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Field Evaluation of Thermal and Moisture Response of Highly Insulated Wood-frame Walls

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ABSTRACT

Over the years, the energy efficiency of the North American housing stock has significantly improved mainly due to higher insulation levels, more efficient windows and, more importantly, adoption of various energy efficiency measures by building codes. The increased insulation levels of building envelopes for homes leads to a multitude of opportunities as well as challenges. A major opportunity is to reduce heat losses and thereby significantly reducing the space heating loads. However, there are many challenges that necessitate changes in the current construction process, durability of products, and more importantly, the effect of higher insulation levels on the overall moisture performance and expected long-term performance of the building envelope. A major barrier to the uptake of highly insulated homes is the lack of proven evidence of reliable thermal and moisture performance of these homes as might be achieved in various climates of Canada. Following a survey of current construction practices, a set of six wall assemblies with different types of exterior insulation systems were chosen for field monitoring study undertaken in two separate Phases over a two year period in a test facility located in Ottawa, Canada. These wall assemblies ranged from total insulation value of RSI-4.8 to RSI 7.9 (R-27 to R-45). Full scale testing included year-round performance monitoring. These wall specimens were installed in a side-by-side test bay and were subjected to local climate conditions of Ottawa, Canada; on the interior of the specimens conditions were nominally maintained at 20°C and 50% RH. This paper provides results of field trials of the six wall assemblies in terms of their hygrothermal performance and risk for condensation over a two year period of operation.

INTRODUCTION - PROJECT OVERVIEW

The Canadian market for new residential home construction and existing retrofits was about 79 million m^2, which represents an investment of about CDN $9.7 billion in 2012 [1]. Conservatively assuming a 25% market share by 2025, highly-insulated (enhanced) envelopes could save 11.6 PJ of energy and 1.2 Mt of Green House Gas per year [2]. This represents a significant economic opportunity for the housing industry within Canada and for value-added exports such as manufactured panelized wall systems. This project is needed to provide the scientific data and analysis necessary to characterize the thermal and moisture performance of advanced residential wall systems. Such information is needed to inform any considerations for further energy efficiency improvements to building codes and voluntary residential energy efficiency program requirements. Evidence was needed to guide the development of highly energy efficient, cost-effective, durable and buildable solutions that are well-integrated with Canadian housing system practices.

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Given the heightened interest of homebuilders to provide homes that met or exceeded Energy Star requirements, and their voiced concerns regarding "super-insulted" homes, the intent of this work was to demonstrate compliance of a set of highly-insulated wall assemblies as compared to a code compliant reference wall in respect to their anticipated thermal and hygrothermal performance when subjected to Canadian climate extremes. On the basis of providing useful information to building practitioners, the National Research Council Canada (NRC) undertook field monitoring and numerical modelling to investigate the risk of condensation in wall assemblies having different combinations of increased thermal resistance (R-value) of insulation for selected insulation products.

To achieve higher wall insulation levels in wood-frame wall assemblies, it has been commonplace to apply rigid, or semi-rigid, board insulation over the inside or outside of the framing. Alternatively, double wall or deep wall construction assemblies can be used to attain the desired level of insulation. However, concerns had been expressed in the building community regarding the use of progressively higher levels of insulation in wall assemblies as a means of attaining greater energy savings. It was felt that the use of higher insulation levels would increase the risk of incurring moisture problems given the perceived effect that highly insulated walls have on the wetting and drying characteristics of walls.

To help address the development of such unintended consequences, a collaborative research project, with government and industry participation, was initiated to explore, develop, test and document the energy performance and moisture response of highly insulated residential wall systems. The information derived from the project will be used to guide the development of durable new wood frame wall assemblies.

DESCRIPTION

The intent of the project was to develop information on the moisture and thermal performance of progressively higher insulated wood-frame wall assemblies. The information is to be used to: (1) Support the evaluation of future code proposals regarding energy efficiency improvements to building envelope systems; (2) Support the development of knowledge, details and practices for advanced wall systems for voluntary residential energy efficiency programs; (3) Help the housing industry meet near- and net-zero energy targets, and; (4) Promote the deployment of highly energy efficient wall details for new and retrofitted existing wood-frame construction. In essence, the primary outcome from this project was to facilitate the widespread adoption of high performance residential wood-frame wall systems (EGH-83 and 86*) that are practical, buildable, durable, energy efficient and affordable.

To achieve these objectives, the project focused on investigating the moisture and energy performance of thermally enhanced wood-frame walls with progressively higher levels of insulation from a base line (2010 National Building Code minimum (RSI 3.27 – 4.13) to new R-2000 performance levels (RSI 7.04 – 7.92). It permitted comparing the heat, air and moisture response of the advanced wall systems to the base line code walls and thereafter conduct the necessary analysis to develop meaningful information that could be used to address, and thereby alleviate, industry concerns regarding the unintended consequences of enhancing the thermal performance of walls with additional insulation on the moisture performance of these wall assembliess over time.

The National Research Council Canada (NRC) in collaboration with the Canada Mortgage and Housing Corporation and Natural Resources Canada, industry partners that included the: Canadian Wood Council, Homeowners Protection Office of British Columbia, and the Cellulose Insulation Manufacturers Association of Canada, developed proposals for 6 wall assemblies that could potentially be used in progressively higher thermally performing houses between baseline code to R-2000 levels. The wall assemblies were exposed to outdoor conditions in NRC's Field Exposure of Walls test facility over a period of 9–months in a yearly cycle,

* EnerGuide for Houses; Energy efficient new house: EGH 81 to 85; High-performance, energy efficient new house: EGH 86 to 99

3 walls tested every cycle.

In this paper, results are provided of the monitoring of the hygrothermal response of a set of six highly insulated wall assemblies to local climate conditions and when subjected to forced exfiltration conditions. Given that experimental tests to determine the hygrothermal performance of different wall systems in different Canadian locations is time consuming and expensive, an advanced hygrothermal modeling tool was used in this project. The modeling tool (hygIRC-C) was benchmarked against experimental data obtained from Phase 1 and Phase 2 of the project [3]. Once the benchmarking of the modeling tool was completed, it was then used to investigate the effect of different outdoor and indoor conditions, as may be found in the different regions of Canada, on the moisture and thermal performance of the wall assemblies.

RESEARCH APPROACH

Scope of Testing

The field monitoring of the six (6) different wall assemblies was undertaken in two separate Phases over a two year period in the NRC's Field Exposure of Walls test Facility (FEWF) located at the NRC campus in Ottawa, Canada. Three (3) wall assemblies were tested in the initial year of Phase 1 of the project (June 2013 to October 2014) and another three (3) wall assemblies were tested in Phase 2 of the second project year (January 2015 to September 2015). A detailed description of the wall assemblies of Phase 1 and 2 are available in [3].

Field monitoring of the test specimens was conducted in each project Phase nominally over a 9-month period; during this periods test specimens were subjected to a broad range of weather conditions as was experienced in Ottawa over the respective time periods.

DESCRIPTION OF WALL SPECIMENS

Phase 1 Test specimens

The three wall test specimens of Phase 1 (1219 mm x 1829 mm / 4 ft. x 6-ft.) consisted of 38 mm x 140 mm (2 x 6-in.) wood-frame walls installed side-by-side in the FEWF (Figure 1). The different material layers and the dimensions of the wall specimens are given in Figure 2 to Figure 4. The backup wall for all three design strategies consisted of interior drywall ((12.7 mm / 0.5 in) thick), polyethylene air and vapour barrier (6 mil thick), 38 mm x 140 mm (2 x 6-in.) wood-frame wall with friction-fit glass fibre batt insulation of R24, and oriented strand board (OSB) (11 mm / 7/16 in. thick). The test specimens were constructed by adding different types of exterior insulation products of different thicknesses to the backup wall. The first wall (Wall 1; Figure 2,) was constructed by adding an expanded polystyrene (EPS) layer of 25 mm (1 in) thick onto the OSB sheathing, yielding a nominal R27. The second wall (Wall 2; Figure 3) was constructed with a 51 mm (2 in) thick extruded polystyrene (XPS) panel and nominally provided R35. The final wall (Wall 3; Figure 4) was constructed with 76 mm (3 in) thick mineral fibre insulation, thereby providing an R35.

Phase 2 Test specimens

The three wall test specimens of Phase 2 (1219 mm x 1829 mm / 4 ft. x 6-ft.) are shown in Figure 5 to Figure 8 and were, as before, installed side-by-side in the FEWF (Figure 5). The common elements of all three test specimens were, towards the exterior of the assemblies, the vinyl siding, polymer-based sheathing membrane, and 11 mm OSB wood-sheathing panel, and for the interior finish, a 6 mil polyethylene air and vapor barrier and a 12.5 mm drywall panel. All walls were of wood frame construction, the difference being that the W4 frame nominally consisted of 38 mm x 140 mm (2 x 6-in.) framing, that for W5, 38 mm x 255 mm (2x10-in.) framing and for W6, 38 mm x 305 mm (2 x 12-in.) framing.

The primary insulation materials for W4 (XPS) were: R24 glass fiber batt insulation over which and towards the interior was installed 51 mm (2 in.) of XPS rigid foam insulation; the overall nominal thermal resistance for W4 (XPS) was R34. For W5 (SPF), the primary insulation materials were: ca. 2.4 in. of Spray Polyurethane Foam (SPF) applied on the interior surface of the OSB sheathing panel and 6.6-in. of glass fiber batt insulation; the overall nominal thermal resistance for W5 (SPF) was R45. For W6 (CFI), the insulation products consisted of cellulose fiber insulation providing a nominal R-value of R40.

Whereas for W4 (XPS) and W5 (SPF) the full depth of the vertical studs was used across the wall assembly, for W6 (CFI), 2 x 4-in. framing was used in the central stud cavity on the exterior and interior of the wall; this arrangement is more clearly evident from the horizontal sectional view provided in Figure 8.

Instrumentation

For the characterization of the hygrothermal response of the walls, the test specimens were instrumented with different sensors to characterize heat transfer across the specimens and to establish values for surface temperature and local relative humidity as well as the presence of moisture accumulation. Heat flux transducers (HFTs: Hukseflux PU11T; PU34T), thermocouples (Omega TT-T-24-SLE), relative humidity sensors, differential pressure transducers (Setra C264), and moisture detection tapes (SMT MDS) were deployed in a grid at each layer of the assembly. A local weather monitoring device (Vaisala Model HMP-60), that included a rain gauge and relative humidity and temperature sensors, was installed to provide information on hourly ambient exterior conditions in close proximity to the wall specimens. The combined package permitted determining the response of the respective wall assemblies to changing weather conditions over hourly, daily and seasonal periods.

For each project Phase, each of the three test specimens was isolated from each other by a vertical chase that provided effective control of heat, air and moisture flow and as well provided room for running wires for instrumentation (Figure 1 and Figure 5). The test specimens were also isolated from the surrounding building envelope of the test house with effective heat, air and moisture control materials (e.g. thermal insulation and self-adhered airtight membranes were used), as well as flashings where warranted.

As a part of the test protocol, more fully described in [3], all HFTs used in the test specimens were calibrated according to ASTM C-1130 “Standard Practice for Calibrating Thin Heat Flux Transducers” [4]. The uncertainty of the heat flux measurements was ± 5%. The locations of the HFTs in the respective test specimens are shown in Figure 2 to Figure 4.

Test Protocol

The test protocol was conceived to ensure that the wall assemblies were monitored to assess their vapour diffusion characteristics over at least a 9 month period, the initial period (A) covering the coldest period of the year. The test protocol consisted of exposing the wall specimens to:

- Exterior weather conditions prevalent at the FEWF test site;
- A set of indoor controlled temperature and humidity conditions.

Indoor controlled conditions were based on that provided in ASHRAE standards [5] as these relate to indoor winter and summer conditions (20°C; 35% RH). To attain these conditions, an indoor climatic chamber was installed and sealed against the perimeter of the test opening, thereby allowing control of indoor conditions to which test specimens were subjected.

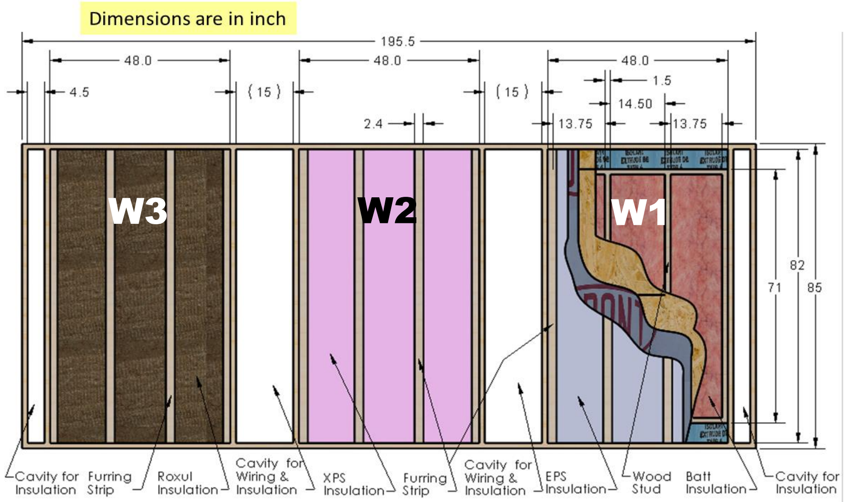

Figure 1. Schematic of three 38 mm x 140 mm (2 x 6 in.) wood-frame wall (residential) test specimens installed side-by-side in FEWF

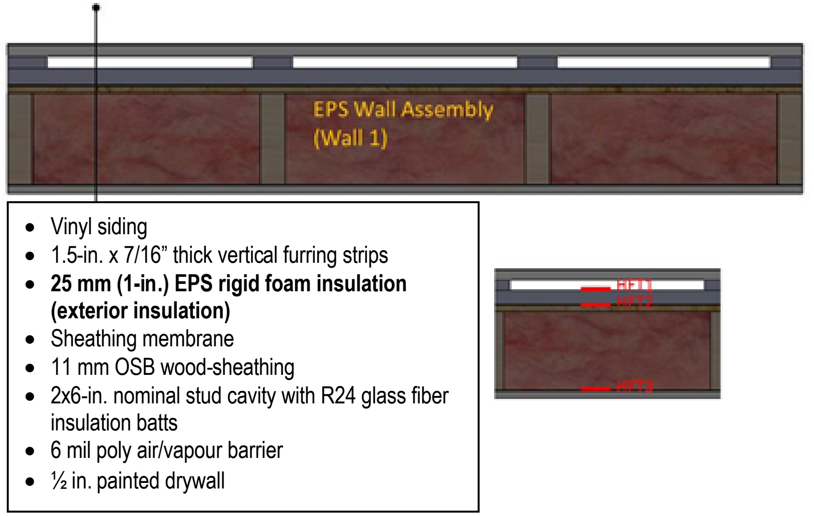

Figure 2. Wall 1 (W1: EPS) - Horizontal cross-section through EPS wall assembly showing locations of Heat Flux Transducers (HFT)

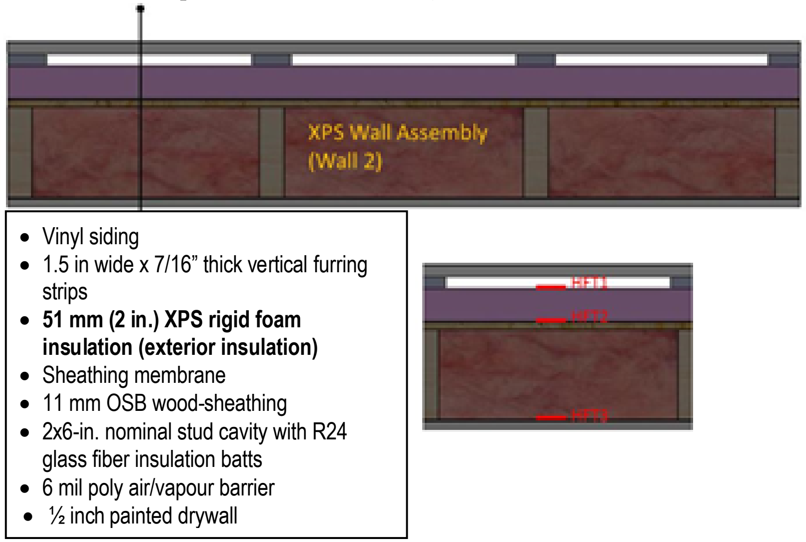

Figure 3. Wall 2 (W2: XPS) - Horizontal cross-section through XPS wall assembly showing locations of Heat Flux Transducers (HFT)

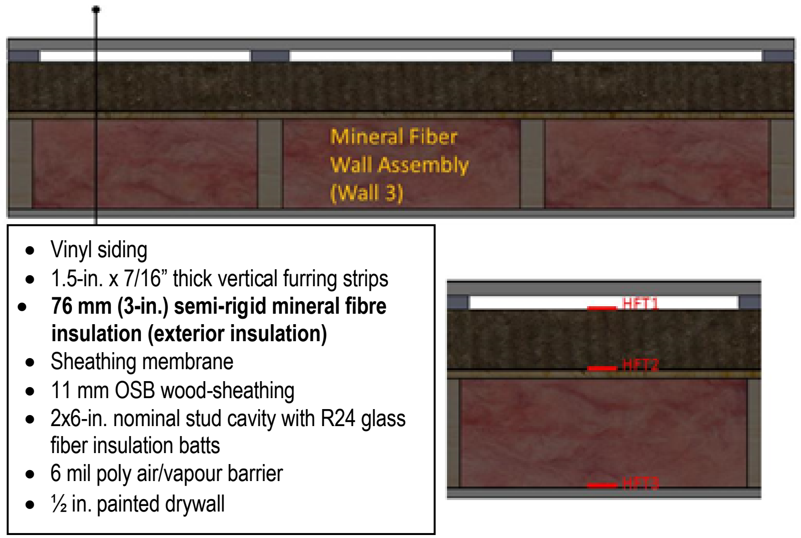

Figure 4. Wall 3 (W3: MF) - Horizontal cross-section through mineral fibre (MF) wall assembly showing locations of HFT

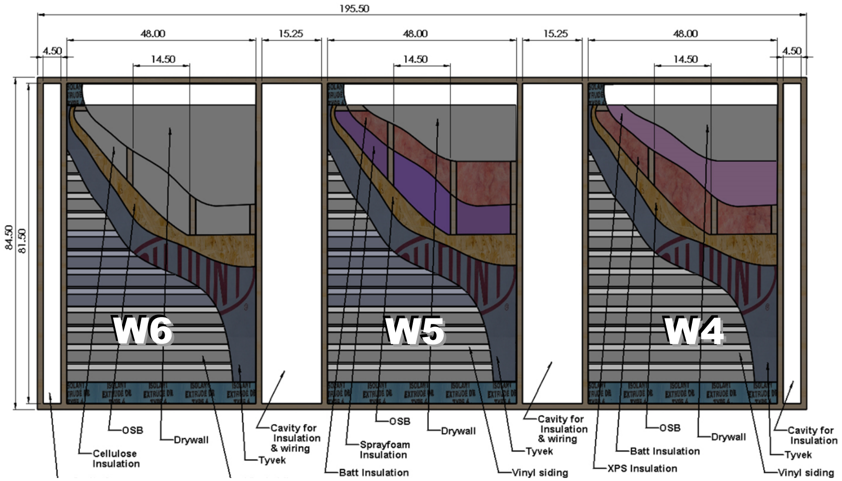

Figure 5. Schematic of three 38 mm x 140 mm (2 x 6 in.) wood-frame wall (residential) test specimens installed side-by-side in FEWF

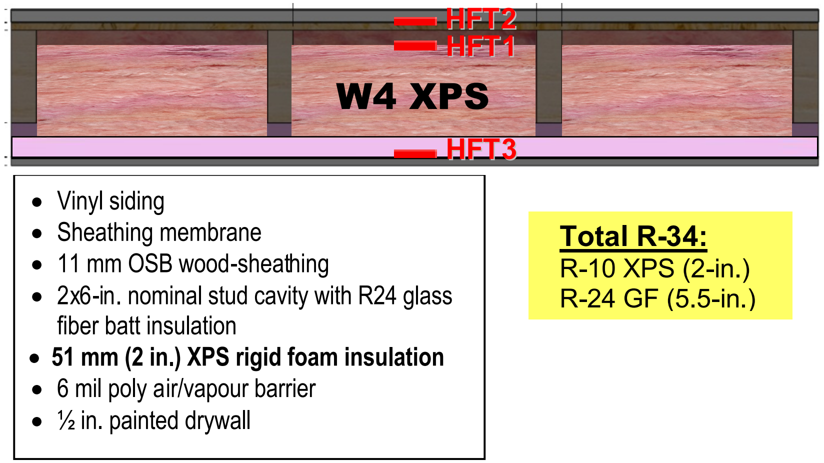

Figure 6. Wall 4 (W4: XPS) - Horizontal cross-section through XPS wall assembly showing locations of Heat Flux Transducers (HFT)

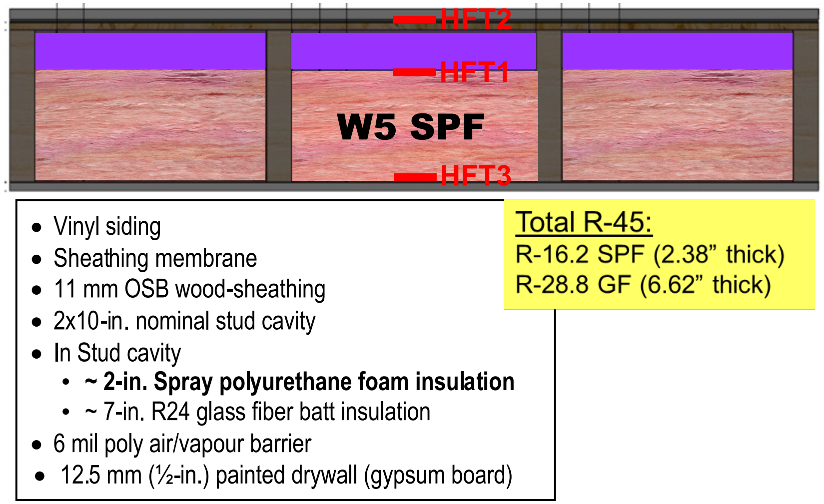

Figure 7. Wall 5 (W5: SPF) - Horizontal cross-section through SPF wall assembly showing locations of Heat Flux Transducers (HFT)

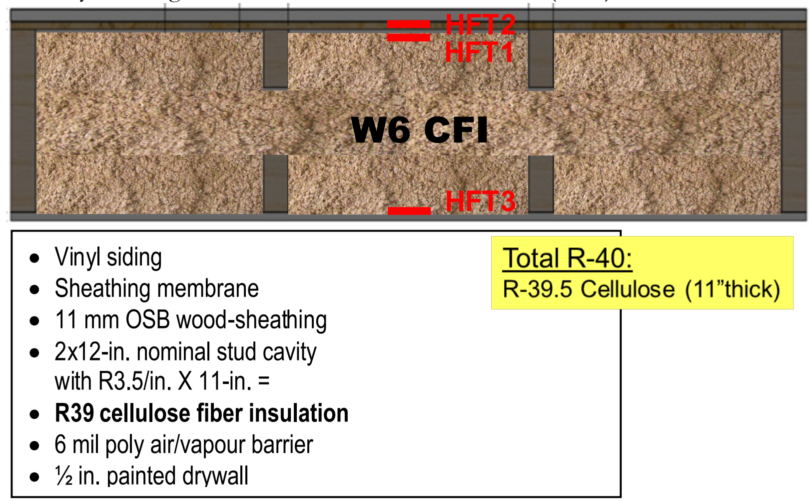

Figure 8. Wall 6 (W6: CFI) - Horizontal cross-section through cellulose fibre (MF) wall assembly showing locations of HFT

Test Periods — The monitoring program was set-up in four (4) periods (A, B, C and D) as provided in Table 1 for Phase 1 and in Table 2 for Phase 2. The length of periods varied, but in essence the initial period, Period A, was intended as a period over which the fluctuations of heat flow, temperature, relative humidity and pressure differences within the assembly were monitored to gain an appreciation of the response of the wall to local weather conditions and when the interior conditions were nominally maintained at 21°C and 35% RH. Period B was meant to subject specimens to conditions where warm moist air (21°C; 50% RH) exfiltrated through intended deficiencies in the test specimens; exfiltration was induced by applying a 10 Pa pressure across the test specimens from the interior enclosure. In this instance, there was interest in bringing about condensation on cold surfaces within the wall. The subsequent period, period C, provided a short period over which the deficiencies remained in the assembly but no exfiltration pressure was applied to the enclosure and interior RH conditions were not controlled to a set RH level as they were for periods A and B. As such, the wall might recover from moisture deposition within the wall and in essence, "dry out". In this way, the propensity for the wall to dry out following occurrences of moisture deposition within the wall provided a means to assess the robustness of the moisture management ability of the wall assembly. The final period (Period D), was again intended as a period over which to gain an understanding of the response of the wall to increasingly cooler periods following the summer months; the deficiencies were not present in this instance and neither was the RH in the interior enclosure maintained to a set level.

Deficiencies in the wall assembly — Each test specimen included a deficiency through which air from the interior was meant to exfiltrate through the test specimens. The size and location of the respective deficiencies are shown in **Figure 9**. Pressure differences across the assemblies, occurring either naturally or through forced air flow to the interior enclosure, induced the flow of air through the deficiencies as suggested in the schematic on the right of the photos in **Figure 9**. The location of the deficiencies at the interior of the test specimens and at the exterior sheathing panel, in principal, permitted a path for air to flow. The air leakage rate at several different enclosure pressures for each of these deficiencies was determined the results of which are given in Table 3. These are given as the leakage rate (L/min.) as a function of pressure difference (Pa) in the exfiltration mode. The coefficients for the best fit equation are given for each test wall as is the degree of fit (R^2). Of importance are the values of air leakage at the exfiltration mode when the deficiencies were present in the walls (Period B-"Deficiency state").

Table 1. Phase 1 (2013/14) - Test protocol over monitoring period

Period	Interior conditions				Exterior conditions	
	Temperature (°C)	**RH (%)**	**Pressure (Pa)**	**Deficiency (3mm slit)**	**Deficiency (3mm slit)**	**Temperature / RH**
A (175 days)	21	35	0	Closed	Open	Ambient local
B (20 days)	21	50	10	Open	Open	Ambient local
C (40 days)	21	Variable / natural	0	Open	Open	Ambient local
D (100 days)	21	Variable / natural	0	Closed	Open	Ambient local

Table 2. Phase 2 (2014/15) - Test protocol over monitoring period

Period	Interior conditions				Exterior conditions	
	Temperature (°C)	**RH (%)**	**Pressure (Pa)**	**Deficiency (3mm slit)**	**Deficiency (3mm slit)**	**Temperature / RH**
A (40 days)	21	35	0	Closed	Open	Ambient local
B (9 days)	21	Variable / natural	Variable	Open	Open	Ambient local
C (47 days)	21	Variable / natural	0	Open	Open	Ambient local
D (167 days)	21	Variable / natural	0	Closed	Open	Ambient local

Figure 9 – Example of deficiencies in wall test specimens showing location and size of deficiency in W4 (XPS)

Table 3 – Air leakage (ξ) characterization of test specimens

Phase	Wall	ξ (L/min) = a ΔP^b	
		a	b
Phase 1	W1	73.5	0.320
	W2	75.9	0.316
	W3	53.4	0.300
Phase 2	W4	0.685	0.989
	W5	0.654	0.766
	W6	0.593	0.953

*ΔP in Pa

Monitoring

Data was gathered continuously over a 9-month period and data analysis consisted of reviewing relevant sensors within the assembly and determining whether there was risk to the formation of condensation within the respective assemblies over the evaluation period.

On the basis of results obtained from monitoring the response of the respective wall assemblies to local climate conditions, the numerical hygrothermal model hygIRC-C was benchmarked against selected experimental data. Thereafter, the model was used to conduct a parametric analysis to investigate the risk of condensation and mold growth in the respective wall assemblies subjected to different climatic conditions for a select set of locations in Canada. A description of the hygIRC-C numerical hygrothermal simulation model and record of benchmarking exercises are available in [6].

RESULTS

Results are provided for Phase 1 and thereafter for Phase 2 of the project. In each of these sections, the hygrothermal response of wall test specimens to local climate conditions is described and those instances when moisture from condensation within the wall assembly was observed are discussed.

Response of Wall assemblies - Phase 1 (2013/14)

The hygrothermal response of those test specimens evaluated in Phase 1 over the monitoring period of ca. 11 months is shown in **Figure 10** for the respective test specimens: (i) W1-EPS; (ii) W2-XPS, and; (iii) W3-MF. The location of the temperature and relative humidity sensors for which values are provided in the figure are shown in the diagram adjacent to the plots. In the plot of **Figure 10** the values recorded for the interior surface temperature and relative humidity of the OSB sheathing panel at mid-height of the wall are shown over the 4 periods of the test protocol (i.e. A, B, C, and D). The daily fluctuations in temperature of both the interior surface of the OSB and well as the interior dew point temperature are superimposed on the seasonal variations; the OSB interior surface gradually rise from below zero °C to upwards of 25°C with maximum values attaining > 30°C in Period C (May -July) and the beginning of period D (July-August). The relative humidity at the interior surface of the OSB panel varies over the monitoring period between ca. 55% and 35%, the lowest values being recorded during period B of the monitoring program.

Period B of the monitoring program was intended to bring about occurrences of condensation within the wall assembly. As noted in Figure 10, this was the "deficiency state" when warm moist air from the interior was to exfiltrate to the exterior of the test specimens under forced flow conditions. Period B was completed over a three week period at the beginning of May (2 May to 22 May 2014). This being the case, and given that the surface temperature of the interior of the OSB sheathing panel had already attained a minimum temperature of ca. 7°C, it was unlikely that any surface condensation would occur given as well that this surface temperature was well above the interior dew point temperature. Consequently, no condensation was induced in this period for any of the 3 walls tested. Then again, neither was any condensation evident for any of the walls over all other periods monitored in Phase 1; this was also visually verified when the walls were taken down following the end of Phase 1.

Response of Wall assemblies - Phase 2 (2014/15)

The information made available for Phase 2 is quite considerable and additional details of this work can be found in [3]. The hygrothermal response of each of the test walls of Phase 2 (W4, W5, W6) are dealt with in turn.

Response of W4 (XPS) — The response of W4 is provided in plots of relative humidity and temperature (RH & T) as a function of the monitoring period in days as provided in Figure 11. The different periods (A to D, inclusive) are highlighted at the base of the figure. The uppermost plot represents the RH (blue color) and T (red color) on the surface of the interior side of the OSB at approximately mid-height of the wall and in proximity to the 3 mm slit through which air could exfiltrate the wall. For the middle plot, the values for temperature given at the bottom of the wall were found to be much lower than that for the top of the wall (by perhaps 20°C), and given in the uppermost plot; the lower temperatures in the bottom plot were considered inaccurate and consequently, in the middle plot it was deemed appropriate to use the values for temperature obtained from the top of the wall as given in the uppermost plot. The middle plot thus provides values of RH on the surface of the OSB towards the bottom of the wall; this location (marked with an X) is shown in the schematic of the test specimen to the right of each plot.

The propensity for the growth of mold at the top or bottom of the wall is shown in the lower most plot of Figure 11, in which is given the mold index value as a function of the monitoring period, in days. The mold index value is based on a mathematical relationship developed by Viitanen et al. [7, 8, 9] in which values for RH and T and information on the type of surface onto which mold may grow permits establishing the susceptibility to mold growth; values for mold index may range between 0 and 6, where 0 represents no mold growth and 6, very heavy (100% coverage) and tight growth. Its application to providing information on wall performance is more fully described in [6].

It is perhaps apparent that the RH (blue lines) at both the top and bottom locations in the wall experienced levels of RH ranging between 50 and 60% during period A, whereas these levels during period B increase significantly. Recalling that period B of the test protocol (see Table 2) was one where purposely placed deficiencies in the wall were open to permit the passage of warm air (21°C) from the interior and through the wall to the exterior. The RH in these instances attained ca. 85% RH at the top of the wall (uppermost plot) and ca. 100% RH (middle plot) at the bottom of the wall, suggesting that with a sufficiently low temperature, condensation could readily occur on the surfaces of the OSB. The values of T used to calculate the mold index are the same as those given in the uppermost plot (top off the wall) for reasons previously explained; these values range from -20 to 0°C.

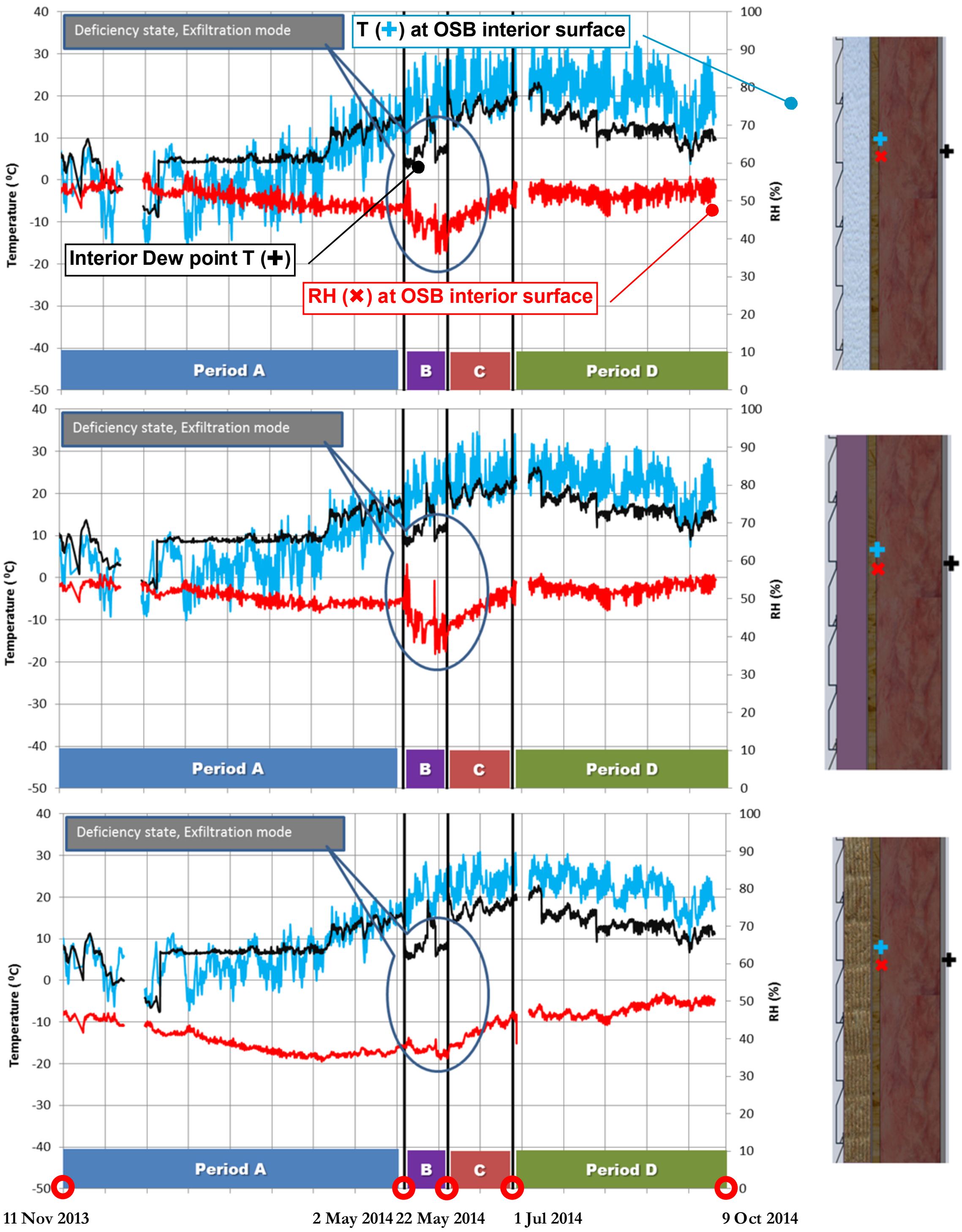

Figure 10 – Response of respective wall assemblies (Temperature [T]; RH at interior OSB surface and dew point T) over monitoring period (2013/14); (i) W1 (EPS); (ii) W2 (XPS); (iii) W3 (Mineral fibre)

Thus condensation could occur at these locations, and this is evident from the information provided in **Figure 14** in which is shown the response of electrical resistance to the presence of moisture at locations provided in the figure. The response of the moisture detection strips to the presence of moisture is marked with a decrease in electrical resistance which manifests itself by an increase in the value for conductivity. The increase in values for conductivity during period B denote the presence of condensation whereas the dissipation of moisture from the same locations in Period C is evidence from decreases in values over time; no moisture detected in Period D. This implies that all moisture that was deposited in the wall over this period could readily dissipate from the wall assembly.

In resepct to the risk for mold growth, given the low temperatures on the wall surface, and moreover that mold does not grow at temperatures below 0°C, the propensity for mold growth during Period B was nil. However, as the temperature at these locations increased over Period C, the susceptbility to mold growth at these locations likewise increased, although, given the ever decreasing level of RH over the same period, the mold index values considerably abated in Period C. Overall, the susceptibility to mold growth in this wall was low.

Response of W5 (SPF) — The response of W5 is provided in plots of relative humidity and temperature (RH & T) as a function of the monitoring period in days as provided in **Figure 12**; as before, periods A to D are highlighted at the base of the figure. The uppermost and middle plots of **Figure 12** represent the RH (blue color) and T (red colour) on the surface of the interior side of the OSB, respectively, at approximately mid-height and towards the bottom of the wall; both these locations (marked with an X) are shown in the schematic of the test specimen to the right of each plot. The propensity for the growth of mold at the top or bottom of the wall is shown in the lowermost plot of **Figure 12**, in which is given the mold index value as a function of the monitoring period, in days.

As was the case for W4, the RH at both the top and bottom locations in test specimen W5 experienced levels of RH ranging between 35 and 65% during period A, whereas these levels during period B, again, increased significantly. In period B, values of RH attained upwards of 85% at the bottom location and 95% at the top location; the corresponding temperatures were again quite low, reaching -20°C. As such, the propensity to the formation on condensation was high although whereas the risk to the formation of mold low.

The information provided in **Figure 15** shows the response of electrical resistance to the presence of moisture at locations provided in the figure. The increase in values for conductivity during period B denote the presence of condensation whereas the dissipation of moisture from the same locations in Period C is evident from decreases in values over time; no moisture detected in Period D as was the case for W4. This implies that all moisture that was deposited in the wall over this period could readily dissipate; this is the same response as was found for W4.

The risk to the growth of mold diminished over period C irrespective of the increase in temperature over this period and the subsequent period of monitoring. Overall, the susceptibility to mold growth in this wall was low.

Response of W6 (CFI) — The response of W6 is provided in plots of relative humidity and temperature (RH & T) as a function of the monitoring period in days as provided in Figure 13; as before, periods A to D are highlighted at the base of the figure. The uppermost and middle plots of Figure 13 represent the RH (blue color) and T (red color) on the surface of the interior side of the OSB, respectively, at approximately mid-height and towards the bottom of the wall; both these locations (marked with an X) are shown in the schematic of the test specimen to the right of each plot. The propensity for the growth of mold at the top or bottom of the wall is shown in the lower most plot of Figure 13. Figure 11, in which is given the mold index value as a function of the monitoring period, in days.

As for W4 and W5, the RH at both the top and bottom locations in test specimen W6 experienced levels of RH ranging between 60 and 70% during period A, whereas these levels during period B, increased, although not as significantly as was the case for W4 and W5. In period B, values of RH attained upwards of 85% at the bottom location and 75% at the top location; the corresponding temperatures in Peiord B were again quite low, reaching -20°C. As such, the propensity to the formation of condensation was high although the risk to the formation of mold low.

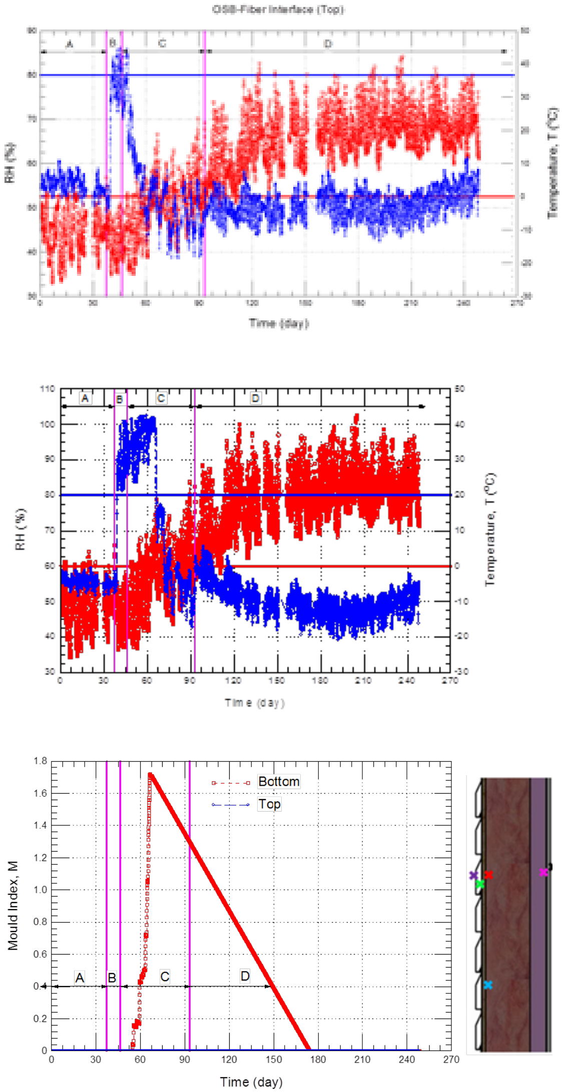

Figure 11 – Response of test wall W4 (XPS) to local weather of Ottawa (ON), Canada – having a nominal R-value of R33;

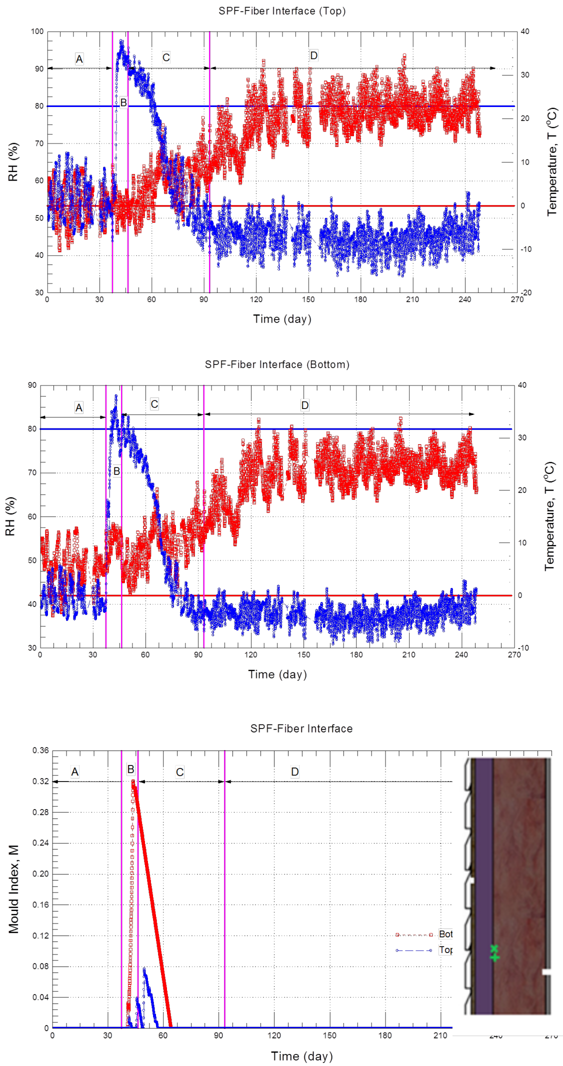

Figure 12 – Response of test wall W5 (SPF) to local weather load of Ottawa (ON), Canada – having a nominal R-value of R42;

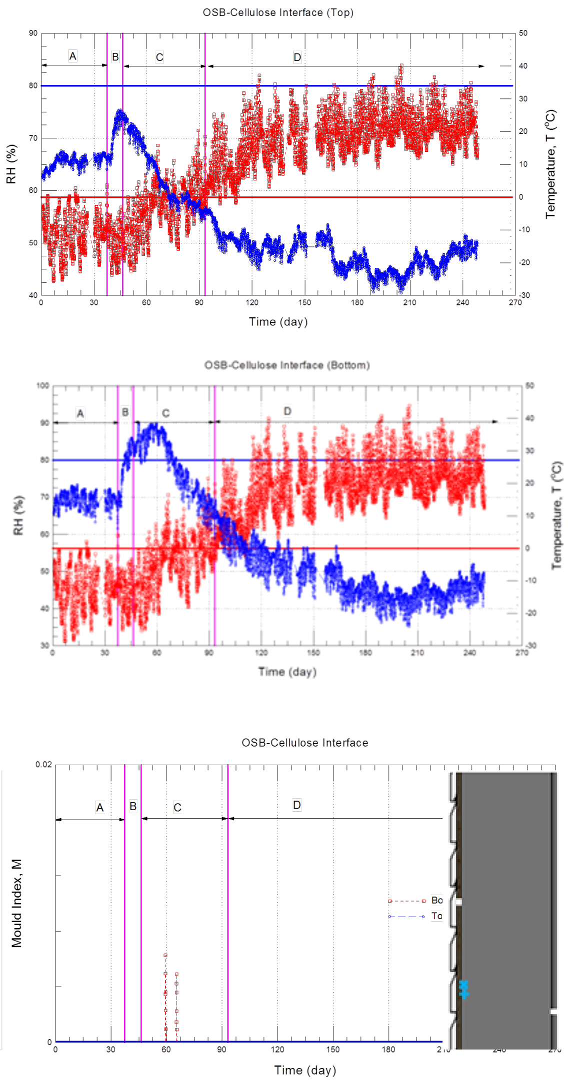

Figure 13 – Response of test wall W6 (CFI) to local weather of Ottawa (ON), Canada – having a nominal R-value of R40;

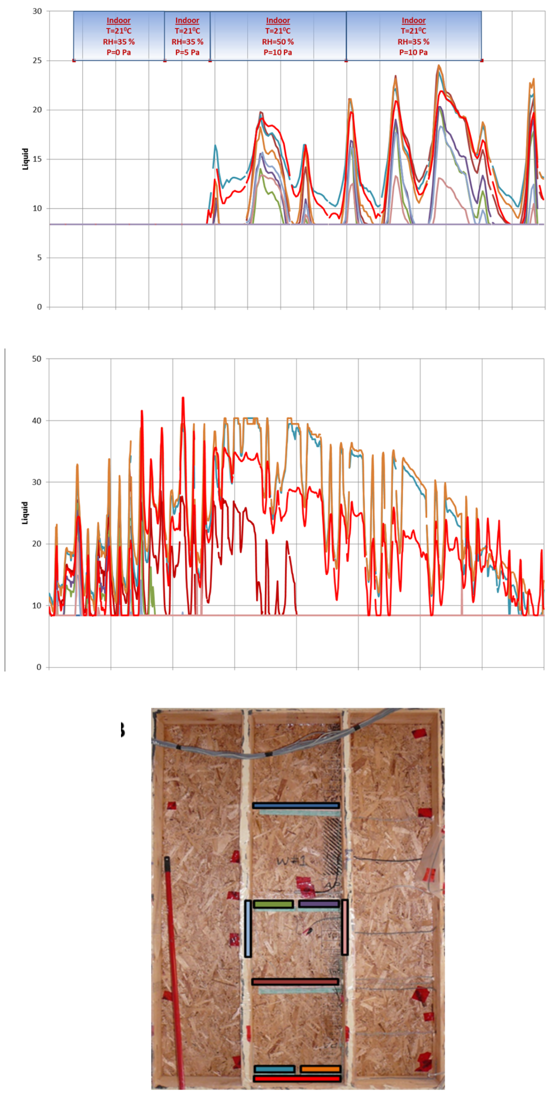

Figure 14 – W4: Response of moisture detection strip to the presence of moisture in the wall

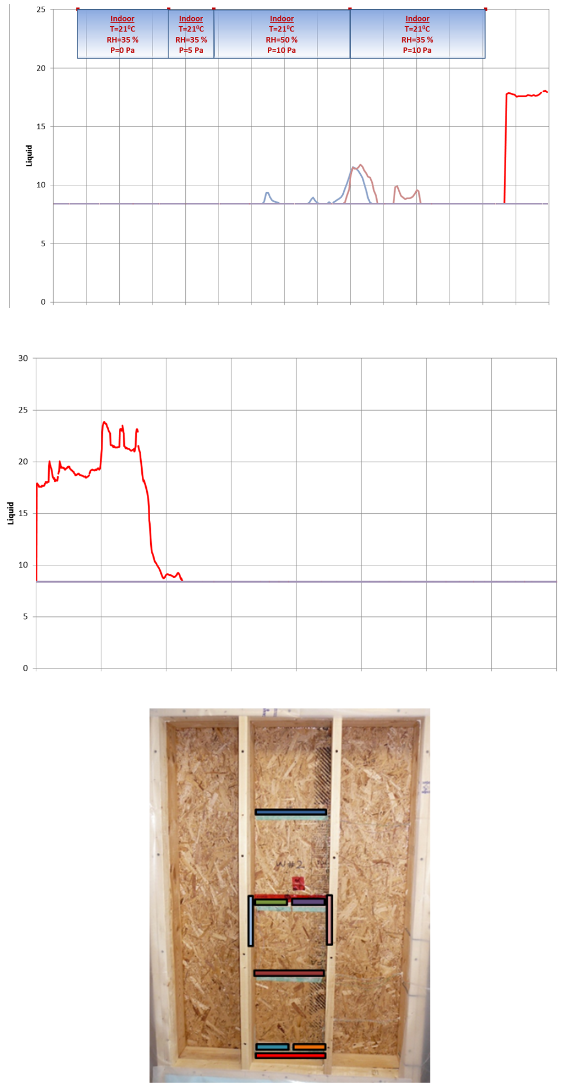

Figure 15 – W5: Response of moisture detection strip to the presence of moisture in the wall

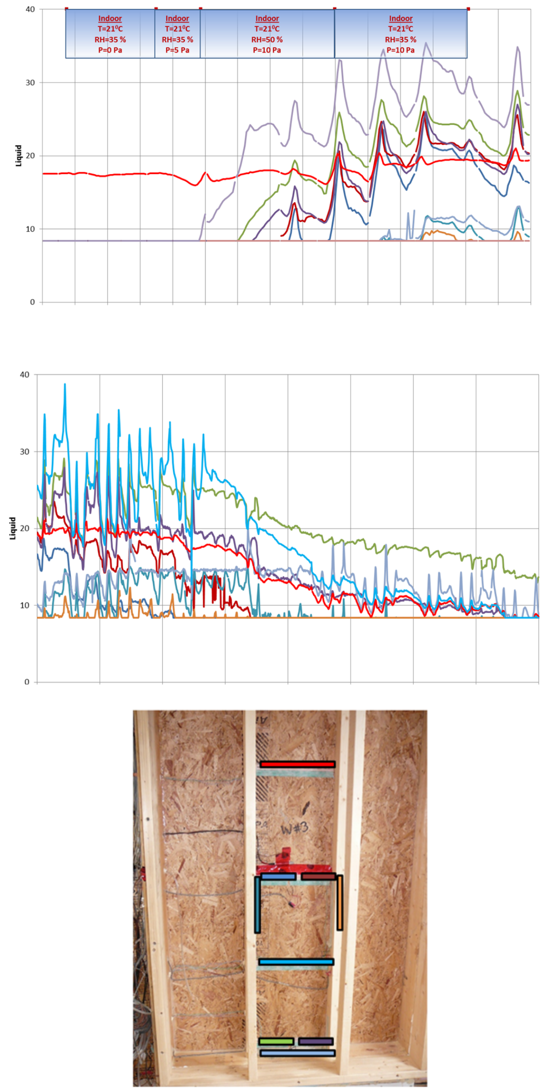

Figure 16 – W6: Response of moisture detection strip to the presence of moisture in the wall

The information provided in **Figure 16** shows the response of electrical resistance to the presence of moisture at locations provided in the figure. During period B the increases in values for conductivity denote the presence of condensation; this is a similar response as that detemend fro W4 and W5. The dissipation of moisture from the same locations in Period C is evident from decreases in values over time; no moisture detected in Period D as was the case for W4 and W5. Again, all moisture deposited in the wall over this period could readily dissipate indiciatvie of the same response as was found for W4 and W5.

The risk to the growth of mold diminished over period C irrespective of the increase in temperature and RH over this period and the subsequent period of monitoring. Overall, the susceptibility to mold growth in this wall was low.

SUMMARY OF RESPONSE OF WALL ASSEMBLIES - PHASES 1 AND 2

The hygrothermal response of 6 highly insulated wood frame wall assemblies Phase, a summary of which is provided in Figure 17, was monitored over a two year period (June 2013-September 2015) to determine whether any of these walls were susceptible to moisture problems as might accrue from inadvertent condensation in the wall assemblies. The walls were subjected to local climate conditions of Ottawa, Canada. To determine the vulnerability of the wall assembles and to assess their robustness to moisture ingress from air leakage, all assemblies were configured to include

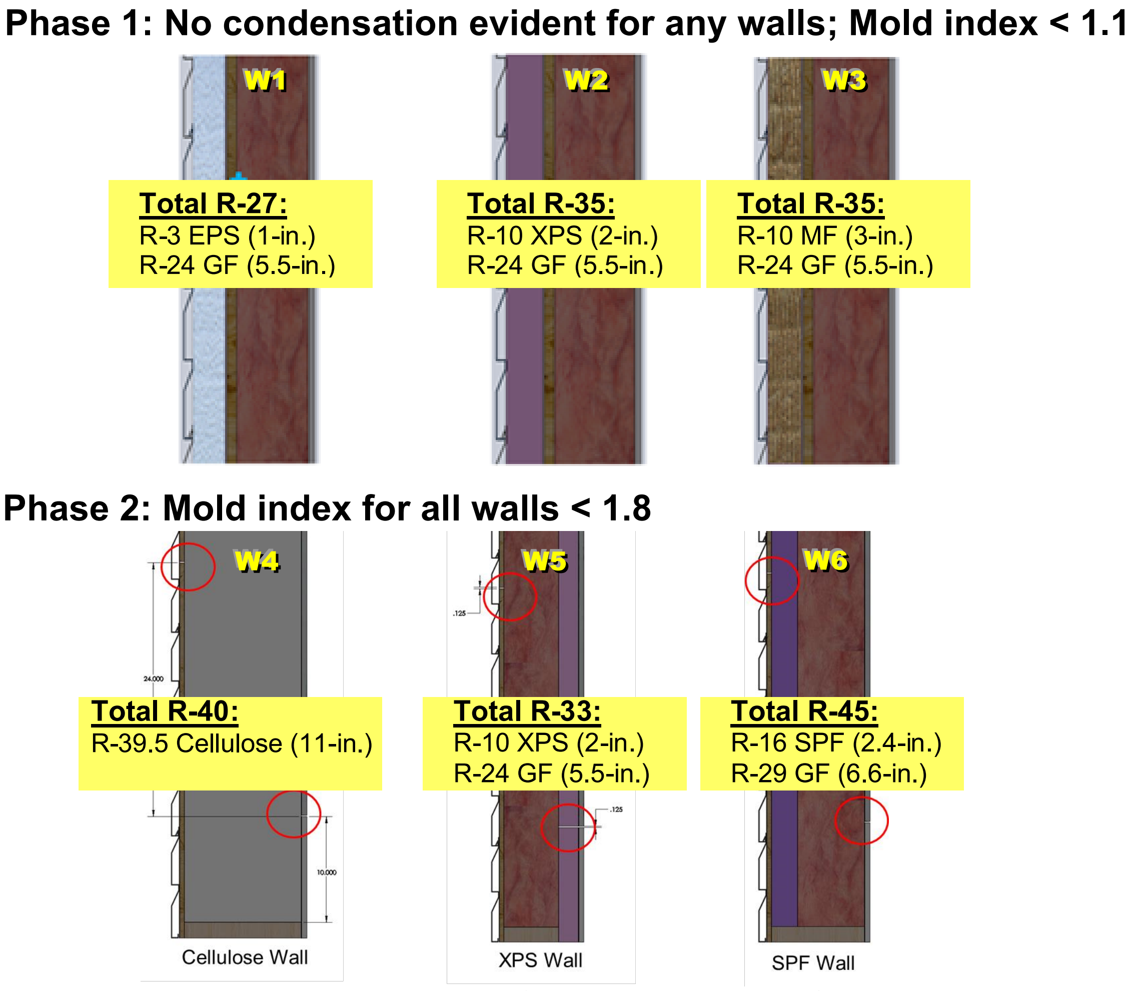

Figure 17 – Summary of Response of Wall assemblies - Phases 1 (W1-W3) and Phase 2 (W4-W6); EPS: Expanded polystyrene; XPS: Extruded polystyrene; GF: Glass fibre; MF: Mineral Fibre; SPF: Spray Polyurethane foam

openings in the air barrier and exterior sheathing paneled to permit the passage of air exfiltration from or infiltration to an interior conditioned enclosure.

Results from this study show that in instances where openings for air leakage exists, there is a risk to condensation in wall assemblies; however, this risk is mitigated by the low risk to the formation of mold (Viitanen mold index value less than 1.8 [6]) given the very low temperatures that exist on the interior surface of the exterior OSB sheathing panel and as well, the ability for moisture to dissipate from within the wall in a period of 2-3 months should moisture be present within the wall.

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REFERENCES

1. Canadian Housing Observer 2014, Canada Mortgage and Housing Corporation, 132p.
2. Canada's Emissions Trends, 2013, Environment Canada, October, 71 p.
3. Lacasse, M. A., Saber, H.H., G. Ganapathy and M. Nicholls, "Evaluation of Thermal and Moisture Response of Highly Insulated Wood-Frame Wall Assemblies ─ Phase 1 and Phase 2: Experimental trials in Field Exposure of Walls test Facility"; Report No. A1-000444.5; NRC-Construction, National Research Council of Canada, Ottawa, Canada; 12 January, 2016.
4. ASTM Designation: C 1130-07, "Standard Practice for Calibrating Thin Heat Flux Transducers", Annual Book of ASTM Standards; Construction, vol. 04.06, Thermal Insulation; Building & Environment Acoustic, pp. 577-584, 2009.
5. ASHRAE. 2009. 2009 ASHRAE Handbook –Fundamentals (SI), Chapter 26, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc.
6. Saber, H. H. and Ganapathy, G., "Evaluation of Thermal and Moisture Response of Highly Insulated Wood-Frame Wall Assemblies — Phase 1; Part II: Numerical Modelling"; Report No. A1-000444.4; NRC-Construction, National Research Council of Canada, Ottawa, Canada; 12 January, 2016; 83 p.
7. Viitanen, H.A., and Ojanen, T., "Improved model to predict mold growth in building materials" Proceedings of Thermal Performance of the Exterior Envelopes of Whole Buildings X, 8 p., 2007.
8. Hukka, A., and Viitanen, H.A., "A mathematical model of mold growth on wooden material, Wood Science and Technology", vol. 33 (6), pp 475-485, 1999.
9. Ojanen, T., Viitanen, H.A., Peuhkuri, R, Lähdesmäki, K., Vinha, J., and Salminen, K., "Mold Growth Modeling of Building Structures Using Sensitivity Classes of Materials", 11th International Conference on Thermal Performance of the Exterior Envelopes of Whole Buildings XI (Clearwater, (FL), USA, December-05-10), 10 p., 2010.