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AN OVERVIEW OF STUDIES TO ASSESS THE THERMAL AND HYGROTHERMAL PERFORMANCE OF HIGHLY INSULATED AND ZERO ENERGY READY WALL ASSEMBLIES

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ABSTRACT

A key component of energy efficient homes in the ever challenging climate of Canada is the highly insulated and well-designed wall assembly. Over the years, residential walls have been constructed using increasingly more insulation. The increased levels of insulation have offered a major opportunity to reduce heat losses in homes thereby significantly improving their energy efficiency and have thus permitted compliance with requirements for high performance housing standards such as those for ENERGY STAR, R-2000, Net-Zero Energy Ready homes and homes conforming to the Passive House Canada concept. However given the use of higher insulation levels, homebuilders face many challenges with the issues that arise from changes in traditional construction practice, in the case of this paper being concerned with the overall moisture performance, and hence durability, of wall assemblies. Canadian building code authorities also require proven evidence that highly insulated wall systems will not be adversely affected by increases to insulation levels given the many different Canadian climates in which they are expected to perform over the long term. Building code authorities are also concerned with the possible effects of climate change on building design, and consequently, there is a growing need for information related to the resilience of wall assemblies for use in high performance housing and small buildings. Several studies have been undertaken in recent years to demonstrate the thermal and hygrothermal performance of highly insulated wood frame wall assemblies and to determine whether these walls perform as well as or better than NECB compliant walls when subjected to Canadian climate extremes.

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In this paper, an overview is provided of research studies focused on the performance assessment of highly insulated wall assemblies whose thermal performance may range, for example, from an effective RSI of 4.8 to RSI 7.9, and that may be useful both to homebuilders and building practitioners. The studies examined include both the results from field experimental work of full-scale wall assemblies as well as those obtained from detailed hygrothermal modelling and parametric simulation studies. Field work is useful in evaluating the risk of formation of condensation in walls when subjected to local climate conditions and benchmarking hygrothermal simulations to known conditions. The results of simulation studies permit assessing the risk to the formation of condensation, mold and wood rot, given the hygrothermal response of the walls to climate conditions as may occur in the different climate zones within Canada. The robustness and resilience of the respective wall assemblies is discussed in light of the use of various insulation product types (e.g. fibreglass, mineral wool, XPS, EPS, dense-pack cellulose, wood fibre) of which the different wall assemblies were comprised.

INTRODUCTION

Over the years, the energy efficiency of the North American housing stock has significantly improved due mainly to higher insulation levels, more efficient windows and, more importantly, adoption of various energy efficiency measures by building codes. For most of the Canadian climate conditions, the thermal resistance (R value) increase is of paramount importance, since heating and cooling of buildings in Canada is estimated to account for up to 17% of national GHG emissions [19]. 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 heating and cooling losses and thereby significantly reduce space heating/cooling loads. However, highly insulated wall assemblies present challenges to the wall assembly, including assessing the durability of products by determining the effect of higher insulation levels on the overall moisture performance and expected long-term performance of the building envelope. A barrier to the uptake of highly insulated homes is the limited amount of proven evidence of reliable thermal and moisture performance of highly insulated homes as might be achieved in various climates of Canada.

Net Zero Energy Homes

There are numerous definitions for net-zero homes, whether or not embodied energy is also considered. Natural Resources Canada (NRCan) defines a net-zero energy home as a home that on an annual basis generates as much energy as it consumes. At present the ‘task’ of generating energy is usually carried out on site with the use of solar photovoltaic arrays that can be installed on the walls of the homes (additionally function as simultaneous shading devices), on roofs, or on a structure that is not attached to home

To evaluate whether homes are net-zero ready, the NECB performance path of compliance is used, instead of the prescriptive path. Two homes having the same location (i.e. nominally the same levels of solar irradiance, temperature, and shading) and both with identical wall assembly R-values can differ considerably in energy generation simply due to the geometry and orientation of the building. Houses with satisfactorily large south-facing walls and roofs can accommodate a photovoltaic (PV) array of 12kW (above 80m^2 of total PV area) or larger, whereas houses with many small roof and wall areas would allow for employment of, for example, only a 5kW PV array with some 35m^2 of the roof area [18]. The energy production and comparison of energy generation vs. consumption would then be substantially more favourable in the case of the larger solar array and for the smaller solar array would likely not allow the building to meet net-zero requirements. Simple calculations for homes with walls of differing R-value and incorporating different sizes of PV arrays are presented in Table 1. It can be observed that in this example a home having R30 for wall thermal insulation in Ottawa and a PV array size of 10kW would not meet NRCan criteria for a net-zero home; however, the home having R40 for wall insulation would approach these limits (e.g. energy deficit ~1.6 MWh/year); whereas the R50 home would indeed meet the criteria (e.g. energy deficit: -1.4 MWh/year). Similarly for Vancouver; R40 and R50 homes would meet net-zero requirements with a reasonably sized 10kW PV array (i.e. energy deficit -0.9 and -3.1 MWh/year respectively for R40 and R50 homes). The information given in these tables clearly indicate the importance of reducing the energy use of homes through increasing the thermal resistance of the building envelope, even before considering installing a PV array.

Table 1 Example of simplified calculation based on energy generation from a PV array and energy consumption based on wall thermal insulation

Wall thermal insulation	**Energy consumption, MWh/year**		**Energy generation, MWh/year**		**PV array**	**Net energy deficit MWh/year**	
m^{2}K/W	Ottawa	Vancouver	Ottawa	Vancouver	kWDC	Ottawa	Vancouver
3.5 **(R30)**	18.5	13.2	6.2	5.5	5	12.3	7.7
7.0 **(R40)**	14.0	10.1	12.4	11.0	10	1.6	(0.9)
8.8 **(R50)**	11.1	7.9	24.7	21.9	20	(13.6)	(14)

Additionally, irrespective of the selection of a specific combination of PV array and wall thermal resistance that permits attaining net zero energy thresholds for a home, there is nonetheless a functional requirement that the overall hygrothermal performance of the building envelope be maintained over the long-term, both for energy conservation over the service life of the building, as well as durability of the structure and safety and health of the occupants.

Assessing Hygrothermal Performance – Overview of Field Experiment and Numerical Simulation

The National Research Council of Canada (NRC) in collaboration with Natural Resources Canada (NRCan), the Canada Mortgage and Housing Corporation (CMHC) and the Canada Wood Council (CWC) undertook, over a 3 year period, a project to develop information on the moisture and thermal performance of progressively higher insulated wood-frame wall assemblies. The information was 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 the 2030 net-zero energy ready 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 (Energy Guide rating: EGH-83 and 86) that are practical, buildable, durable, energy efficient and affordable.

To achieve these objectives, the project focused on investigating the hygrothermal response of a series of thermally enhanced wood-frame walls with higher levels of insulation from that of the National Building

Code minimum (RSI 3.3 – 4.1) to net-zero energy or net-zero energy ready performance levels (i.e. RSI 7.0 – 7.9). Three consecutive years of field experiments were conducted whereby for each year a set of 3 wall assemblies, each of different configuration and thermal resistance, were monitored over a 9-10 month period starting in the winter months (December). During the monitoring period, sensors within the respective wall assemblies permitted determining, temperature (T), relative humidity (RH) and heat flux at specific locations in the wall assemblies. Moisture sensors were also used to determine the presence of liquid moisture as might have arisen due to condensation of moisture on the surface of wall components within the wall assembly. The results of each experimental study period were also used to benchmark results from hygrothermal simulation model of the same assemblies. The benchmarked hygrothermal model was used to conduct a parametric study in which the risk of condensation in the wall assemblies was investigated for four other locations across Canada. The locations were selected as representative of the various climate zones as occur in Canada, and to simulate the hygrothermal response of the wall assemblies when subjected to conditions of the different climate zones present in Canada. As such and over a 3-year period, a set of nine (9) wall assemblies with different types and levels of insulation systems were evaluated in respect to their hygrothermal performance.

In this paper, information is provided on construction details for each of the 9 wall assemblies investigated, the experimental set-up to assess the hygrothermal response of the walls to local ambient conditions in Ottawa, and the hygrothermal simulations that were completed to benchmark the model and to undertake the parametric analysis. Thereafter, selected results are provided for both the experimental work and the parametric analysis. The risk to the formation of condensation in wall assemblies having enhanced levels of wall insulation is briefly discussed in light of requirements for achieving net zero energy homes across the many different climate zones of Canada.

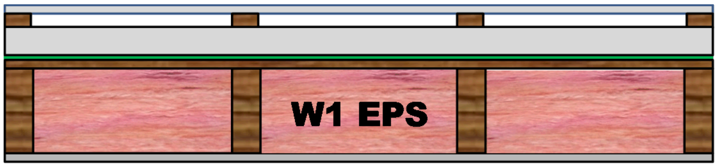
CONFIGURATION OF HIGHLY INSULATED WALL ASSEMBLIES

A description of the configurations of the nine (9) wall assemblies studied in this project is provided in Table 2 that also includes the nominal thermal resistance of each of the walls. It can be seen that values for thermal resistance varied from RSI (m^2K/W) 4.8 (Wall 1) to a high of RSI (m^2K/W) 7.9 (Wall 6). Common wall elements to all assemblies included the exterior cladding (vinyl siding), sheathing membrane (spun-bonded polyolefin), and the interior finish (½ in. painted gypsum drywall panel). All other elements varied in relation to the nominal requirements for insulation and interest in evaluating the position of highly insulated wall assemblies having novel wood-based wall components.

The first three walls (W1-W3) were representative of a typical 50 x 150 mm (2 x 6-in.) wood stud frame in which was placed RSI 4.2 (m^2K/W) | R24 glass-fibre batt insulation and that would be retrofitted to achieve a minimum level of thermal insulation for above-grade walls and for a range of EnerGuide 80 compliance packages. As such, the base-wall of Wall 1 was overlaid with 25 mm (1-in.) of EPS insulation to yield an effective RSI of 4.8 (m^2K/W); Wall 2 had 51 mm (2-in.) of XPS insulation overlay the base-wall to achieve RSI 6.2 (m^2K/W), and; Wall 3 had 76 mm (3-in.) of semi-rigid mineral fibre insulation overlay the base-wall to achieve RSI 6.2 (m^2K/W).

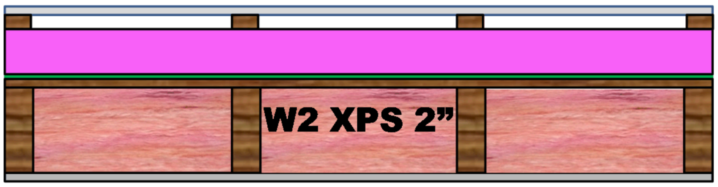
The second set of 3 walls (W4-W6) had values for thermal insulation, ranging from RSI 6.0 to 7.6 (m^2K/W). In this instance, W4 was a typical 50 x 150 mm (2 x 6-in.) wood stud frame wall with glass

Table 2: Wall Assembly configurations evaluated



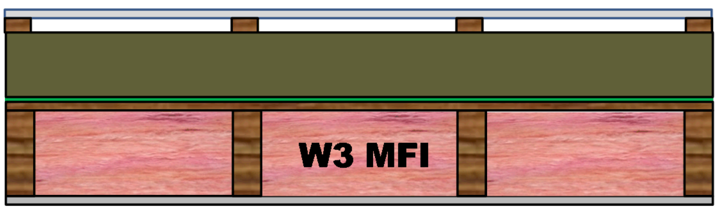
RSI | **4.8 [m^2K/W]**
R-value | **27 [hr-ft^2-°F/BTU]**

- Vinyl siding
- 1.5-in. x 7/16" thick vertical furring strips
- **25 mm (1-in.) EPS rigid foam insulation (exterior insulation)**
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x6-in. nominal stud cavity with R24 glass fiber insulation batts
- 6 mil poly air/vapour barrier
- ½ in. painted drywall



RSI | **6.2 [m^2K/W]**
R-value | **35 [hr-ft^2-°F/BTU]**

- Vinyl siding
- 1.5 in wide x 7/16" thick vertical furring strips
- **51 mm (2 in.) XPS rigid foam insulation (exterior insulation)**
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x6-in. nominal stud cavity with R24 glass fiber insulation batts
- 6 mil poly air/vapour barrier
- ½ inch painted drywall

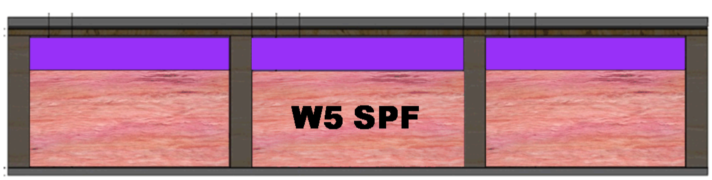


RSI | **6.2 [m^2K/W]**
R-value | **35 [hr-ft^2-°F/BTU]**

- Vinyl siding
- 1.5-in. x 7/16" thick vertical furring strips
- **76 mm (3-in.) semi-rigid mineral fibre insulation (exterior insulation)**
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x6-in. nominal stud cavity with R24 glass fiber insulation batts
- 6 mil poly air/vapour barrier
- ½ in. painted drywall

RSI | **6.0 [m^2K/W]**
R-value | **34 [hr-ft^2-°F/BTU]**

- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x6-in. nominal stud cavity with R24 glass fiber batt insulation
- **51 mm (2 in.) XPS rigid foam insulation**
- 6 mil poly air/vapour barrier
- ½ in. painted drywall

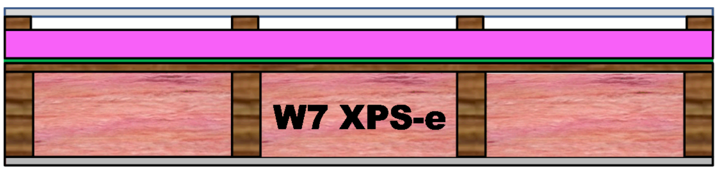


RSI | **7.9 [m^2K/W]**
R-value | **45 [hr-ft^2-°F/BTU]**

- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x10-in. nominal stud cavity
- In Stud cavity
  - **~ 2-in. Spray polyurethane foam insulation**
  - ~ 7-in. R24 glass fiber batt insulation
- 6 mil poly air/vapour barrier
- 12.5 mm (½-in.) painted drywall (gypsum board)

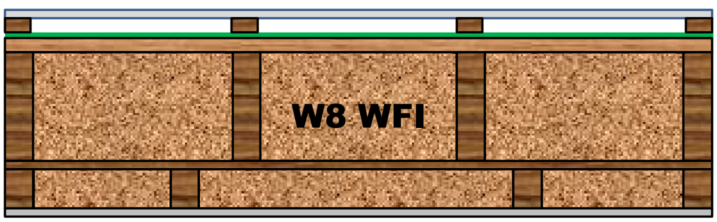
- Vinyl siding
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 2x12-in. nominal stud cavity with R3.5/in. X 11-in. =
- **R39 cellulose fiber insulation**
- 6 mil poly air/vapour barrier
- ½ in. painted drywall

RSI	**7.0 [m²K/W]**
R-value	**40 [hr-ft² -°F/BTU]**



- Vinyl siding
- 3x0.75-in. nominal vertical furring strip (actual 2.375-in. wide and ¾-in. thick)
- 1-in. XPS rigid foam insulation (R5)
- Sheathing membrane
- 11 mm OSB wood-sheathing
- 1.5x5.5-in. nominal wood stud cavity
- R24 glass fiber batt insulation for 6-in. cavity
- 6 mil poly air/vapour barrier
- ½-in. painted drywall

RSI	**5.1 [m²K/W]**
R-value	**29 [hr-ft² -°F/BTU]**



- Vinyl siding
- 3x0.75-in. nominal vertical furring strip (actual 2.375-in. wide and ¾-in. thick)
- Sheathing membrane
- 24mm Diffusion board
- 1.5x9.13-in. nominal wood stud cavity
- Wood fibre insulation for 10-in. cavity
- 11 mm OSB wood-sheathing; joints taped
- 1.5x3.5-in.studs (Service wall interior)
- Wood fibre insulation for 4-in. cavity
- ½-in. painted drywall

RSI	**7.6 [m²K/W]**
R-value	**43 [hr-ft² -°F/BTU]**

- Vinyl siding
- 3x0.75-in. nominal vertical furring strip (actual 2.375-in. wide and ¾-in. thick)
- 1-in. XPS rigid foam insulation (R5)
- 1.5x5.5-in. nominal wood stud cavity
- R24 glass fiber batt insulation for 6-in. cavity
- 11 mm OSB wood-sheathing; joints taped
- ½-in. painted drywall

RSI	**5.1 [m²K/W]**
R-value	**29 [hr-ft² -°F/BTU]**

fibre batt insulation in the stud cavity to which 51 mm of XPS was added to the inside of the wall (as opposed to W2 where the XPS was placed to the outside) to achieve a RSI of 6.0 (m²K/W); Wall W5 was a novel use of 50 x 254 mm (2 x 10-in.) wood stud frame in which was placed 50 mm of spray polyurethane foam over which was installed glass fibre batt insulation attaining a RSI of 7.9 (m²K/W); Wall W6, also a novel design, having a 50 x 305 mm (2 x 12-in.) wood stud frame in which was placed several layers of cellulose fibre insulation to obtain a RSI of 7.0 (m²K/W).

The final set of 3 walls had values for thermal insulation, ranging from 5.1 to 7.6 RSI (m²K/W); Wall W7 and W9 were essentially the same construction, the difference being for Wall 9 in the use of an 11 mm OSB wood sheathing panel in lieu of a polyethylene membrane to act as a vapour barrier; in wall W8 wood fibre insulation imported from abroad was used and a wood fibre 24 mm “diffusion board”, also imported, was used as an exterior sheathing panel. For wall W8, there was interest by the stakeholders in knowing whether wood fibre products of the type used in this wall assembly had merit for use in Canadian homes.

FIELD EXPERIMENTS

These wall specimens were installed in a side-by-side test bay of the NRC-Construction's Field Exposure of Walls test facility (FEWF); they were instrumented with pressure, temperature, relative humidity, and moisture sensors in various locations throughout the assembly.

All the specimens were subjected to local climate conditions of Ottawa, Canada and conditions on the interior side of the test specimen were nominally maintained at 21°C and 35% RH.

At the start of the experimental evaluation, each wall assembly was subjected to conditions intended to increase the overall moisture content of the assembly by exfiltrating air through the wall. Increased moisture levels were induced to all specimens by pressurizing the building interior over a period of 3 to 4 weeks, and causing conditioned indoor air to exfiltrate through purposely created 3.5 mm deep slits in the interior finish and vapour barrier layers. The slits were then closed and the response of the respective specimens was monitored over a specified time period such that drying out of the cavities within the wall might be compared to moistening the assembly during the process of air exfiltration. Based on the results obtained for temperature and relative humidity, mould index calculations were completed for specific locations in each respective wall assembly considered to be susceptible to mould growth.

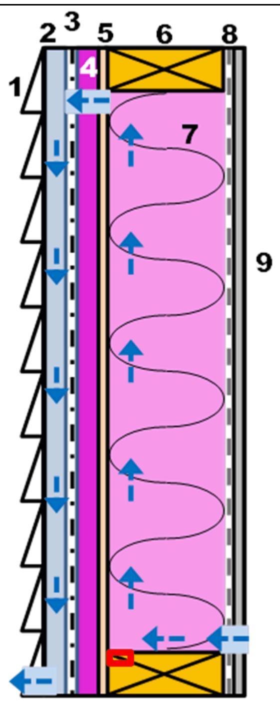
Figure 1 NRC's Field Exposure of Walls Test Facility (FEWF)

Figure 2: Example of test specimen showing instrumentation

HYGROTHERMAL SIMULATIONS

Model Benchmarking

As it was important to ensure that the results of the research were meaningful in all regions of Canada, the analysis was extended through the use of simulation tools to representative cities in the Atlantic, Prairie regions, the lower coastal mainland of BC, and in the North of Canada; an advanced hygrothermal modeling tool was used to conduct the hygrothermal simulations. The modeling tool (hygIRC-2D) was benchmarked against experimental data obtained from the results of the previously described field experiments. The numerical model was used to simulate exfiltration conditions for each wall assembly and to assess the risk to the formation of condensation in highly insulated wall assemblies. An example of the configuration path selected for air movement in the wall assemblies is shown in Figure 3. It should be noted that the air leakage path and areas assessed for mould growth differed slightly between wall assemblies. However, the overall evaluation method was the same: i.e., specific locations in each wall assembly were selected that would be at risk to the formation of condensation.



As Constructed	As Modeled	Label
Vinyl Siding (3mm)	Vinyl Siding (3mm)	1
19mm Strapping & air space	Airspace (19mm)	2
XPS (25mm)	XPS (25mm)	3
Sheathing membrane	Spunbonded Olefin (0.15mm)	4
OSB Sheathing (11mm)	OSB Sheathing (11mm)	5
Wood Studs (5.5in)	Pine (140mm)	6
R24 Glass-fibre insulation (Stud cavity insulation)	Low Density Glass Fibre (140mm)	7
6 mil poly air/vapour barrier	Polyethylene (0.15mm)	8
1/2in –painted drywall	Primed Gypsum (12.7mm)	9

Region of focus

Figure 3: Example of wall assembly configuration and wall details to permit benchmarking the numerical model

Parametric Analysis

Once the benchmarking of the modeling tool was completed, it was then used to investigate, given specific indoor conditions, the effect of different outdoor conditions, as may be found in the different regions of Canada, on the moisture and thermal performance of the wall assemblies. Locations used for this analysis were those of: Vancouver, BC, Yellowknife, NT, Edmonton, AB, and St. John's, NL.

The annual hygrothermal performance of all wall assemblies used in field experiments was evaluated by averaging the temperature and moisture content within the “region of focus”, selected as an area in the wall assembly which was considered to be at risk to the formation of condensation due to exfiltration air from the interior; the region of focus is marked in red in Figure 3. Wall performance for any given climate location was compared by calculating the response of the wall in the region of focus based on the average values of temperature and %RH derived from simulation in these areas, and from which the performance criteria based on mould growth was calculated; this is described by Hukka and Viitanen [9] and Viitanen and Ojanen [10], and the values calculated were referred to as either the: (i) RHT(92) index, or; Mould index (M).

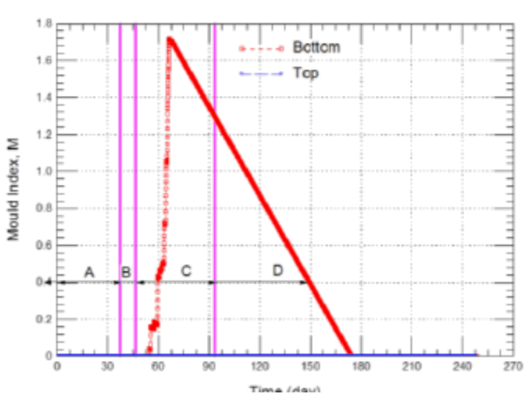
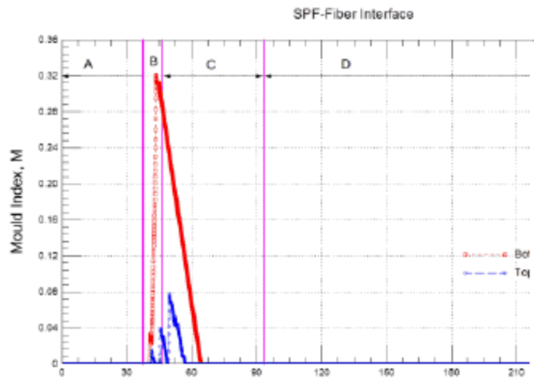
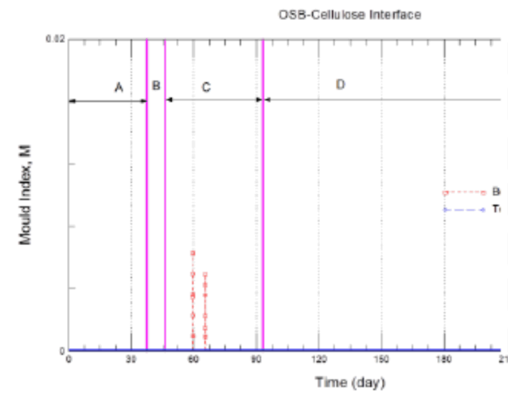
FIELD EXPERIMENT AND NUMERICAL SIMULATION RESULTS

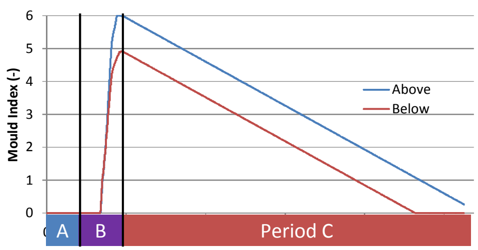
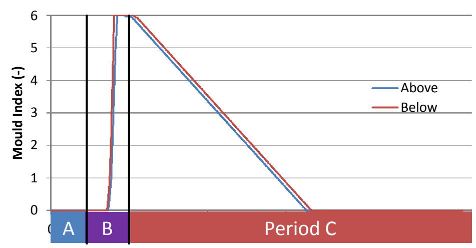
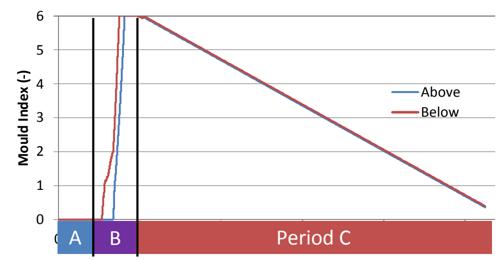
Field Experiment Results

Each wall assembly was evaluated in the experiment in terms of hygrothermal performance by the process of increasing the moisture content of the wall assembly. This was achieved by causing the exfiltration of interior and moisture laden air into the wall stud cavity through a purposefully made slit in the interior sheathing panel and vapour barrier. After this stage of exfiltration (ca. 3-4 weeks), the exfiltration process was ended and the wall sealed from the interior. Relative humidity and temperature were then monitored at critical areas in the wall assembly, considered to be at high risk to the formation of condensation and correspondingly at risk to the formation of mould or wood decay. The temperature and relative humidity results were monitored over time to determine the capacity of the wall to dissipate any moisture that had accumulated in the stud cavity over the exfiltration stage. The mould growth index was calculated in those regions in the wall based on the results of date acquired over this time period. The mould growth rate and its dissipation over time as calculated form the experiment results is shown for walls W4 to W9. Values for mould growth for walls W1 to W3 were not available as the facility was unable to create condensation in the stud cavity during this initial set of experiments. However, it should be noted that at no time over the course of the experiment for Walls W1 to W3 was condensation observed to occur in the wall assemblies, thus indicating that for Ottawa, these wall assemblies performed adequately under the imposed the environmental conditions to which they were subjected, regardless of the rating for their thermal insulation.

An analysis of all assemblies tested, with smaller differences in drying out rate between assemblies, confirmed the following overall trend: under common in–service conditions of Ottawa all assemblies performed well and the condensate that had accumulated over cold periods was readily able to dissipate during the subsequent warmer periods. Temperature runs and dew point calculations in these critical locations and for the entire range of R-values encompassed in these series of wall assemblies were very similar. The moisture accumulated over the initial set-up period dissipated at a greater rate for specimens having fibre-based thermal insulation (cellulose, wood and mineral fibre) and at a more moderate rate for wall incorporating XPS panels. The drying out time for the assembly with the EPS insulation was the longest. However, in each case the moisture dissipated over time, to which one would conclude that for the Ottawa conditions to which the walls were subjected, the wall assemblies were not susceptible to deterioration as might arise from the presence of condensation regardless of R-value of the wall assembly.

Table 3: Mold growth index for experiment results, Walls 4 - 9

Wall 4	Wall 5	Wall 6
		

Wall 7	Wall 8	Wall 9
		

Numerical Simulation Results

(1) Model benchmark

Data retrieved from a local NRC weather station was used to generate the climate file for benchmarking the numerical simulation. Given the source data, results of simulated temperatures within assemblies were entirely independent from field data as measured by temperatures sensors. The experimental and numerical model results were compared using the temperature at the location of focus in the wall assembly (e.g. below slit in OSB panel); an example of the temperature profile derived from the experiment and simulation is given in Figure 4.

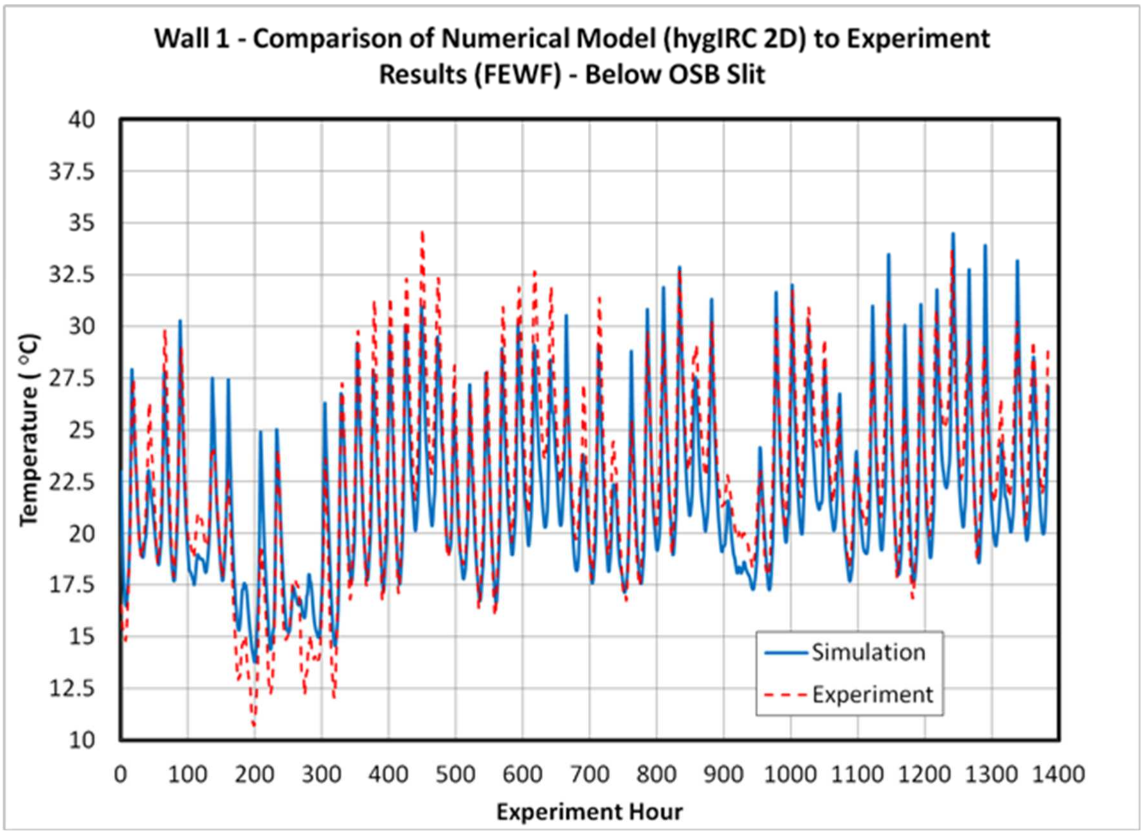


Figure 4: Example of a comparison between results obtained from simulation and that acquired from the experimental

(2) Parametric analysis

Subsequent to the comparison between experimental and numerical simulation results, the model was then used to determine the relative performance of wall assemblies when subjected to the climate of different locations across Canada, specifically: Ottawa, O.N., Vancouver B.C., Yellowknife, N.W.T., Edmonton, A.B., and St. John's, N.L. The performance of the wall assemblies was determined by using the average temperature and average relative humidity of the "region of focus" for each wall assembly to calculate the mold index value. The results for the average mould index and the maximum mould index determined for each wall assembly in each climate location are presented in Figure 5 **Error! Reference**

source not found. and Figure 6.

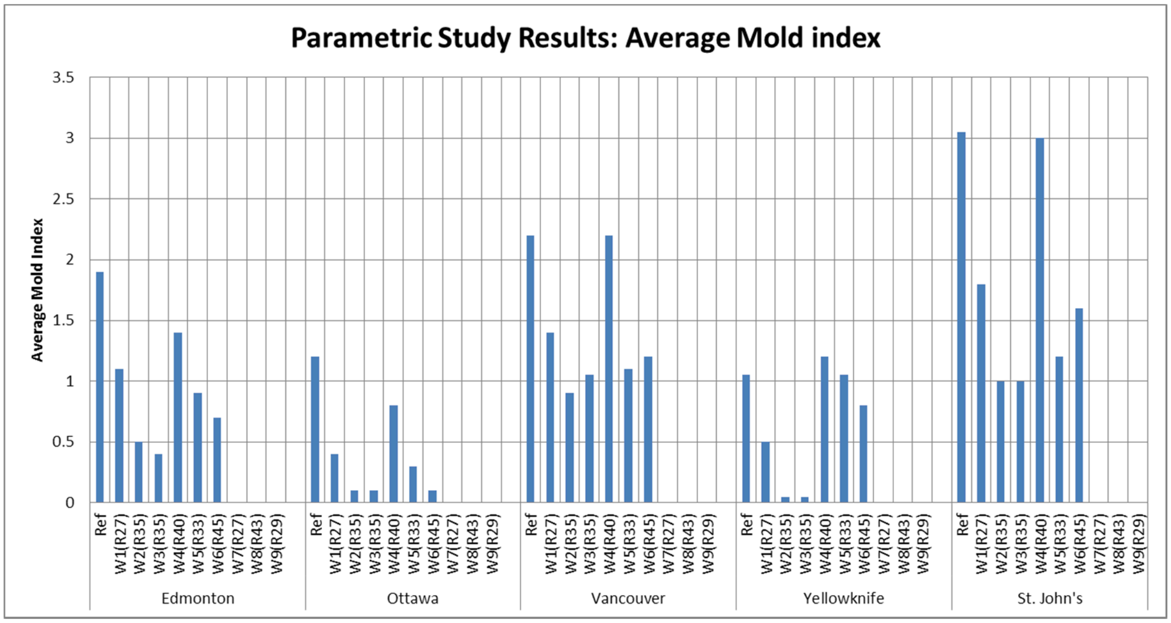


Figure 5: Parametric study results showing values for average mold index for all wall assemblies subjected to selected climate locations in Canada

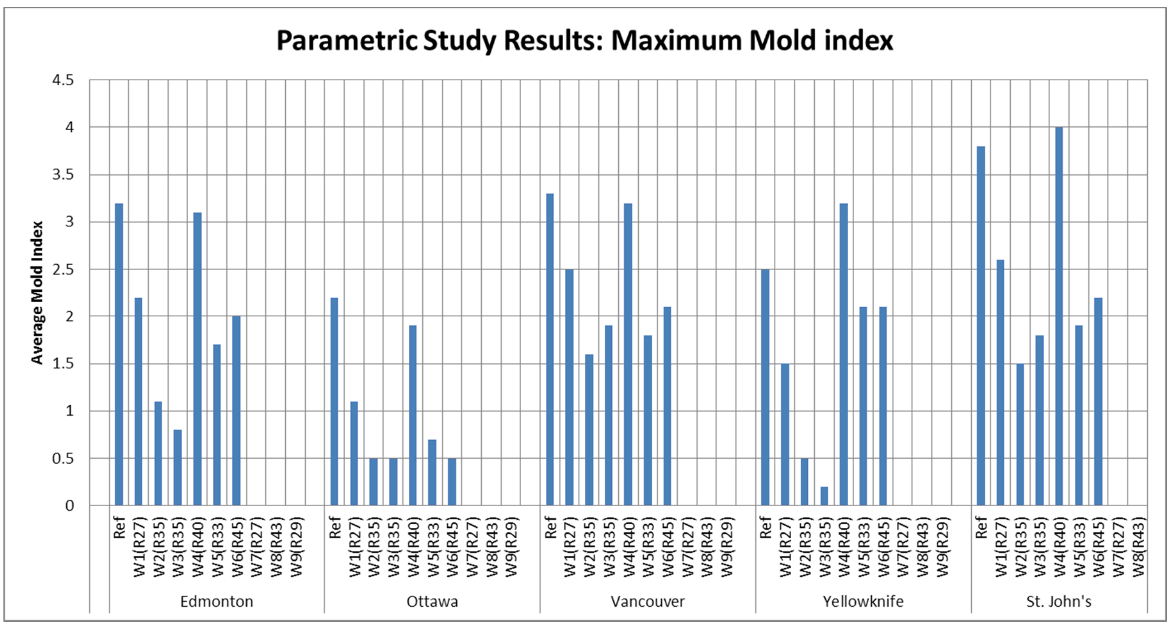


Figure 6: Parametric study results showing values for maximum mold index for all wall assemblies subjected to selected climate locations in Canada

Overall the results for mould index indicate that there is very little correlation between the risk to deterioration of the wall assembly, and the thermal resistance for that wall assembly. The results indicate that hygrothermal performance is generally more dependent on the selection of materials in the wall assembly and the ability of these materials to dry out given events in which condensation occur. In instances where air exfiltration from the interior and through the assembly is the main contributor to moisture ingress into the wall cavity, those wall assemblies having materials with a higher water vapour permeance are better at resisting the formation of mould growth than those with a comparatively lower water vapour permeance.

CONCLUSIONS

Increased energy efficiency code requirements result in utilizing wall assemblies with increased thicknesses of thermal insulation. This trend helps to achieve Canada's net-zero energy ready buildings plan by 2030, but it also creates concerns regarding durability of such wall assemblies due to possible moisture accumulation problems leading to premature structure deterioration. High R values wall assemblies with foam thermal insulations (EPS, XPS) as well as fibre insulations (cellulose, wood, mineral, glass) were examined at the NRC; experimentally for Ottawa, ON climatic conditions and numerically for other Canadian climatic conditions (Ottawa, O.N., Vancouver B.C., Yellowknife, N.W.T., Edmonton, A.B., and St. John's, N.L.).

Both, experimental and simulation results confirmed that highly insulated assemblies are capable of adequate thermal and hygrothermal performance ensuring buildings' expected longevity.

It can be summarized that mineral fiber based thermal insulation performs better in dry climates (Edmonton, Yellowknife) whereas XPS foam insulation outperforms if used in walls located in humid climates (Vancouver, St. John's).

It is perhaps self-evident to note that acceptable building performance is heavily dependent on the quality of workmanship. Even the best designed wall assembly having high quality materials will nonetheless fail prematurely if any given vapour or air barrier layer is not properly installed (continuous) and not adequately sealed. It is therefore prudent to establish a quality assurance protocol during construction to help prevent the occurrence of defective installation practices.

Simplified calculations of energy consumption as compared to energy generation in small homes helped confirmed that above ground wall assemblies having thermal insulation values ranging between R35 to R50 are capable of achieving a net-zero energy status for certain locations in Canada.

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