud cavity; the exterior sheathing was maintained at temperatures very close to outside temperatures at all times. The presence of the exterior thermal layer (about RSI 1.76 or R10) in W2 and W3 resulted in a raised temperature at the exterior sheathing. On the coldest day, the temperature at the interior face of the exterior sheathing of W2 and W3 was approximately -5°C, while the sheathing of W1 was -20°C. Raising the temperature of the exterior sheathing can help reduce the potential for wintertime interstitial condensation, assuming all other contributing factors are equal.

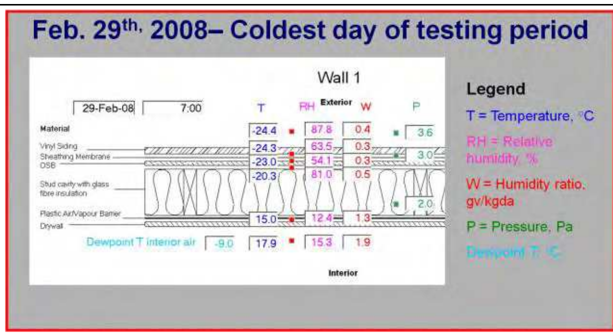

Figure 9 Configuration A2: Snapshot of Wall 1 cross-section (coldest outdoor temperature)

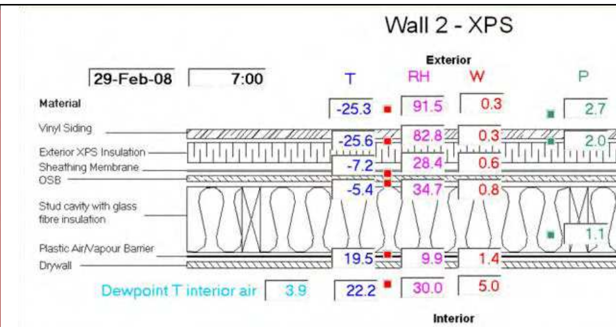

Figure 10 Configuration A2: Snapshot of Wall 2 cross-section (coldest outdoor temperature)

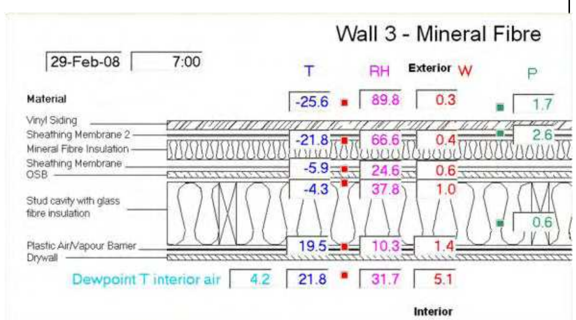

Figure 11 Configuration A2: Snapshot of Wall 3 cross-section (coldest outdoor temperature)

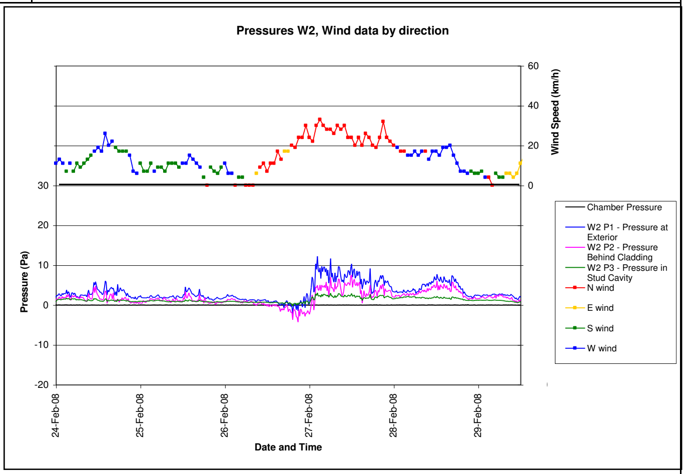

Figure 12 Configuration A2: Wall 2 pressure measurements and wind data

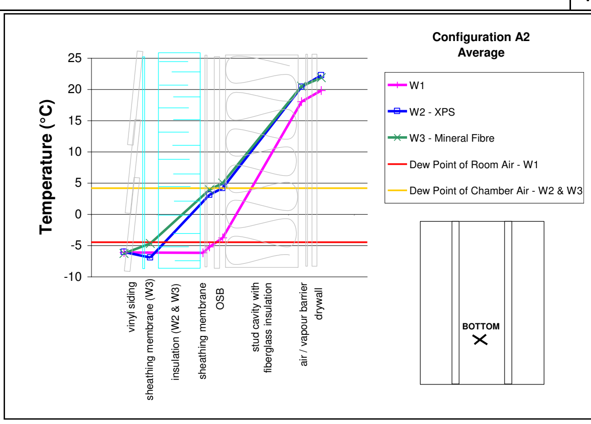

Figure 13 Configuration A2: Average temperature profile for the full configuration time period

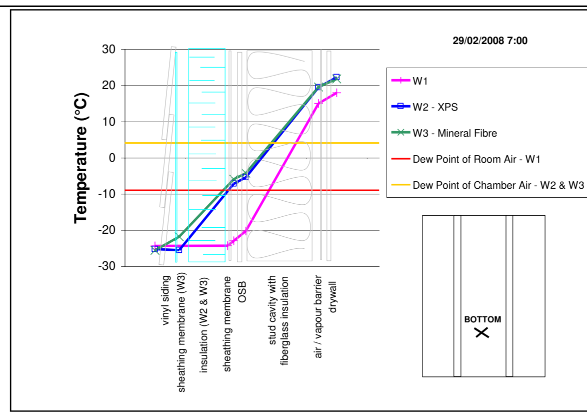

Figure 14 Configuration A2 - Temperature profile for 7:00 29-Feb-08 (the coldest temperature for Phase 2)

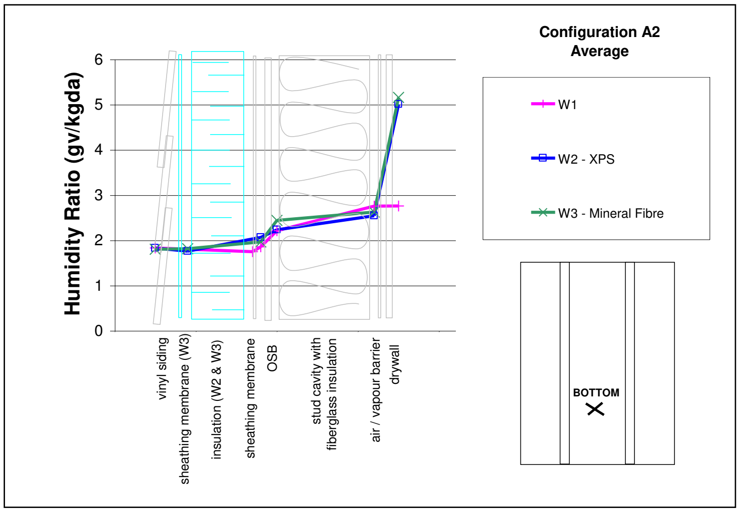

Figure 15 Configuration A2: Average humidity ratio profile for the full configuration time period

Phase 2- Configuration E2: 50% Humidity, 10 Pa Chamber Pressure and a deficiency in the ABS

This configuration was selected to investigate the effect of an increase in pressurization of the indoor space on the hygrothermal response of the test specimens. One episode of condensation was detected during the test period. On March 29th wetting was detected on the interior surface of the sheathing board of Wall 2 and Wall 3. There were under air exfiltration mode while the indoor conditions in the indoor climatic chamber were 50%RH and 10 Pascal pressurization above indoors (referred to as Condition E2).

The temperature, moisture and pressure levels measured in the test walls at the time of condensation detection are shown in Figure 16 and 17.

Most notably: while the humidity level of the air at the interior surface of the sheathing board was similar for both walls (about 6,7 g/kg dry air, the humidity level of the air in proximity of the exterior face of the sheathing board of Wall 2 (XPS) was higher than for Wall 3, at 6,4 and 4.0 g/kg respectively. This could be explained by the difference in air and vapour permeance of the two exterior insulation boards: W3 exhibited a higher air and vapour permeance, providing a higher rate of vapour transport to the outside.

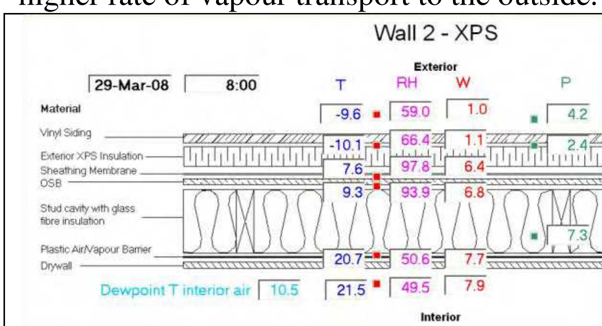

Figure 16 Configuration E2: Wall 2 cross-section and snapshot of T, RH, W (absolute humidity ratio) and P measurements at each layer at the time that moisture was detected on the interior surface of the wood-based sheathing

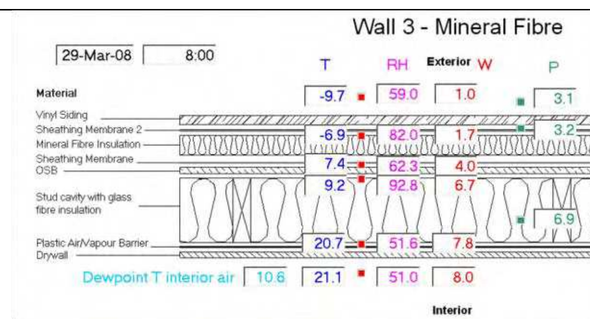

Figure 17 Configuration E2: Wall 3 cross-section and snapshot of T, RH, W (absolute humidity ratio) and P measurements at each layer at the time that moisture was detected on the interior surface of the wood-based sheathing

Effect of Wind on Pressure Distribution into the Wall Assemblies

A strong relationship between pressure distribution in the test walls (which drives the movement of air) and wind conditions was observed. The plan view of the research house and the FEWF presented in Figure 18 shows the FEWF is located on the West façade of the building. Prevailing wind direction during the testing program had an impact on the dominating forces driving air in or out of the wall assemblies. Figure 19 summarizes the air pressure measurements in the wall specimens during the 13 days of Condition E2 testing and wind speed and direction (at Ottawa airport). During this period, a 10 Pa pressure was applied in the indoor climatic chamber adjacent to the interior face of W2 and W3 test specimens. It was found that most of the time in the E2 test period, this indoor pressurization subjected these wall assemblies to positive pressure, resulting in the exfiltration of indoor humid air into the stud cavity. However events of westerly winds (in blue) caused the pressure at the exterior face of the wall assemblies to rise, inducing a driving force for cold air infiltration into the wall specimens, and counteracting efforts to operate the walls under air exfiltration mode. This phenomenon was clearly demonstrated on April 1st 2008 when a 40 km/h westerly wind prevailed, and air infiltration dominated, even though the indoor climatic chamber was pressurized relative to indoorswas produced. Interestingly easterly winds in yellow were expected to cause negative pressures on the face of the FEWF and had no noticeable effect on the pressure distribution across the test specimens, likely due to the counteracting? stack effect pressures casuing air infiltration drive on the first floor of the house.

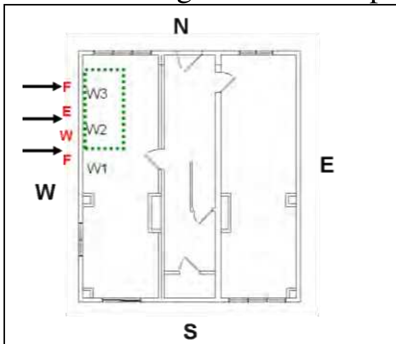

Figure 18 Plan view of the research house and orientation of FEWF

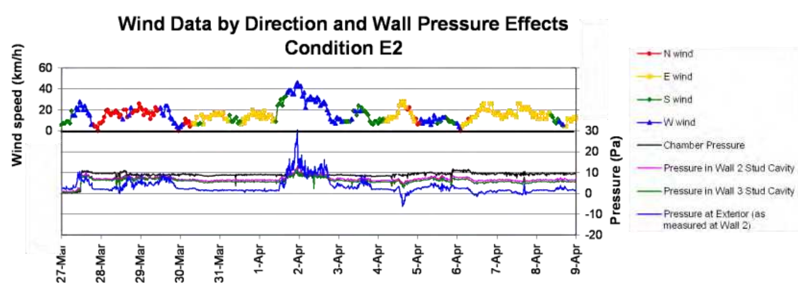

Figure 19 Configuration E2: Wall 2 pressure measurements and wind direction and speed data (similar pressure measurements were seen in Wall 3)

Hygrothermal Response under Infiltration and Exfiltration

During most of Condition A2 (0 Pa chamber pressure, 30% indoor RH), the retrofitted wall assemblies were predominantly in a state of infiltration, except for a brief period when easterly wind created exfiltration conditions. Under air infiltration mode, the humid indoor air of the chamber did not enter the stud cavity, even though an air leakage path created by a slit in the polyethylene air barrier and a gap in the sheathing board was present. As shown in Figure 15, the air in the stud cavities of W2 and W3 wall specimens remained as dry as that of Wall 1 (exposed to dry room air only, and without an air leakage path). This indicates that unless all necessary conditions are present simultaneously, interstitial condensation will not take place.

Figure 21 shows the average humidity conditions at each layer of the wall assemblies during Condition E2 (10 Pa chamber pressure, 50% indoor RH). During this period, the 10 Pa pressure forced exfiltration on all but one day. As a result, moist indoor chamber air was driven into the wall. The graph shows the effect of air exfiltration on the increase in moisture content of the air at each layer of W2 and W3 assemblies. Of note: on average for this 13-day period, the moisture content of the air on the exterior side of the sheathing board of W3 (with mineral fibre exterior insulation) was slightly and consistently lower than that of W2 (extruded polystyrene foam boards) wall assembly. Such difference in the rate of moisture transmission can be related to their different air and vapour permeance. To investigate further the lower rate of moisture transmission and potential lower rate of drying to the outside of the test specimen with the exterior extruded polystyrene, the research team continued the experimental work on W2 in 2008-09.

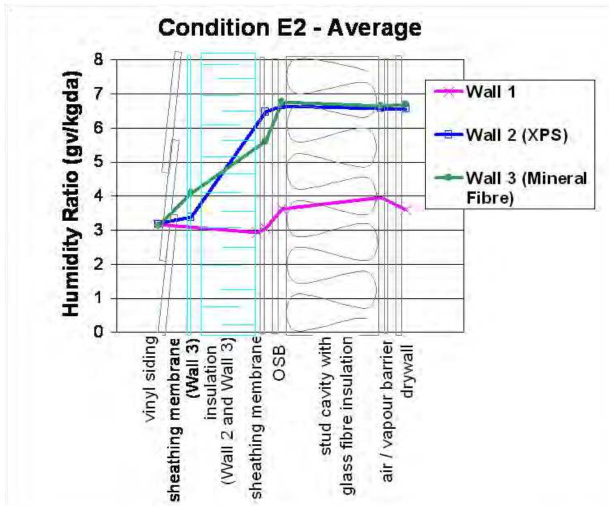

Figure 20 W2 and W3 were predominantly subjected to air exfiltration, and exposed to 50%RH indoors. W1 was not changed from Condition A2 and had no air leakage path in place.

Detection of Liquid Moisture Deposition

On March 29th 2008, a number of the moisture detection tapes installed on the interior surface of the sheathing board of W2 and W3 detected the deposition of liquid moisture. It happened that the moist indoor air exfiltrating into the stud cavity (thanks to the pressurized indoor chamber, collaborating wind and a leakage path through the assemblies) combined to cold surface temperatures at the sheathing board provided the necessary conditions for condensation to form.

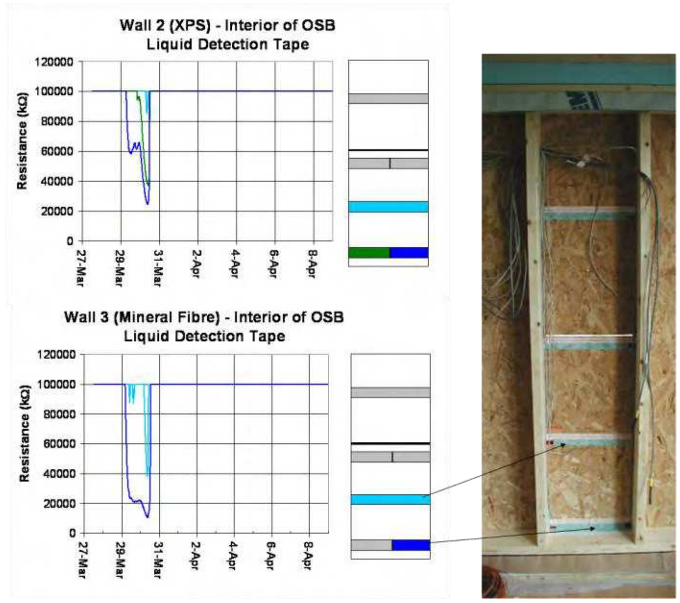

Figure 21- Measurements of electrical resistance drop below a given threshold is an indication of wetting on the surface of the detection strip.

CONCLUSION

The following are elements of conclusion regarding the study to date:

Performance of the test walls

- The test walls responded in different ways to the test conditions. Some of the comparative differences in hygrothermal response of the test specimens W2 and W3 can be explained by the difference in air and vapour permeance of the exterior insulating sheathing. This was apparent in the difference in absolute moisture content of the air at the wood-based sheathing/ sheathing membrane interface located inboard of the insulating exterior sheathing seen during condition E2. The absolute moisture content at this location was higher for the test wall with exterior XPS foam (W2) than for test wall with exterior mineral fibre insulation (W3), and approached near moisture saturation level (100% RH). The XPS foam exhibited lower vapour and air permeance than the mineral fibre insulation and this difference in hygric properties can explain the lower rate of moisture transmission through the XPS foam to the outdoors.
- W1, without an air leakage path and not being exposed to challenging indoor conditions of humidity and pressure, served as a reference but could not be compared on the same plain level field to the other two specimens. This could be addressed with a follow-up field study.
- One of the four hypotheses for the study was that the properties of the thermal insulation installed on the exterior of the wood-frame wall cavity affects the temperature, vapour and air pressure gradients, and will consequently affect the wetting and drying potential of the assembly. Both test specimens that experienced wintertime interstitial wetting had dried by the spring without apparent damage. In the study the wetting was short-lived as the right conditions for condensation ended up being in place for a few days at the time. That amount of wetting was well handled by both types of wall assemblies in the study.

- A second hypothesis for the study was that air leakage through an assembly was a potent factor in transporting moisture to and from enclosed cavities. The study confirmed this hypothesis. The findings have shown that the test wall not subjected to air leakage experienced no indoor moisture transfer into the wall assembly in wintertime. The test specimens subjected to air exfiltration in wintertime clearly experienced some gains of moisture into the wall cavity.
- A third hypothesis for the study was that an increase in indoor relative humidity levels can result in higher potential for wetting of stud wall cavity elements. The results do not allow for validation of this hypothesis. When the test protocol called for an increase in indoor RH levels, the walls were not operating in the exfiltration mode due to strong winds causing prevailing air infiltration through the test specimens.
- The fourth hypothesis for the study was that wall assemblies with exterior insulation are less prone to interstitial condensation than similar walls without such exterior thermal lining. The study showed that the addition of an exterior insulating sheathing raised the temperature of the stud cavity materials and can maintain it above the dew point of interior air, thus reducing the likelihood and duration of interstitial condensation, within limits. When the outdoor climate was very cold, the benefit of the insulating sheathings on reducing the condensation potential was reduced.

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