Construction and Field Monitoring of Exterior Walls Using Vacuum Insulation Panels (VIPs) in a Net Zero Home

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ABSTRACT

Vacuum insulation panels (VIPs) are an emerging technological breakthrough for Canadian residential construction. The high-insulating values of VIPs can contribute to reducing the thickness of highly-insulated building envelopes. The first known Canadian field demonstration of VIPs was located in Burnaby, British Columbia. The project team for the net-zero energy Harmony House Project has used exterior walls with VIPs. Using a number of mock-ups and field tests, the Harmony House team successfully installed 15 mm (9/16 in.) thick VIPs in the center of the stud cavity, covered by a 50 mm foil-faced isocyanurate foam board on the exterior and spray-foam on the interior. This provides an estimated effective insulation value, when averaged over the entire wall, of 6.8 $m^2 \cdot K/W$ (RSI) or 38.5 $ft^2 \cdot F/Btu$.

Design-stage thermal and hygrothermal analyses and the construction and monitoring of VIP wall assemblies showed that these systems do exhibit superior overall performance. Field construction of a home with VIPs demonstrated that builders in cold-climate countries can build thin-profile, low-heat loss wall systems.

Based on the construction and monitoring of VIP wall assemblies, it appears that VIPs are a viable option in the marine climate of Northwestern North America. Field performance of VIP walls show that the wall assembles must utilize a vented rain-screen cavity to protect from wind-driven rain penetration and to promote drying to the exterior; most importantly, north facing and other walls that do not receive exposure to solar radiation must use a preservative-treated exterior structural sheathing to minimize the possibility of fungal growth on the sheathing.

INTRODUCTION

In cold-climate housing markets, in order to achieve net zero energy (NZE) performance, the thermal characteristics of the building envelope have to be radically improved. For low-rise housing, a typical house built in Canada per the current energy efficiency regulations has an annual heat loss ranging from 80 to 130 GJ (~760 to 1230 therm) per year depending on the climate (Parekh & Kirney 2012). As shown in Figure 1, these heat losses must be further reduced by at least 50% or better to 40 to 65 GJ (~380 to 616 therm) per house to achieve NZE performance levels. With significantly reduced heat losses, the size of renewable energy systems can be minimized reducing overall costs.

By definition, NZE houses on an annual basis produce as much energy as they consume—all energy used in a home including that for space heating, hot water, ventilation, air conditioning, base electricity, and plug loads. This is typically achieved by significantly reducing heating, cooling, lighting, and appliance loads and supplying the energy needs of the building through on-site passive and active renewable energy systems. In order to reduce space heating and cooling loads to a level where on-site renewable energy systems can supply all the energy requirements, the building envelope is typically highly insulated and airtight. For low-rise residential buildings (three stories or less) in Canadian climates this requires insulation values in the range of RSI 4.2 (R-24)[1] for the basement or crawlspace floor slabs, RSI 5.3 to RSI 7.0 (R-30 to R-40) for

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below-grade and above-grade walls, and RSI 10.6 to RSI 14.1 (R-60 to R-80) for ceilings. Achieving these insulation levels in walls and ceilings using conventional insulations (such as mineral and glass fiber batts, rigid polystyrene boards) requires very thick assemblies in the range of 406 to 610 mm (16 to 24 in.). These thick assemblies can lead to:

- Reduced total usable interior floor area,
- Reduced-ground floor area for a given footprint area,
- Additional flashings and detailing around doors and windows if they are set to the inside face of exterior walls,
- Additional interior wall finishes and mouldings if the windows and doors are set to the outside of the exterior wall,
- Additional framing to accommodate thicker insulations, therefore high costs of construction, and
- Higher costs per unit liveable floor area.

One or more of the above conditions will impede the adoption and construction of NZE housing. Recently, there has been great emphasis on the development of high R-value insulating materials that can provide significant thermal resistance per unit thickness. High-density fiberglass insulation batts can raise the insulation level from RSI 0.024 to RSI 0.030 per mm thickness (R-3.5 to R-4.4 per in.), which is close to a 26% improvement. The re-engineered polymeric foam insulation boards can provide close to RSI 0.045 per mm (R-6.5 per in.), a 30% better insulation value than conventional rigid insulation sheathing. These developments are certainly encouraging; however, these are still incremental. In the last several years, vacuum insulation panels (VIPs) have been developed for use by the construction industry and hold the promise of significantly higher levels of thermal performance.

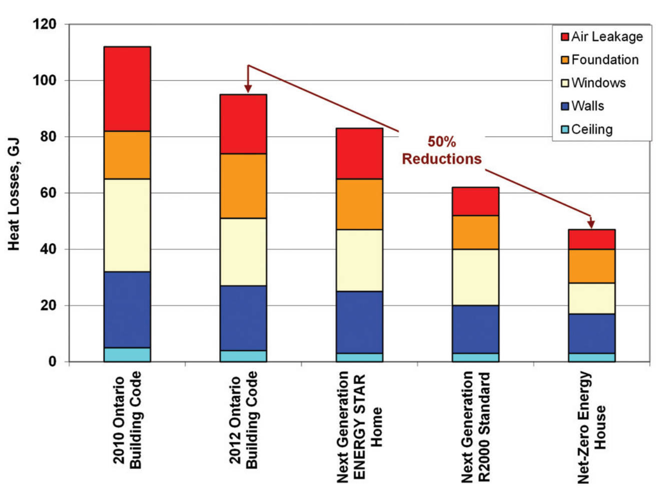

Figure 1 *Annual heat losses of a typical 186 m^2 (2000 ft^2) 2 story home built in Ottawa, ON.*

[1] RSI–thermal resistance expressed in $m^2 \cdot K/W$ and R in $ft^2 \cdot F/Btu$

This paper documents the construction details of exterior above-grade walls with VIPs and provides assessments of hygrothermal performance of these walls over a period of one year. The annual energy performance of the net zero home using these VIPs is being evaluated over a period of two years and will be presented in a future paper.

VIPS

VIPs have been successfully integrated in wall assemblies and demonstrated in a number of European houses and buildings (Binz et al. 2005; Simmler et al. 2005; Erb et al. 2005) and Japanese houses (Super-E Japan 2008). In the Canadian context, VIPs are among the newest emerging technologies for residential construction. Used successfully for cryogenics and in the space industry, VIPs can achieve significantly higher insulation values with thinner wall construction than when using conventional insulation materials.

VIPs are either made with an open porous powder or a rigid porous core made from silica gel, compressed silica, or fiberglass board. The core is encased in a gas-impermeable skin of aluminum foil or aluminum/plastic composite laminate and placed under vacuum (less than 20 to 100 Pa [0.2 to 1 mbar]) to reduce convection and conduction heat transfer. The encased material is impregnated with desiccants and getters for absorbing any gases that may enter the VIP over time. As a result, the thermal insulating capacity of VIPs is up to ten times higher than current commercially available insulating materials. The VIPs are particularly useful in places where space is at a premium or where energy demand is high. The higher insulating values of VIPs can effectively reduce the thickness of building envelopes. The thermal resistance of VIP ranges from RSI 0.21 to RSI 0.31 per mm (R-30 to R-45 per in.) thickness (Mukhopadhyaya et al. 2008).

With technological improvements in the last several years, including improvements in core materials and manufacturing processes, the quality and durability of VIPs have improved significantly. Several manufacturers of VIPs are now claiming 40 to 60 year life spans (NRCC 2013). The recently published, ASTM Standard C1484-10 deals not only with product specifications and insulation performance tests but also puncture tests—which somewhat alleviate concerns regarding the handling of fragile VIPs, though the panels still should be handled carefully and protected during construction. When using VIPs in a building envelope assembly, it should be noted that:

- The wall area covered with VIPs form an absolute vapor barrier; however, the edges of VIPS should be properly lapped and sealed to prevent moisture transfer;
- All framing materials in the wall assembly must be dry before closing in; and
- The consequences of vacuum failure in VIPs could potentially lead to moisture accumulation in building envelope assemblies as well as radically reduced thermal performance.

VIPs should not be used as stand-alone insulation materials due to practical and construction-related considerations, and they work best when integrated and protected with polystyrene plastic insulation boards or other rigid protective layers.

The first known Canadian field demonstration of VIPs is in Burnaby, British Columbia near Vancouver, shown in Figure 2. This is a coastal marine climate with heating degree-days of 2925°C (5265°F). The Harmony House project team, successful winner of CMHC's EQuilibrium™ Sustainable Housing Demonstration Initiative, has built exterior walls using VIPs (CMHC 2010). The Harmony House is a two-story, 438 m^2 (4714 ft^2) home with a basement that includes a self-contained secondary suite and an attached garage.

HARMONY HOUSE WALL ASSEMBLIES WITH VIPS

The design goals for the Harmony House above-grade wall assemblies were as follows:

- To construct a wall no thicker than currently used by the housing industry in Canada. The most common exterior wall system used in Canada and the northern US is based on 38 × 140 mm (2 × 6 in.) framing. Builders and subtrades are used to working with this dimension of lumber and windows and doors are manufactured for walls of this thickness;
- To achieve an effective thermal insulation value for the entire assembly in the range of RSI 7.04 (R-40);
- To construct a durable wall assembly that will not be affected by moisture accumulation from rain penetration or condensation formation due to exterior or interior airborne moisture;
- To construct a wall assembly that will protect the VIP during and after construction; and
- To produce an airtight wall assembly resulting in a measured airtightness of 0.35 cm^2/m^2 (0.005 $in.^2/ft^2$) at 10 Pa normalized leakage area or lower.

These criteria were addressed by the wall design shown in Figure 3; the wall was constructed in the following manner starting from the exterior cladding and moving inwards:

- The exterior cladding is supported on vertical preservative-treated 12 × 50 mm (1/2 × 2 in.) plywood strapping that provides a vented rain-screen cavity allowing for both drainage and drying by natural convection.
- A layer of commercial grade spun-bonded polyolefin building wrap (water resistive barrier) stapled to the exterior face of the 12.7 mm (1/2 in.) thick plywood wall sheathing. This prevents wetting of the wall sheathing while also allowing for drying. The design-stage hygrothermal analysis predicted the potential for moisture accumulation in the north wall sheathing; therefore, all north wall sheathing was treated with a preservative.
- The 38 × 140 mm (2 × 6 in.) studs are spaced at 610 mm (24 in.) on center and advanced framing details were used to minimize lumber in the wall assembly, such as two stud corners, single top plates, and let-in lintels and rim joists. Advanced framing reduces the thermal bridging through framing enhancing the thermal characteristics of the wall. Conventional framing practices typically result in 23% of the wall surface area covered in framing, whereas in this case only 9% of the wall area was covered in framing.
- A 50 mm (2 in.) layer of foil-faced isocyanurate foam board was placed between the studs behind the exterior plywood wall sheathing; this provides an RSI 2.1 (R-12), which in Vancouver's climate ensures in the case of VIP failure that the interior face of the VIP will be kept above the indoor air dew point temperature.
- A 15 mm (9/16 in.) thick VIP with an insulation value of RSI 6.59 (R-37.4)[2] is then placed with double sided tape on the inside face of the foam board and sealed to the sides of the studs and to the wall top and bottom plates with urethane foam; this secures the VIP and helps contribute to the wall assembly airtightness. Placing the VIP near the center of the wall cavity depth provides the most protection possible from nails and screws during and after construction.

2. Based on test results according to ASTM C 518 (2010) produced by National Research Council of Canada on an 15.0 mm (9/16 in.) thick VIP.

Figure 2 *Harmony House Net Zero Energy House front; south elevation showing triple-glazed windows, photovoltaic array and solar domestic water heating system; and interior. (source: www.harmony-house.ca).*

- The inner layer of insulation consists of a castor bean oil-based low-density spray foam insulation which both insulates and air seals.
- The interior finish consists of 12.7 mm (1/2 in.) thick gypsum wall board which is air sealed to the wall framing using low-density closed-cell foam tape, screws and sealants using a technique called airtight drywall.

The design stage thermal and hygrothermal evaluations verified construction specifications, corner details, and also the long-term moisture and energy efficiency performance of wall assembly. The high-insulating values of this wall assembly, along with the placement of the vapor barrier formed by the VIP, led to concerns that the intent of the British Columbia Building Code would not always be met with in regard to ensuring no moisture accumulation in the assembly (BCBC 2006). A hygrothermal analysis was carried out using commercially available hygrothermal software to ensure code compliance when the VIPs were both new and if their performance degraded due to damage or aging; the findings are summarized as follows (Parekh and Mattock 2012):

- Heat transfer analysis was conducted using the two-dimensional heat transfer modeling program based on the finite-element method with THERM 5.2 (LBNL 2007). Temperature and heat-flux isotherms showed that the majority of heat flow occurs through the wood framing members. As the VIP has the highest thermal resistance, the largest thermal gradient occurs across the panel. The interior surface of the VIP could be expected to have a minimum surface temperature of 15.6°C (60°F) when the exterior temperature is –7°C (19.4°F), and well above normal indoor dew point temperatures of approximately 10°C (50°F) during the wintertime.
- Hygrothermal analysis of the VIP wall assembly was performed using WUFI 5.1 (ORNL 2010). Analyses showed that north facing walls and other walls that do not receive exposure to solar radiation are more prone to higher humidity for framing materials (sheathing and bottom headers). The VIP wall relies on cladding ventilation for drying of the exterior sheathing.

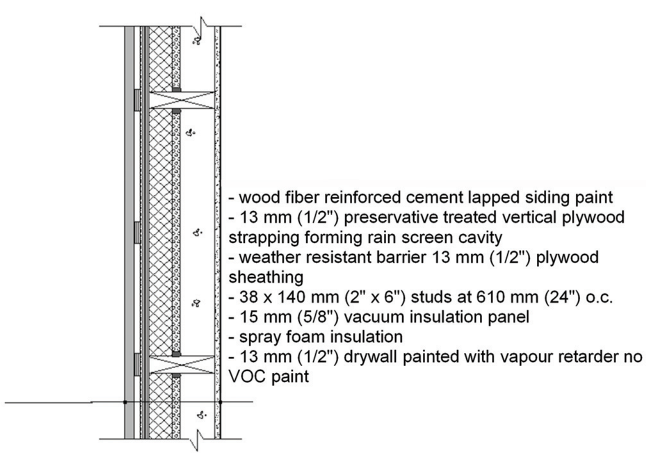

Figure 3 *Plan section through the Harmony House above-grade exterior wall assembly.*

CONSTRUCTION SEQUENCING

All exterior walls are framed using advanced framing techniques to minimize lumber and related thermal bridging. The 50 mm (2 in.) thick foil-faced isocyanurate foam board is installed between the studs behind the wall sheathing upon completion of framing and installation of the building wrap and a waterproof membrane on the roof. In order to minimize the possibility of damage, all electrical, plumbing, and heating and ventilation services were installed before the VIPs. All wiring in exterior walls is for electrical receptacles only; this allows the wiring to be kept low and makes for easy installation of the VIPs. All light switches, daylight sensors, and occupancy sensors in the home are wireless and therefore can be surface mounted later on the finished drywall, and therefore do not interfere with the installation of the VIPs. Figures 4 and 5 show photos taken during the construction.

Airtightness

The home was blower-door tested upon completion of the air barrier and was measured at 0.75 ach at 50 Pa and found to have a normalized leakage area of 0.35 cm^2/m^2 at 10 Pa exceeding the performance target of 1.0 ach.

EXTERIOR WALL PERFORMANCE MONITORING

Monitoring of the thermal and moisture conditions at various locations in the wall assembly was carried out over a 12 month period. The location of the sensors that measured temperature, wood moisture content, and relative humidity are shown in Figure 6. The sensors are wireless and communicate with an internet gateway located in the home. The sensors shown in Figure 7 have been calibrated prior to installation. Readings for all three parameters were taken every 5 min. Information measured and transmitted by the sensors passes through the gateway to a web site maintained by the sensor manufacturer. This allows the monitoring data to be accessed at any time and downloaded for analysis. If a longer monitoring period is desired, the battery powered wireless sensors will continue to operate for at least 10 more years and will allow for extended monitoring.

Wireless Sensors

The sensors are available in two variants both with identical electronics, but one with a larger profile and the other with a thinner profile.

Sensor Installation

During the wall construction process, sensors were installed in the main floor wall assemblies in the four cardinal orientations as shown in the Figures 8 and 9.

MONITORING RESULTS

Construction of the Harmony House was completed in late fall of 2011. The Burnaby, British Columbia climate is generally rainy during the fall; however, the construction crew took enough care to keep the wood-framing shielded from direct rain and water. The initial moisture content (MC) of sheathing and frame component ranged from as low as 7% to as high as 26%. Sensors were installed in the walls during the construction and the gathering of data started in January 2012.

The results of the monitoring of the wall assembly essentially confirmed the trends predicted by the hygrothermal modeling. The wall component that has proven the most critical and the best indicator of long-term durability in the Vancouver climate is the exterior structural sheathing.

The north wall sheathing experienced elevated MC levels ranging between 15.3% to 22%, as shown in Figure 10. This appears to be due to a combination of the fact that the wall is shaded over the entire year, no drying can occur to the interior, and the high thermal resistance of the wall assembly.

The south-facing wall-sheathing moisture contents ranged from 7.3% to 12% as shown in Figure 11. Solar exposure ensures drying of the sheathing.

East wall sheathing MC ranged from 9.9% to 20.1% as shown in Figure 12. Figure 13 shows the west wall sheathing MC ranged from 8.3% to 15.9%. In the cases of the east and west walls, there appears to be a slight drying trend in the wall sheathing year to year.

In the case of the north wall, while some drying occurred in the summer, the MC level then returned to the values seen

Figure 4 *Left photo showing north kitchen wall 38 × 140 (2 × 6) advanced framing and second floor rim joist. The let-in laminated veneer lumber (LVL) rim joist allows for the vacuum panels to run up past the edge of the upper floor. Right photo shows north side of north kitchen wall showing preservative treated plywood sheathing.*

Figure 5 *Left: Foil faced isocyanurate foam board placed between the 38 × 140 (2 × 6) studs behind the structural sheathing on north wall. Middle: wall after installation of the vacuum insulation panels. Right: interior spray foam application.*

the previous winter as the year progressed. The south wall sheathing started off being very dry, probably due to solar exposure during construction and then accumulates moisture over the winter, drying out again the following summer. All structural sheathings are below 26% MC throughout the year, which is the point at which fungal germination occurs.

Temperature, RH, and MC of Framing Wall Components

The MC, RH, and temperature at various locations in the four walls were recorded over the year. All framing in the east, west, and south walls was below, and in most cases well below, 20% MC for the entire year. Only the north wall bottom-plate

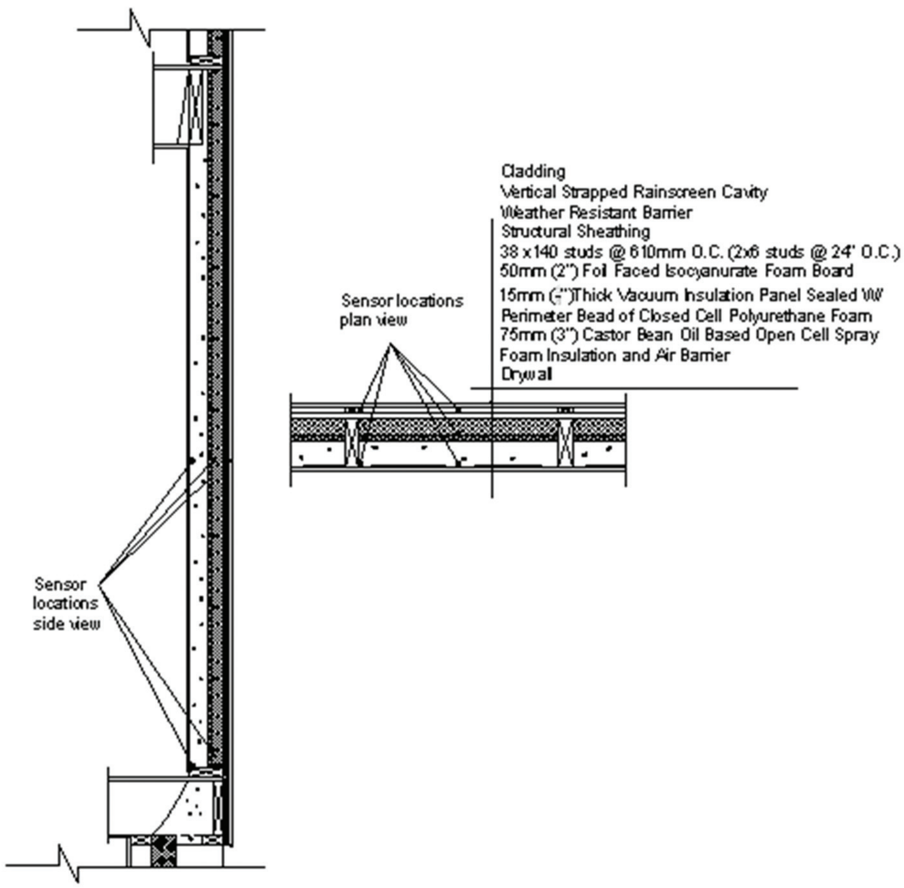

Figure 6 *Vertical and horizontal sectional views of the exterior wall assembly showing sensor locations.*

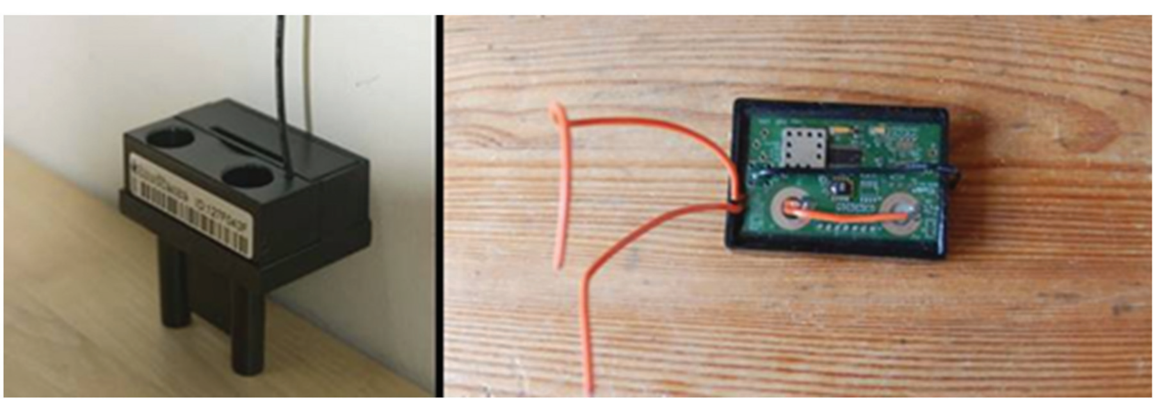

Figure 7 *On left wireless sensor: stainless steel screws pass through the sensor body and the posts on the bottom of the sensor to secure it to a wood substrate and to act as probes for moisture content readings; and on right thin profile sensor, the two wire leads are stripped at the ends and secured with stainless steel screws to measure moisture content.*

outer point exhibited MC levels consistently close to 20% MC, as shown in Figures 14 and 15. In all cases, the MC was below 26%, which is the beginning point for fungal germination.

Discussion

VIPs offer a breakthrough enhancement to the thermal performance of wall assemblies without increasing the thickness of those assemblies. The following lessons were learned from this project.

Thermal and hygrothermal analysis must be an integral part of the design of new high-performance wood-frame wall assemblies, particularly with high levels of insulation such as VIPs. This is to allow for optimization of the thermal aspects of the wall design and to ensure potential areas of moisture accumulation are identified and dealt with at the design stage.

The construction of wall mock-ups prior to construction is an extremely useful tool for refining the wall design and finalizing construction details and sequencing. Wall mock-ups usually include framing, insulations, a corner, a window, and plumbing and wiring. These mock-ups were built mainly to test and verify constructability.

Our construction mock-up also showed that VIPs should not be placed in direct contact with oriented strand board (OSB); this is due to the fact that OSB has small protruding shards of wood that can puncture some VIP skins.

Before specifying sealants, adhesives, and insulations to use in conjunction with VIPs, check with the manufactures to ensure long-term product compatibility or carry out field tests.

Due to the fact that the VIPs cannot be cut, and in the case of this project the most common VIP used in stud bays is 550 × 1500 mm (21.6 × 59 in.), a strict framing module of

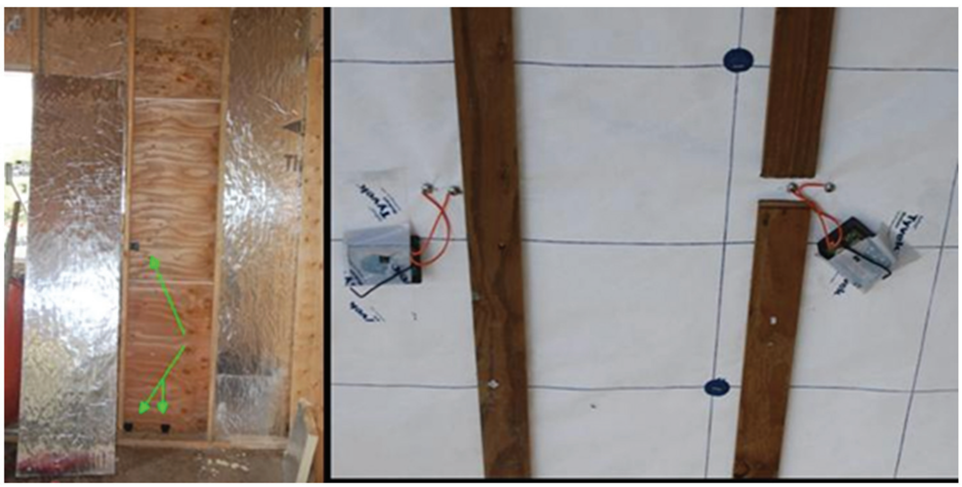

Figure 8 *Left: west wall showing foil faced isocyanurate foam board temporarily removed and three wireless sensors installed behind sheathing on the outside of the stud and bottom plate. Right: thin profile sensors installed on the exterior of the wall sheathing for measuring temperature and RH in the rain-screen cavity and moisture content.*

Figure 9 *Left: South wall showing installation of sensors on the inside of the studs and plates. Right: thin profile sensor installed on the inside face of the isocyanurate foam board at the center of the stud bay, to measure temperature and RH immediately outside the VIP.*

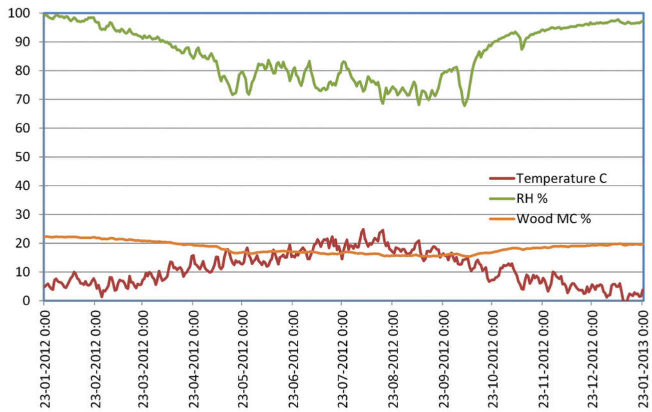

Figure 10 *North wall exterior sheathing MC, RH, and temperature for the rain-screen cavity for full year.*

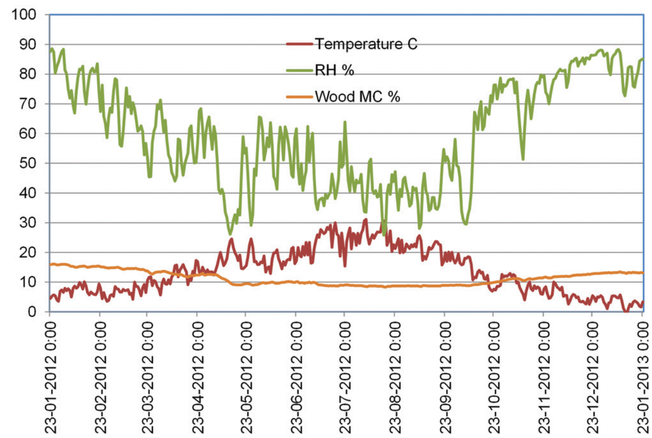

Figure 13 *West wall exterior sheathing MC, RH and temperature for the rain-screen cavity.*

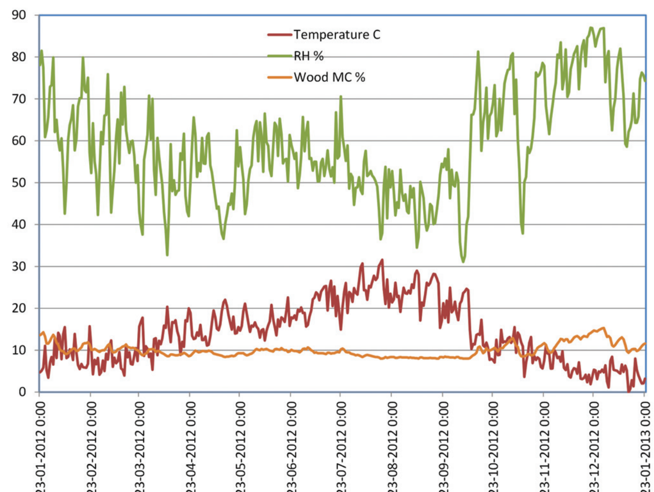

Figure 11 *South wall exterior sheathing MC, RH, and temperature for the rain-screen cavity.*

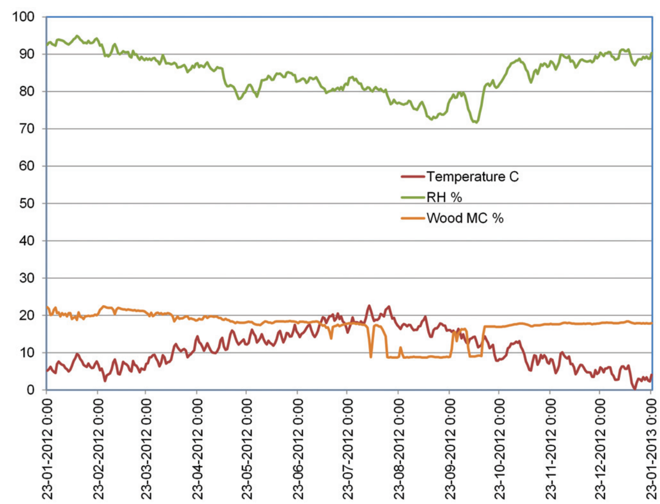

Figure 14 *North wall bottom plate outside face adjacent to stud.*

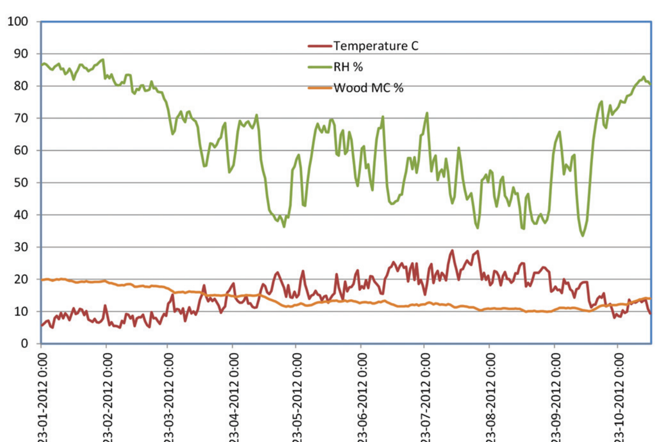

Figure 12 *East wall exterior sheathing MC, RH, and temperature for the rain-screen cavity.*

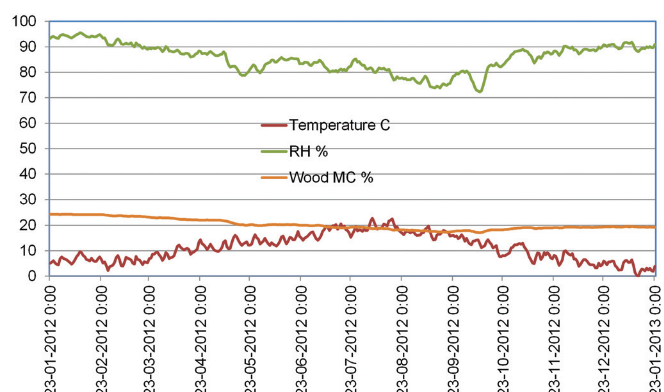

Figure 15 *North wall bottom plate outside face centre of stud bay.*

610 mm (24 in.) on center had to be maintained throughout. The designer must keep this in mind when developing the overall dimensions of the building and determining size and locations of windows, doors, and structural elements such as columns and beams.

Window sill and head heights were dictated by VIP dimensions. Again this will influence window dimensions and their vertical locations in wall assemblies.

The VIPs were overlapped vertically when the stud cavity was not tall enough to accommodate two panels for their full height.

The smaller VIPs used beneath windows were overlapped horizontally where the stud bay was not wide enough to accommodate two full-width panels.

In the case of sloped ceilings, triangular sections at the top of the stud cavities were only filled with the isocyanurate foam and a greater depth of spray foam.

At the design stage where possible, plumbing, wiring, and HVAC services should be confined to interior walls. Where services occur on exterior walls, care should be taken with location and installation of wiring and plumbing services to allow later installation of the VIPs.

The use of wireless switches and sensors greatly reduced the need for wiring in exterior walls and the potential for VIP damage.

CONCLUSIONS

VIPs can be integrated into 38 × 140 mm (2 × 6 in.) wall assemblies, with the thermal and hygrothermal performance being enhanced by the adoption of the advanced framing techniques, reducing the lumber content of the wall thereby reducing thermal bridging. For the application of VIPs in housing assemblies, it should be noted that:

- VIPs installed with lapped and sealed edges form an excellent vapor barrier assembly;
- All framing materials must be dry before the wall assembly is closed in; and
- The consequences of vacuum failure in the VIPs can be high in terms of thermal performance and potential moisture accumulation and must be accounted for in the wall assembly design.

Based on the design, modeling, construction, and monitoring of this wall assembly, it appears that a wall assembly of this type utilizing high-performance VIPs is viable option in the marine climate of northwestern North America for NZE housing with the following provisos:

- The wall assembly must utilize a vented rainscreen cavity to protect from wind-driven rain penetration and to promote drying to the exterior.
- The wall assembly must be very airtight to prevent leakage of interior air into the wall cavity that could cause interstitial moisture accumulation.
- North walls and other walls that do not receive exposure to solar radiation must use a preservative-treated exterior structural sheathing to minimize the possibility of fungal growth on the sheathing.

ACKNOWLEDGMENTS

The Harmony House Project is part of Canada Mortgage and Housing Corporation’s (CMHC’s) highly successful EQuilibrium™ Sustainable Housing Demonstration Initiative. Technical and financial contribution was provided by CMHC and Natural Resources Canada’s Program on Energy Research and Development (PERD) as part of Built Environment Portfolio (BEP) subprogram on Building Envelopes.

REFERENCES

ASTM. 2010. ASTM C518-10, *Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus*. West Conshohocken, PA: ASTM International.

BCBC. 2006. *British Columbia Building Code 2006*, Table 9.25.1.2. Victoria, BC: Office of Housing and Construction Standards, BC Ministry of Energy and Mines.

Binz, A., A. Moosmann, et al. 2005. Vacuum insulation in the building sector: Systems and applications. http://www.ecbcs.org/docs/Annex_39_Report_Subtask-B.pdf.

CMHC. 2010. Harmony house. www.cmhc-schl.gc.ca/en/inpr/su/eqho/haho/index.cfm.

Erb, M. 2005. Vacuum insulation: Panel properties and building applications—Summary. http://www.ecbcs.org/docs/Annex_39_Report_Summary_Subtask-A-B.pdf.

LBNL. 2007. THERM—Two-dimensional building heat-transfer modeling. University of California, Berkeley: Lawrence Berkeley National Laboratory. http://windows.lbl.gov/software/therm/therm.html.

ORNL. 2010. WUFI—Moisture design tool. Oak Ridge, Tennessee: Oak Ridge National Laboratory. http://www.ornl.gov/sci/ees/etsd/btric/wufi_software.shtml.

Mukhopadhyaya P., K. Kumaran, N. Normandi, D. Reenan, J Lackey. 2008. High performance vacuum insulation panel: development of alternative core materials. *Journal of Cold Regions Engineering* 22:4.

NRCC. 2013. Integration of VIPS into Canadian wood frame walls—Performance assessment in the laboratory. Client Report, National Research Council Canada, Ottawa, ON.

Parekh, A. and C. Kirney. 2012. Thermal and mechanical systems descriptors for simplified energy use evaluation of Canadian houses, *Proceedings of SimBuild*, *Madison, WI*.

Parekh, A. and C. Mattock. 2012. Incorporation of vacuum insulation panels in a wood frame net zero energy home. *Proceedings of 7th International Cold Climate HVAC Conference, ASHRAE*.

Simmler H., H. Brunner, S. et al. 2005. Vacuum insulation panels—Study on vip components and panels for service life prediction of vip in building applications. IEA ECBSC Annex 39 Report.

Super-E Japan. 2008. Sapporo net-zero energy home Hokkaido, Japan http://www.super-e.co.uk/PDF/SE_SapporoCaseStudy_HokkaidoJapan.pdf.