

Understanding Vapour Permeance and Condensation in Wall Assemblies

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ABSTRACT

The use of polyethylene vapour barriers is well integrated into building codes and the Canadian construction industry, a result of significant investment in research and training. Their use has resulted in significant improvement in building envelope air tightness when properly detailed. Contractors and inspectors have developed a strong understanding of the details and practices required to achieve tight and reliable enclosures.

However, some groups have expressed concerns that polyethylene vapour barriers may reduce drying and entrap moisture. In particular, problems have been encountered with below-grade walls where inward drying of initial construction moisture within the concrete foundation walls is trapped by polyethylene sheets. Problems have also been identified in above-grade walls where absorptive and non-ventilated claddings are employed.

A research program is currently underway to determine the significance/insignificance of potential moisture problems due to plastic sheeting in above-grade and below-grade wall assemblies. The research is aimed to outline cases where performance can be improved, and changes that could reduce inappropriate use. Finally, the research aims to address the benefits/risks with polyethylene sheeting with clearer delineation of the situations in which it is necessary, potentially damaging, and unimportant.

This paper presents key findings from the research work and field test results collected to date within the following framework:

- The literature review;
- Field testing of four common below-grade wall assemblies (with and without polyethylene sheeting) in a southern Ontario home;
- Field testing of six common above-grade wall assemblies (with and without polyethylene sheeting) in the University of Waterloo test exposure facility (BEGHut);
- Comparison of the field testing data and computer models, to provide validation of the model against this installation.
- Extending the test results to broader practice across Canada through computer modeling.

Future papers will provide more detailed analysis and computer model verifications after the project is complete.

1.0 INTRODUCTION

A research program is currently underway to determine the significance/insignificance of potential moisture problems due to plastic sheeting in above-grade and below-grade wall assemblies. The research is aimed to outline cases where performance can be improved, and changes that could reduce inappropriate use. Finally, the research aims to address the benefits/risks with polyethylene sheeting with clearer delineation of the situations in which it is necessary, potentially damaging, and unimportant. The concern in this research is low permeance interior vapour retarders. Polyethylene sheeting is the most common but other materials such as vinyl wallpaper are of interest and are referenced.

The goals of the literature review were to (1) determine where and under what conditions the use of plastic sheeting could cause failure or has been shown to cause problems; and (2) summarize potential adverse consequences if impermeable vapour barrier layers are omitted. A full CMHC report will be published with a comprehensive literature review. Excerpts of our review are as follows:

1.1. SUMMARY OF THEORY AND LITERATURE

- Inward vapour diffusion driven by solar heating of the exterior parts of walls has long (since the 1950's) been observed to cause damaging levels of condensation in Canadian walls (Hutcheon 1953).
- The incidence, severity, consequences, and hence significance of solar driven inward drives are not well understood.
- The factors that have been demonstrated or calculated to affect the quantity and significance of solar driven inward diffusion include the:
 - orientation to wind-driven rain and sun heating
 - rain absorptive and storage capacity of the cladding
 - presence of ventilation behind the cladding
 - vapour permeance of the sheathing layers behind the cladding
 - vapour permeance of the interior finish / vapour control layers
 - interior temperature

This research project focuses on the fifth bullet above, as polyethylene sheeting has a very low vapour permeance. This research also has orientation and permeance of sheathing as experimental variables.

- An air barrier should be installed in all walls. If plastic sheeting (used as an air barrier) is removed, then other measures/systems/materials need to be employed to provide the airtightness in a wall assembly.
- There is no consensus of the maximum vapour permeance allowable on the interior of Canadian walls to reduce cold weather diffusion problems. Recommended values in the literature vary with exterior climate, wall assembly, and interior humidity conditions, but range from 60 to over 1000 metric perms ($\text{ng}/\text{Pa s m}^2$). However, there appears to be little doubt that a layer with the vapour permeance of polyethylene sheeting will control winter diffusion.
- Omission of plastic sheeting in walls has been shown in some instances to increase the risk of mould growth on interior finishes like drywall (Lawton & Brown 2003).

1.2. ABOVE-GRADE (AG) WALLS

1.2.1. AG WALLS - CONDITIONS WHERE PLASTIC SHEETING COULD CAUSE PROBLEMS

Risks related to inward vapour drive during periods of warm weather have been identified by Christensen (1985), Straube & Burnett (1995), Pressnail et al (2003), Derome & Huang (2005) and others. In some situations, high humidity and condensation has been in evidence at the interior surfaces of the building envelope. Moisture-sensitive organic materials are often present at these locations; warm-weather inward vapour drive can create temperature and moisture conditions favourable for mould growth and wood rot.

1.2.2. AG WALLS - POTENTIAL CONSEQUENCES OF OMITTING INTERIOR IMPERMEABLE LAYERS

By removing interior impermeable layers that have traditionally been relied upon as a vapour barrier, wall assembly moisture could escape to the interior when vapour drives are in this direction. However, this may also increase vapour flow into wall assemblies at other times; typically during cold weather, creating conditions which are favourable for mould growth and wood rot (Goldberg 2001).

Water penetration into a wall or solar heating of saturated absorptive cladding will increase the potential for mould growth on interior drywall finishes if the polyethylene is removed. Polyethylene has been found to protect interior drywall even where studs had rotted and corroded from water ingress (Lawton & Brown 2003).

Where low vapour permeability interior finishes (such as vinyl wall coverings) are employed in lieu of plastic sheeting or accidentally in walls without plastic sheeting, moisture may accumulate within the interior drywall (Building Research Establishment 1989).

1.2.3. AG WALLS - RECOMMENDATIONS TO ADDRESS INWARD VAPOUR DRIVE

Measures to control inward vapour drive are identified by Christensen (1985), Straube & Burnett (1995), Pressnail et al (2003) and others; they include employing ventilated cavities within the walls, lower permeance external cladding or sheathing, and/or cladding with low or reduced water absorption.

1.3. BELOW-GRADE (BG) WALLS

The challenges of the interior insulation assemblies in the below-grade environment have been addressed by Timusk (1997), Huelman and Cheple (2001) and others. One issue is the contrasting requirements for the above-grade and below grade portions of the wall: the former has an outwards wintertime vapour gradient, suggesting the need for an interior vapour control layer, while the latter in Southern Ontario, British Columbia and the Maritimes has a year-round inwards vapour gradient (colder regions may vary), suggesting that drying to the interior is often necessary. Furthermore, similar to above-grade wall assemblies, inwards vapour drives can result in issues, as found in the literature below.

1.3.1. BG WALLS - CONDITIONS WHERE PLASTIC SHEETING COULD CAUSE PROBLEMS

Swinton & Karagiozis (1995): Case studies and hygrothermal modeling of basement walls, looked at fresh concrete foundation walls with interior fibreglass insulation and polyethylene sheeting. With this construction, extensive condensation on polyethylene was seen, even with partial height insulation and finishes installed 3 months after foundations were poured. Modeling suggested that vapour diffusion driven by inward and downward temperature gradients (i.e. higher temperature at top and outside of wall) is a probable contributing factor to condensation and pooling water.

Goldberg & Aloï (2001): Field-testing in Minnesota involved concrete block basement walls insulated from the interior with glass fibre insulation, and polyethylene inboard of the insulation. The wall had condensation form within the insulation from March to September, primarily at the upper section of the wall. The insulation was not likely to dry out before condensation/moisture absorption was likely to recur. This wall was not deemed to be appropriate for long-term use with fibreglass insulation.

Lstiburek & Yost (2002): Numerous basements with concrete foundation walls, interior batt insulation and interior polyethylene, vinyl or foil interior have been found with serious problems with mould, decay, and odours.

Goldberg (2004): Field-testing in Minnesota involved a low-density open cell spray foam insulation. Polyethylene between insulation and block led to condensation on the polyethylene interior in the winter and condensation on the polyethylene exterior in summer. Condensate rundown was noted but there was no visible mould growth. Interior polyethylene led to condensation on the wall side of the poly during the summer with an upwards-trending wetting and drying cycle (i.e. net moisture accumulation from year to year). Condensate rundown was noted and there was visible mould growth on the spray foam surface and wood studs.

1.3.2. BG WALLS - POTENTIAL CONSEQUENCES OF OMITTING INTERIOR IMPERMEABLE LAYERS

Onysko, Gates & Van Rijn (2003): Field Testing in Ottawa found that preserved wood foundations with exterior plywood sheathing with interior glass fibre insulation, polyethylene and unpainted drywall showed little condensation on the interior of the exterior plywood sheathing. When the polyethylene was removed there was an accumulation of moisture in the above grade portions of the plywood sheathing. And the rate of drying was slower then when polyethylene was used.

Goldberg & Aloï (2001): Field-testing in Minnesota involved concrete block basement walls insulated from the interior with glass fibre insulation, and polyethylene outboard of the insulation. Condensation collected on the insulation side of the polyethylene during the winter, primarily at the upper section of the wall, and ran downwards and collected on the floor. Condensation also formed on the exterior side of the polyethylene in summer. This wall was not deemed to be appropriate for long-term use with fibreglass insulation.

1.3.3 BG WALLS - RECOMMENDATIONS TO REDUCE INWARD VAPOUR DRIVE RISKS

Field testing in Minnesota by Goldberg & Aloï (2001) and Goldberg (2004) found that concrete block basement walls insulated from the interior with glass fibre or low-density open cell spray foam and with no polyethylene provided a stable wetting and drying cycle that did not lead to moisture accumulation. This did not lead to gross wetting or condensate running down the wall surface.

Lstiburek & Yost (2002) report that moisture from initial construction, air leakage, capillary rise, diffusion, and/or ground water leakage must be allowed to dry to the interior since it is unable to dry to the exterior below grade. They describe analysis by Jeong (2001) at the University of Waterloo on several basement wall configurations with insulation and with and without polyethylene. Extruded polystyrene insulation (XPS) on the interior (25mm to 89mm thick) performed well. Thin XPS (38mm) can be used outboard of a fibre-glass insulated cavity providing the interior relative humidity does not exceed 50%. Further recommendations include vapour-permeable and moisture-tolerant interior finishes.

2.0 FIELD TESTING METHODOLOGY

Literature review provided focus for scheduled field testing; typical assemblies with and without polyethylene sheeting were tested side by side to allow direct comparisons.

2.1 ABOVE-GRADE WALLS

Three above-grade assembly types (north and south duplicates; six walls total) were installed in the University of Waterloo's BEGHut exposure facility; Table 1 details these assemblies. The interior of the hut was maintained at a 50% relative humidity and 20° to 21° C year round. This is a very high interior relative humidity for winter conditions, and was expected to cause wintertime diffusion wetting. The temperature is lower than most residential applications in summer, and hence is expected to increase the risk of summer condensation problems.

Wall sensors measure temperature, relative humidity, and wood moisture content, using methodology described in Straube et.al. (2002). Wood resistance sensors, similar to those examined by Carll and TenWolde (1996) are also installed; they provide surrogate moisture content measurements. These sensors (referred to as 'wafer sensors' or 'moisture content blocks' here) include moisture accumulation in their response to changing humidity conditions. Interior and exterior test hut conditions are also measured, including temperatures, relative humidity, wind speed & direction, horizontal solar radiation, and rainfall. The same sensor layout was used in all walls, in order to allow direct comparisons between the walls. All sensors were installed at the vertical centerline of the wall, as shown in Figure 1 and Figure 2. Wall assembly 2 is essentially the same as wall 1 but without the polyethylene sheeting.

Table 1: Above grade wall assemblies

Layer	Above grade wall 1: 2x6 with Polyethylene	Above grade wall 2: 2x6 without Polyethylene	Above grade wall 3: 2x4 with XPS
Interior finish	½"/12.7 mm gypsum wallboard w. latex paint	½"/12.7 mm gypsum wallboard w. latex paint	½"/12.7 mm gypsum wallboard w. latex paint
Vapour control layer	6 mil polyethylene	None	None
Framing/insulation	2x6 16" o.c. with R-20/RSI-3.5 fibreglass batt	2x6 16" o.c. with R-20/RSI-3.5 fibreglass batt	2x4 16" o.c. with R-12/RSI-2.1 fibreglass batt
Sheathing	½"/12.7 mm OSB	½"/12.7 mm OSB	1"/25 mm XPS R-5/RSI 0.9
Water resistive barrier	Spun-bonded polyolefin (SBPO) housewrap	Spun-bonded polyolefin (SBPO) housewrap	Spun-bonded polyolefin (SBPO) housewrap
Drainage cavity	1"/25 mm space; bottom vents only	1"/25 mm space; bottom vents only	1"/25 mm space; bottom vents only
Cladding	Single wythe brick veneer	Single wythe brick veneer	Single wythe brick veneer

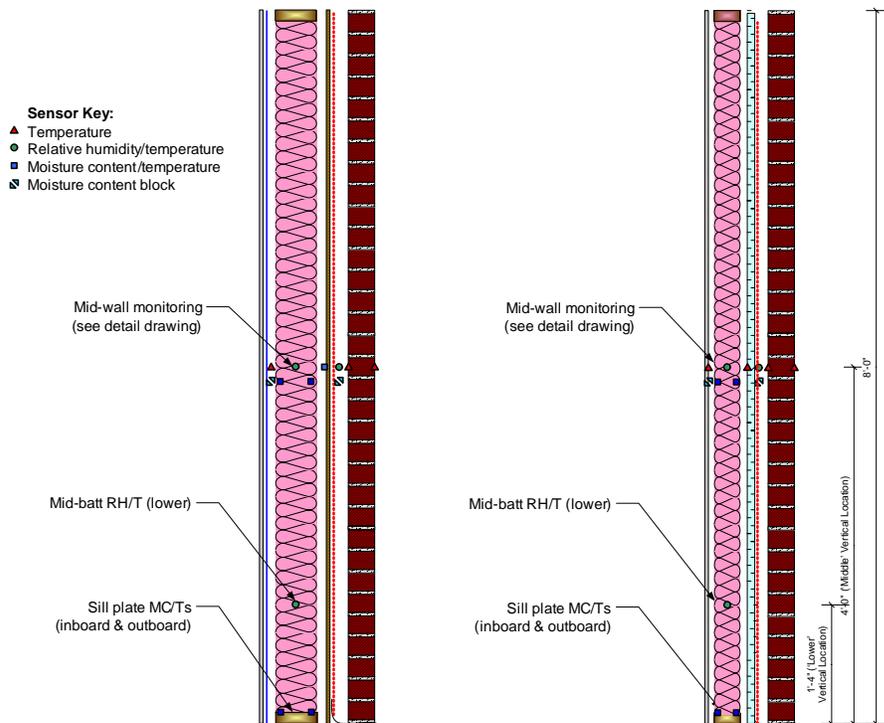


Figure 1: Section and monitoring layout for above grade walls 1 and 2 (left) and 3 (right)

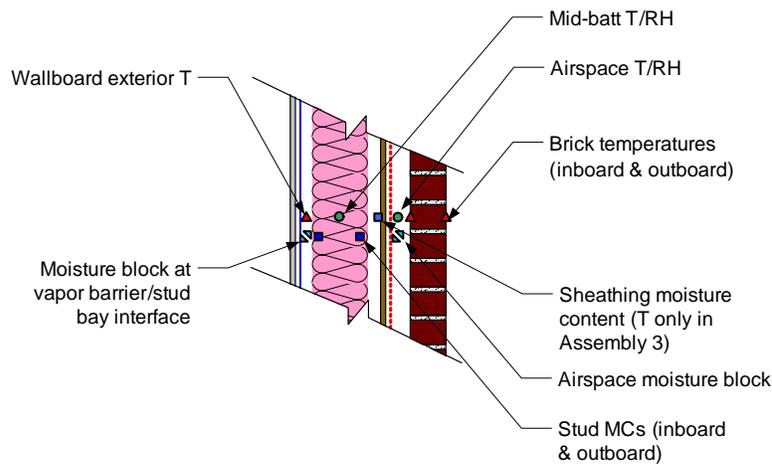


Figure 2: Detail of mid-height monitoring locations

2.2 BELOW-GRADE WALLS

Four interior wall insulation assemblies were constructed and monitored in a house in Kitchener, Ontario. Installation and instrumentation was completed in the first year of service; the test walls are roughly south facing. The below-grade wall assemblies are detailed in Table 2; schematics and sensor layouts are shown in Figure 3. Below grade wall 4 is the same as wall 3 without the polyethylene sheeting.

Table 2: Below grade wall assemblies

Layer	Below grade wall 1: 2" XPS	Below grade wall 2: vinyl fibreglass roll blanket	Below grade wall 3: 2x4 with polyethylene	Below grade wall 4: 2x4 without polyethylene
Interior finish	½"/12.7 mm gypsum wallboard w. latex paint	Polyethylene roll blanket facing material	½"/12.7 mm gypsum wallboard w. latex paint	½"/12.7 mm gypsum wallboard w. latex paint
Other	19 mm / ¾" airspace and furring strips	None	6 mil polyethylene	None
Framing/insulation	2"/50 mm extruded polystyrene (XPS) R-10/RSI 1.8	R-12/RSI-2.1 fibreglass roll blanket	2x4 16" o.c. with R-12/RSI-2.1 fibreglass	2x4 16" o.c. with R-12/RSI-2.1 fibreglass

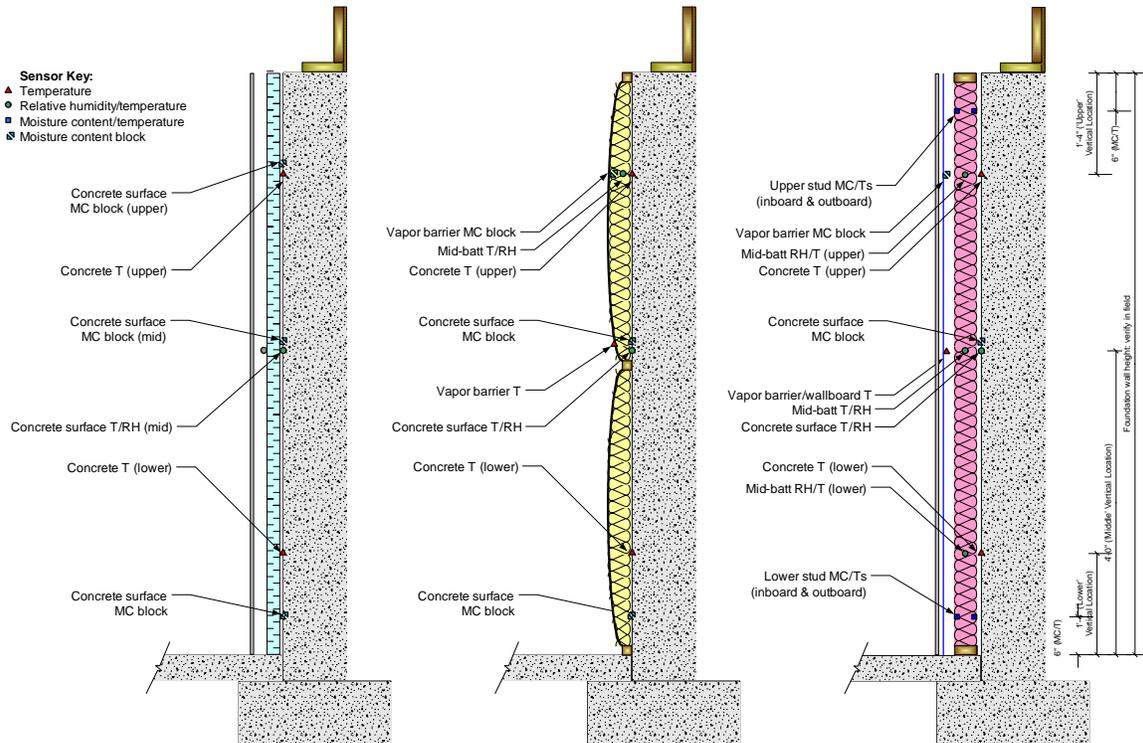


Figure 3: Below grade wall assemblies 1, 2, and 3

In addition to the wall sensors, interior and exterior temperature and relative humidity were recorded. Soil temperatures and moisture content were recorded at multiple depths and lateral locations to provide foundation wall boundary conditions.

3.0 KEY FINDINGS TO DATE

3.1. FIELD TESTING OF ABOVE GRADE WALLS

The above grade walls have been in operation for a full twelve months. Data presented here is for the period of September 7, 2005 through September 19, 2006. Temperature and humidity boundary conditions for the interior and exterior are shown in Figure 4.

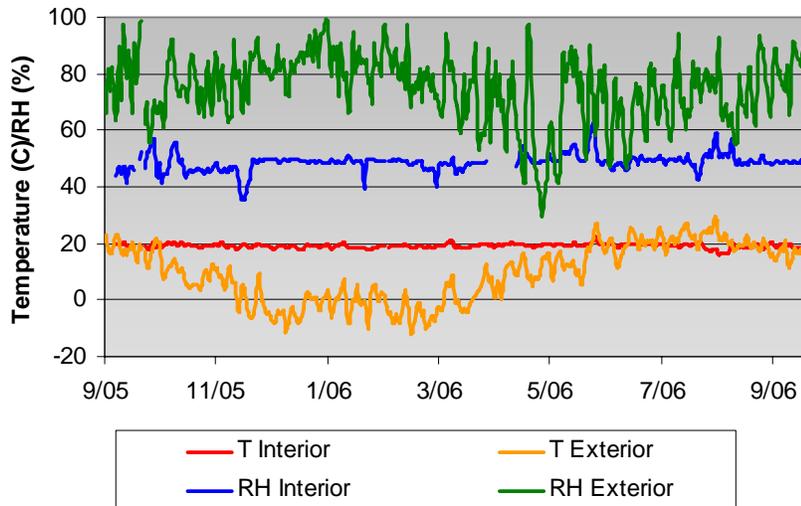


Figure 4: Interior and exterior temperature and humidity conditions (daily avg. values)

The following points summarize the key findings:

- Over the winter, the walls with polyethylene showed the lowest moisture levels, in terms of relative humidity, dewpoint, or wood moisture content. In comparison, the walls with an interior latex paint layer as vapour control (XPS wall and no polyethylene/2x6) had higher moisture levels in the winter. Wood moisture content measurements in the XPS and "no poly" walls showed levels above the generally accepted safe limits (20-25% MC); however, data going into the summer shows drying down to safe levels. It must be emphasized that these walls have exceptionally high interior moisture loading (50% RH in a cold climate, approximately 4200 HDD18° C / 7600 HDD65° F). Dewpoints are considered high when compared to those measured in a CMHC cross Canada study by Ruest et al (1993). This study conducted on 52 houses, with 10 in Ontario, found average wintertime first floor dewpoints to be 2.0°C across Canada, and -2.0°C in Ontario, which compares to an average winter time Dewpoint of 9.3°C in the field testing. The interior moisture loading in this study is higher than approximately 93% of the first floors in the cross Canada study (100% in Ontario).
- During the summer, the polyethylene walls showed elevated moisture levels, especially towards the interior surface (i.e., accumulating at the vapour barrier). This was seen in framing moisture content measurements, MC wafer measurements, and humidity/dewpoint measurements. The MC wafer measurements and framing measurements show evidence of condensation and rundown on the south poly wall. It must be emphasized that the interior temperatures are maintained slightly below most residential applications (20-21° C).
- Condensation risks during the winter and summer seasons were examined by plotting stud space dewpoints with temperatures of potential condensing surfaces, for the respective worst cases. During the winter, the polyethylene functions as designed, reducing the stud space dewpoint below the sheathing temperature for most of the winter hours. However, this is also true of the XPS wall, which only uses latex paint as a vapour control layer. In the "no poly" wall, stud space dewpoints go above sheathing temperatures for considerable parts of the winter.

- During the summer, the increase in stud bay dewpoint due to the polyethylene is evident, and there is significant condensation risk. In comparison, the XPS and "no poly" walls have minimal to no risk of condensation.

The following graphs present the collected data in greater detail.

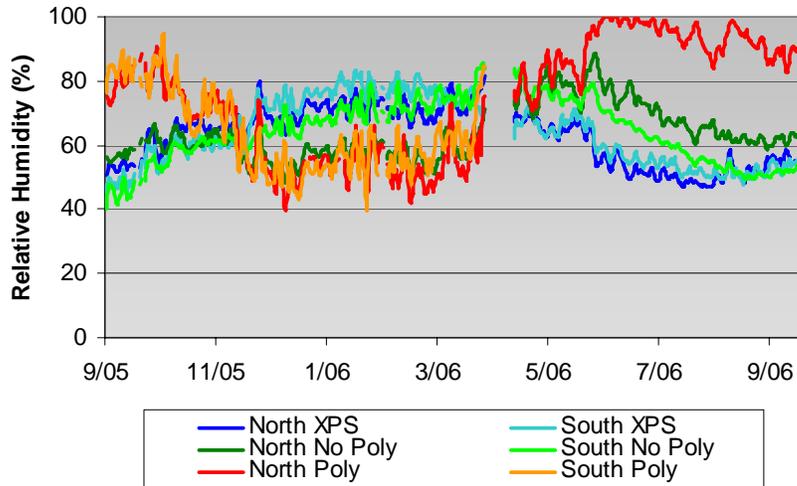


Figure 5: Stud bay mid-batt mid-height humidity levels (daily avg. values)

The poly walls have elevated humidity during the early fall of 2005, and the lowest in the winter. The walls with latex paint as interior vapour control (XPS and "no poly") have the lowest humidity levels in summer, which then rise to the 70-80% range in winter.

In the summer of 2006, the poly walls have RH levels near 100%. The XPS walls have the lowest humidity levels; they are dryer than the "no poly" walls; this could be a combination of less wintertime moisture accumulation (due to the insulating sheathing), and/or the lower vapour permeance of the XPS sheathing, compared to OSB and housewrap. The south poly humidity sensor failed in April, but a similarly placed sensor shows continued elevated humidity levels, similar to the north side.

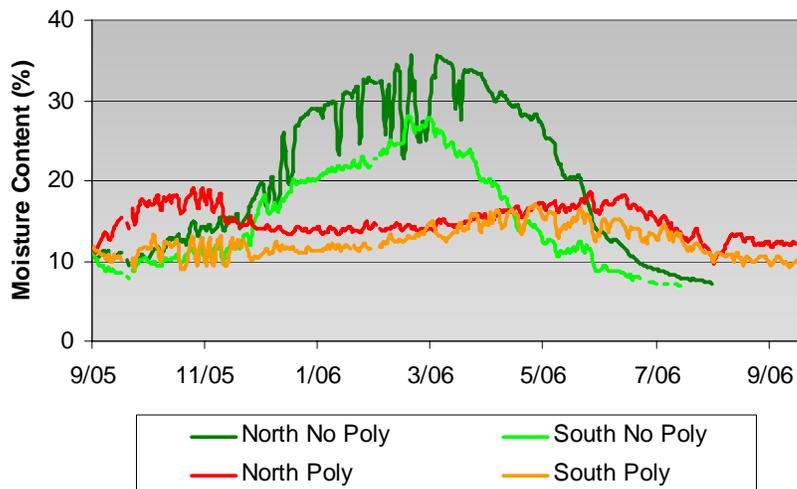


Figure 6: Sheathing moisture content (Walls 1 & 2), north & south (daily avg. values)

Moisture content readings of the OSB sheathing are compared in Figure 6 ("poly" and "no poly" walls). Note that the OSB moisture readings are uncorrected for species, but the framing MC is expected to be accurate within 2%. In the winter, the "no poly" walls show substantial rises in MC (peaking at approximately 35% and 28%, north and south, respectively), while the poly walls remain in the 10-15% range. As the high moisture contents of the No Ploy walls occurs during warm exterior temperatures there is a risk for mould growth during this period. However, by early summer, the "no poly" walls have dried to safe levels. The poly walls show some rise in moisture content, relative to the winter, but generally stay in the safe range (under 20%).

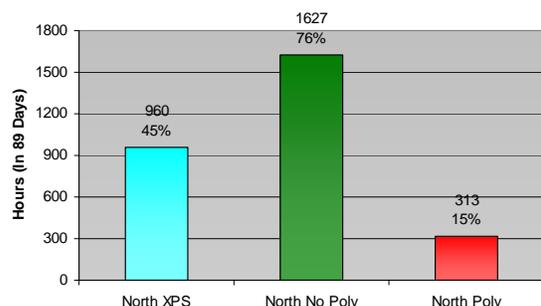


Figure 7: Number of hours with wintertime condensation risk

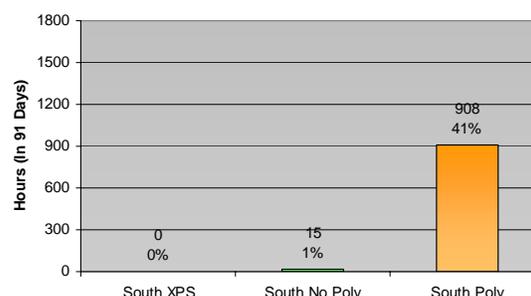


Figure 8: Number of hours with summertime condensation risk

The risk of wintertime condensation is examined further by plotting the number of hours when stud bay dewpoint was above sheathing surface temperature. Figure 7 plots these values for the north walls, for the three months of winter (December through February, 89 days).

It shows that the 2x6 wall with no polyethylene has a considerable condensation risk for a majority of those hours (76%). The XPS wall has approximately two-thirds the number of hours at risk (45%), and the polyethylene wall has the safest wintertime performance.

Summertime moisture risks due to polyethylene sheeting are of particular interest. The number of hours when stud bay dewpoint was above drywall surface temperature is plotted in Figure 8, for the south walls, for the three months of summer (June through August, 91 days). Where the 'South-Poly' mid-height relative humidity sensor stopped working in March (see Fig. 5), the lower-height sensor was used to calculate dewpoint. The dewpoints for mid-height and lower-height locations trend very closely in all other cases (within 1°C) so this represents a clear comparison.

It shows that the XPS wall has no risk of condensation: this is likely due to the low vapour permeance of the sheathing. In comparison, the "no poly" wall has a minimal (1% of hours) condensation risk. However, the poly wall has a considerable risk of 41% of hours at condensing conditions, due to the low permeance interior vapour control layer.

3.2. FIELD TESTING OF BELOW-GRADE WALLS

Data provided is for the period of August 30, 2005 through July 25, 2006; interior and exterior temperature and humidity conditions are shown in Figure 9. The basement conditions are relatively stable and presumed to be typical of new residential construction. The interior relative humidity is considered moderate when compared to those measured in a CMHC cross Canada study by Ruest et al (1993). This study conducted on 52 houses, with 10 in Ontario, found average wintertime basement dewpoints to be 0.6°C across Canada, and -2.75°C in Ontario, which compares to an average winter time Dewpoint of 1.9°C in the field testing. The interior moisture loading in this

study is higher than approximately 60% of the basements in the cross Canada study. Interior dewpoints could be higher, but this is not recommended.

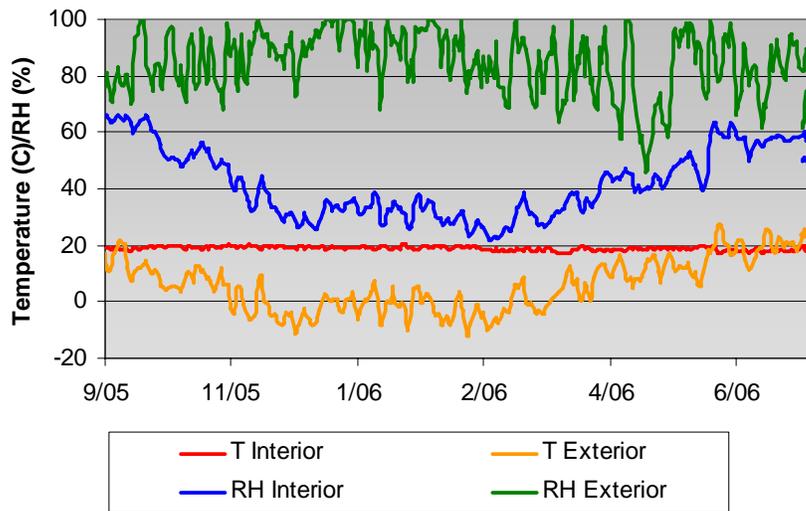


Figure 9: Interior and exterior temperature and humidity conditions for below grade walls (daily avg. values)

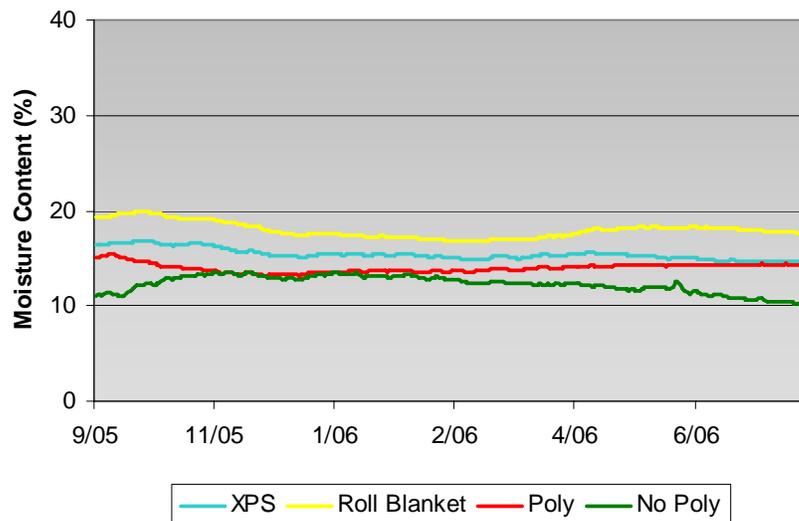


Figure 10: Moisture content wafer response, concrete-insulation interface, mid-height (daily avg. values)

The response of the MC wafers (moisture content blocks) at the interface between the concrete wall and the insulation system at mid-height is plotted in Figure 10. The response shows the accumulation of moisture at the concrete behind the insulation system; it demonstrates that the below grade environment (approximately 1 meter below grade) is relatively static, compared to the dynamic response of above grade walls. However, several points can still be discerned. The "no poly" wall gains some moisture into the winter, but moving into the summer, it is able to dry to the interior. In contrast, the poly wall has a relatively stable but higher moisture content. However, both walls are at safe moisture levels (~10-15% MC). The roll blanket is consistently the wettest, and shows a slight rise in moisture during the warmer seasons.

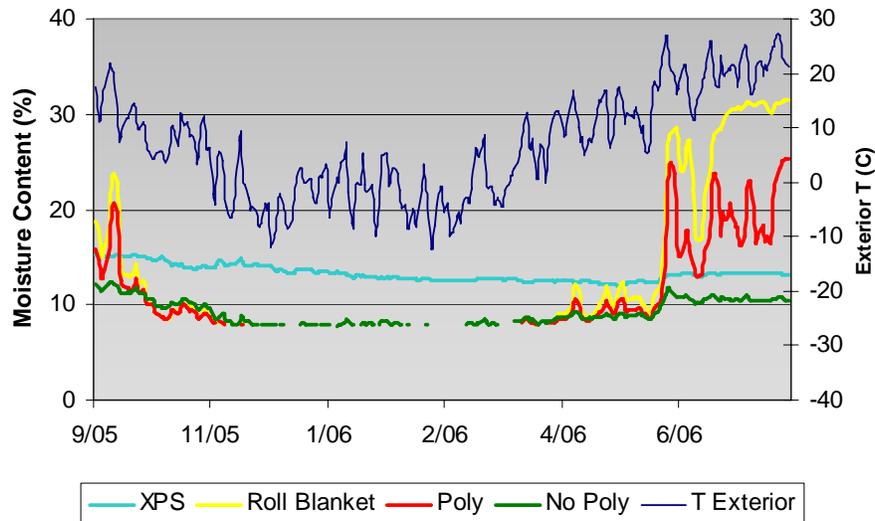


Figure 11: Moisture content wafer response, interior side, upper height with exterior temperature (daily avg. values)

In contrast, the MC wafers at the upper location (roughly at grade) show a much more dynamic response, due to the effects of above-grade weather. Wafer response and exterior temperature are plotted in Figure 11. This wafer sensor is located between the insulation and the polyethylene for walls 2 and 3, between the insulation and drywall for wall 4, and between the XPS and concrete in wall 1. Looking at the roll blanket and poly walls, we see that there is a strong rise in moisture content that coincides with the thermal gradient changing from outwards to inwards in late May. Moisture content levels rise to 25% in the poly wall and over 30% in the roll blanket wall; the latter is likely experiencing condensation at the poly layer. In contrast, the "no poly" wall shows a slight rise in moisture content, but well within safe levels, and the XPS wall remains at safe levels throughout. The moisture behaviour of the roll blanket and poly walls is correlated strongly with the outdoor temperature (i.e., thermal gradient across the wall).

The behaviour of the stud frame wall systems during the winter was compared by looking at framing moisture content at the upper portion of the wall. The polyethylene wall remained very dry through the winter (~8% MC), while the framing in the no polyethylene wall showed a rise in moisture content. However, the moisture content peaked only at 12-13%, which is well within safe ranges. Furthermore, by early summer, the no polyethylene walls dried to approximately 8%. At the same time, the polyethylene walls began to gain moisture (but still within the safe range), rising to 14% by late summer.

4.0 CONCLUSIONS AND FURTHER WORK

The field monitoring of above grade walls demonstrated several points: first, it showed that the presence of a polyethylene vapour barrier reduces the potential for wintertime condensation and moisture damage of the wall cavity at high interior relative humidity (50%) conditions. However, the presence of the polyethylene significantly increased the occurrence of summertime condensation in the stud bay cavity when using an absorptive cladding. In both cases, the wall with extruded polystyrene foam sheathing and no interior vapour barrier had good performance; it showed the greatest resistance to summertime condensation.

It should be noted that summertime condensation is of particular concern for moisture damage of walls, because it occurs during a temperature regime favourable to microbial growth. In comparison, wintertime sheathing condensation occurs at temperatures that are less conducive to

mould growth; damage then becomes a function of how quickly drying occurs relative to the onset of warmer temperatures.

The operating conditions of the test hut are extreme; 20 to 21° C during the summer is lower than a typical residential interior setpoint, and increases the condensation risks on the interior surfaces. Winter operation at constant 50% relative humidity requires substantial humidification of the interior space, and is a stringent winter condition. These conditions resulted in condensation events in both the "poly" and "no poly" walls, at different times of year. Under normal operating conditions, problems will be reduced. Modeling will be used to provide greater insight into critical interior conditions.

Material property testing of wall component samples will be performed at the conclusion of one year of testing. In addition, the walls will be opened and inspected for signs of moisture damage and mould growth. One goal of this inspection is to address Lawton and Brown's (2003) concern with drying to the interior: the danger of moisture accumulation and damage of gypsum board when not protected by polyethylene. Finally, this study compares the vapour control strategies of latex paint and polyethylene, which have permeance values that are two orders of magnitude apart. It may be worthwhile to perform field monitoring of a vapour control material that is between these extremes, but still meets code requirements for a vapour barrier.

The below grade field monitoring results demonstrated that summertime inwards vapour drives can cause significant moisture accumulation and condensation in impermeable wall assemblies, especially the "roll blanket" insulation, which is typically installed in an airtight manner. Both the no poly and XPS walls show moisture levels throughout the year that are below the danger threshold for mould growth. The interior relative humidity is considered moderate for this climate, and modelling will be done with higher relative humidity in various climate regions to further explore internal moisture loading impacts.

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