COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

Vacuum Insulated Panels

Construction techniques and cold climate testing

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Contents

Vacuum Insulated Panels

Introduction

CCHRC was contracted to work with Panasonic's Vacuum Insulated Panels (VIPs) to develop potential best practices for building with them and to study their performance in a cold climate. CCHRC worked with the raw Mylar covered panels in multiple configurations to develop suggestions for residential construction methods using the panels. In addition, the installed panels were monitored to study their thermal performance in cold Fairbanks conditions.

The project was developed in stages. In the first, two one inch (25 mm[1]) panels were installed on the outside of the CCHRC Mobile Test Lab (MTL) to test a wall retrofit scenario. Next, several trial walls were built in the lab to experiment with a variety of VIP wall construction methods. Finally, CCHRC constructed three large wall panels with different VIP installation techniques to put into an exterior test wall that was exposed to Fairbanks winter conditions on one side. Both 1 and ½ inch (25 and 12 mm) VIPs were installed on the large wall panels. Interior finish wall boards were added to the large wall later in the study when they arrived to the test site.

The MTL and large wall panels were monitored to evaluate thermal performance at varying outside temperatures. The MTL test panel was monitored from October 2017 to May 2018. The large wall panels were monitored from late February to May 2018.

Mobile Test Lab Wall

CCHRC's MTL is used to evaluate different wall configurations for durability under high interior moisture loads. One of the walls in the MTL had two, 1 inch (25 mm) thick VIP panels installed side-by-side, as the outside insulation on the upper half of a wall. The wall was subjected to a high interior moisture load (RH 40% with slight pressure). The exterior of the wall was exposed to ambient Fairbanks winter conditions.

The 1 inch (25 mm) VIP panels were installed outside of the plywood sheathing over the weather resistant barrier. The VIPs were held in place with 2 inch (51 mm) Expanded Polystyrene EPS foam profiles milled on a table saw. The foam was cut into 4 inch (102 mm) wide strips with a 1 x 1 inch (25x25 mm) dado cut along the back edges to fit over the perimeter of the panels and provide a 2 inch (51 mm) wide fastening surface in the center (see Figure 1). The VIP panels were placed against the wall with the foam strips placed between them with the dado overlapping the edges 1 inch (25 mm). The foam profiles were fastened to the wall with screws and plastic washers through the center of the strips

[1] SI units are rounded, approximations are provided to give a rough idea of the sizes.

and 1x4[2] (19x89 mm) furring strips were fastened over the foam to create a rain screen cavity and provide nailers for the attachment of the siding.

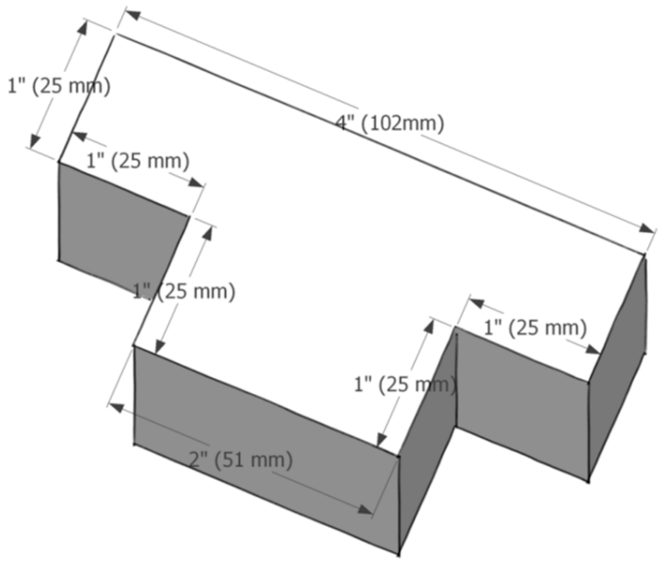


Figure 1. Profile of the foam strips. The 1 inch (25 mm) VIPs fit well into the dado cuts. All penetrations go through the 2 inch (51 mm) center of the profile.

The VIP section of the MTL is the top half of one small test bay. The interior of the VIP section does not have any insulation or finish so that the cavity is accessible for data collection. Figure 2 shows the wall from the outside and Figure 3 shows the inside of the wall. The final outside wall was covered in vinyl siding. The MTL was completed in October. Temperature data was collected on both sides of the wall and heat flux was monitored over the winter.

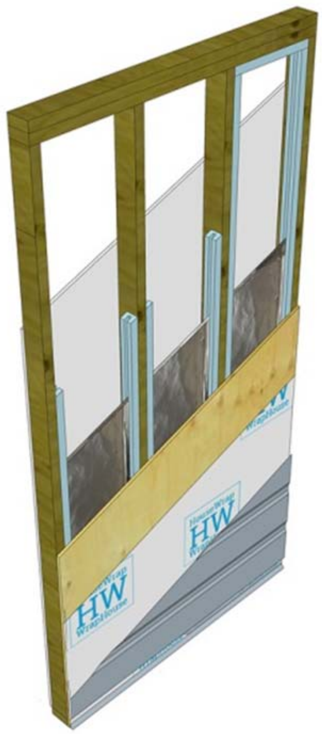
Figure 2. VIPs exterior wall installation on the MTL. Finalizing installation of the VIP and sensors on the MTL. The wall was finished on the outside with vinyl siding

Figure 3. Inside of the VIP wall in the MTL. The sensors are under the red tape on the right.

[2] 1x4 and 2x4 are standard dimensional lumber; the nominal sizes are 0.75x3.5 inches and 1.5x3.5 inches respectively.

Initial Trial Walls

Three quick wall designs were constructed in the lab to see if they would be a good fit for testing in the large wall assembly. A 2x4 (38 x 89 mm) wood stud wall with VIP in-fill was developed. Two different in-fill ideas were tried: friction fitting the VIPs with foam sill sealer in order to provide a tight fit and reduce potential puncture from wood splinters, and fitting the VIPs in with table saw milled Extruded Polystyrene (XPS) foam strips (see Figure 4). Figure 5 shows the two in-fill cavities.



Materials from Inside to out:

- 1/2” (25 mm) Gypsum Wall Board
- 2x4 (38 mm x 89 mm) wood studs 16” (406 mm) O.C.
- Extruded Polystyrene Channels cut on site
- 1/2” (25 mm) Vacuum Insulated Panels (on Plywood Side)
- 1/2” (25 mm) Plywood Sheathing
- Air Barrier
- Exterior Cladding

Figure 4. In-fill schematic. This was an attempt to incorporate the VIPs into current wall construction techniques.

Figure 5. VIPs in-fill. These walls were 2x4 (38X89 mm) on 16 inch (406 mm) center with 14 inch (356 mm) wide VIPs.

A second trial wall was very similar to the MTL wall, only using XPS instead of EPS and covering a full wall with multiple columns of VIPs and XPS strips on all sides of the VIPs. The wall was finished out with 2x4 (38x89 mm) furring strips that could hold siding. Figures 6 and 7 show this wall in various stages.

Figure 6. Exterior retrofit VIPs. Two inches (51 mm) between the VIPs and along the edges only have a 2 inch (51 mm) thermal bridge of XPS

Figure 7. Exterior insulation retrofit method. The exterior 2x4 (38x89 mm) furring strips are shown. The final step in this wall would be adding siding to the furring strips.

The third trial wall used double metal stud wall construction to create a cavity to hold VIPs. The metal stud walls were set 1½ inches (38 mm) apart. The outside wall was covered with a weather resistive barrier after all metal joints with cut edges were taped to eliminate sharp edges. The inside wall had ½ x 1½ inch (12 x38 mm) XPS strips applied to the face of the studs with tape. Once the walls were in place the VIPs were taped together to form large panels with sealed joints and slid into the cavity between the walls. Figures 8 through 13 show the process of building this wall.

Figure 8. Assembling the exterior portion of a double steel stud trial wall with typical window framing. All the sharp corners were carefully covered.

Figure 9. Weather Resistive Barrier (WRB) applied to framing. This was added to keep the VIPs away from sharp metal.

Figure 10. Assembling the interior portion of a double steel stud trial wall with typical window framing. Rigid foam used as a thermal break/gasket material for the VIPs in conjunction with the steel studs.

Figure 11. Friction fitting VIPs with the rigid foam gaskets into stud bays of trial wall. These VIPs were slid in individually.

Figure 12. Inserting VIPs into protected cavity of the trial wall. There was some consideration of being able to replace broken panels at a later date. This is possible with this design but it would not be easy.

Figure 13. Final metal stud wall. This side of the wall would be the interior of the wall covered in gypsum board.

The metal stud wall took a great deal of preparation to make sure there were not sharp edges that might puncture the VIPs. Even using extreme care to protect the VIPs a few were still punctured. The fine metal shavings that come off metal studs when they are cut or shards from screws were found to be highly problematic. Figure 14 shows a VIP that was compromised by a metal shaving. The next iterations of wall designs did not use metal studs.

Figure 14. VIP with lost vacuum. The large wall was built using wood studs rather than metal studs to avoid any potential sharp metal shavings that might compromise the panels.

Large Test Wall

CCHRC built a large exterior test wall in their South Lab test bay. The test wall had multiple configurations that tested in-fill, continuous insulation interior double wall, and continuous insulation exterior wall with curtain wall rain screen designs. There were three in-fill techniques tested on 16 inch (406 mm) on center stud spacing, one test wall section of an exterior application with adhesives applied to the warm side, and one test wall section of an interior application with adhesives applied to the cold side. Multiple types of adhesives were tested on the continuous insulation panels.

Stud In-Fill

The stud in-fill techniques are shown in Figures 15-18. The panels were ordered to fit in the 16 inch (406 mm) on center stud bays. Each VIP was 14 inches (356 mm) wide and 4 feet (1.2 m) long. Two stud bays tested friction fit ideas and one stud bay tested bi-axial reinforced double sided mounting tape. Stud bay one used sill sealer around the edges with small XPS stop blocks around the perimeter to hold the VIPs against the sheeting without air sealed joints between the VIPs or around the perimeter. Stud bay two had milled XPS channels to hold the VIPs (shown in Figure 16) with air sealed joints between the VIPs. In stud bay three the VIPs were held in place with double sided tape and air sealed on all joints and perimeters with polyurethane spray foam.

Several VIPs got damaged using the second in-fill technique with the milled XPS profiles. Figure 18 shows some damage. The panels are well protected from general house damage, but making sure the fit was precise enough to limit air leakage meant panels got squeezed too much during installation causing them to lose their vacuum. The third stud bay application technique using double sided tape was the fastest and easiest application process and held the VIPs fast and flat to the exterior sheeting without distorting the panels. The first stud bay friction fit application also accommodated inherent stud cavity dimensional variations like the third bay's double sided tape techniques without causing stress and distortion but did not provide adequate mounting support of the VIPs for long term application.

Figure 15. Large test wall section framing. Relative humidity sensors were embedded in the center cavity.

Figure 16. Friction fit cavity assembly technique. Mortised rigid foam was developed to accommodate the VIPs.

Figure 17. Completed large test wall sections. This shows all 3 in-fill techniques.

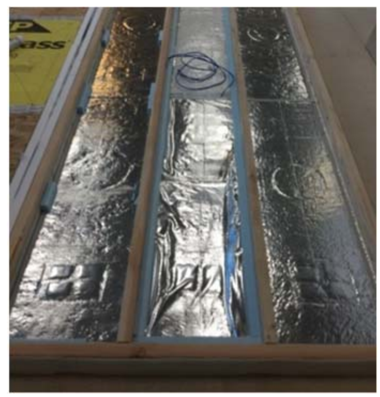


Figure 18. Compromised VIPs. The friction fit on the center bottom panel was too tight. The stress caused this panel to lose vacuum.

Continuous Exterior Insulation

The central part of the large wall had an exterior continuous insulation design. VIPs were glued to the sheathing outside the 2x4 (38x89 mm) framed wall using a variety of adhesives. A variety of sheathing materials were also used in order to test adhesion on a variety of substrates. Once the wall was in place an external curtain wall constructed of 2 inch (51 mm) metal studs with painted plywood siding was installed to protect the VIPs from the outside, representative of a rain screen curtain wall design. Figure 19 shows the final wall construction.

Materials from Inside to out:

- 1/2" (12 mm) Gypsum Wall Board
- 2x4 (38 mm x 89 mm) wood studs 16" (406 mm) O.C.
- Fiberglass Insulation
- 1/2" (12 mm) Plywood Sheath-ing
- 1" (25 mm) Vacuum Insulated Panels taped together
- Air Barrier
- 1/2" (12 mm) Air Space
- Curtain Wall
- Exterior Cladding

Figure 19. Continuous exterior insulation with a curtain wall. The VIPs were glued directly to the plywood.

The VIPs were adhered to the sheathing with the adhesives shown in Figures 20 and 21. The joints between the VIPs were taped in some cases and sealed with spray foam in others (see Figure 21). A weather resistive barrier was laid over the VIPs and taped in place.

Continuous Interior Insulation

The final section of the wall was designed to test adhesives at low temperatures. A small 2x4 (38x89 mm) wood stud wall was built with VIPS glued to the inside of the wall. The outside was covered in plywood siding. This section of wall is shown in Figure 22. In this configuration a second interior stud wall would be built over the interior VIPs to provide a plumbing and electrical chase.

Once the walls were completed in the lab they were stood up in the test space. They were not built in place because construction took place in January, which was too cold to keep the test space open for as long as the build took. In addition, the adhesives that were tested with the exception of the spray contact adhesive and double sided tape required cure time to set; requiring the walls be constructed flat. Figure 23 shows how the wall sections were tipped into place.

Figure 20. VIPs were applied to the exterior of this wall. Different sheathing materials were evaluated.

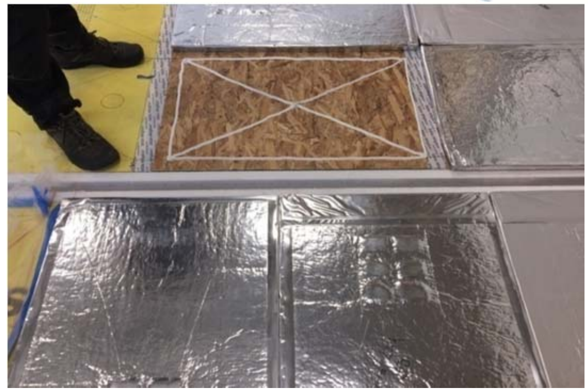


Figure 21. Applying adhesives to exterior side of wall. All adhesives were applied in the same pattern.

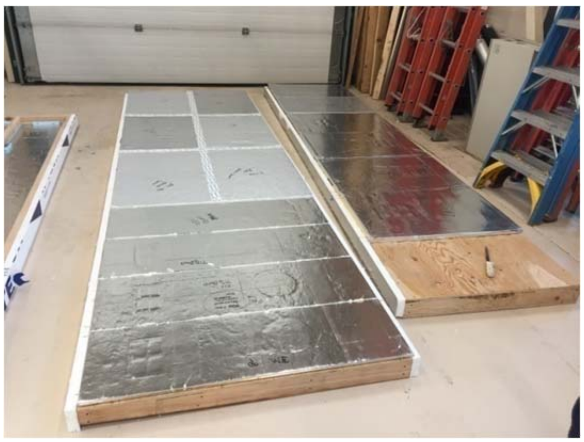


Figure 22. Completed exterior insulation test section. This section of the large wall has both ½ and 1 inch (12 and 25 mm) VIPs.

Figure 23. Standing up the large test wall. The three sections were stood up independently and attached together in place.

Figures 24 through 26 show the final touches to the large wall both inside and outside. The wall was completed in mid-February and data collection started the first week in March. Figure 27 shows the inside wall with some of the interior finish wall boards installed, these boards were installed the last week of March.

Figure 24. Completed installation of large test wall. The partial curtain wall is laying on the floor

Figure 25. Installation of exterior sensors. Part of the curtain wall siding is swung to the side.

Figure 26.Completed installation of large test wall. The center is the curtain wall.

Figure 27. Installing the new finish wall boards on the inside of the large wall. The boards have nailing edges where they can be affixed. There are non-VIP finish wall boards in use in places that needed cutting.

Results

Temperature, heat loss, and relative humidity data was collected from the MTL and the large wall. Some of the panels with compromised vacuum seals were also tested for heat loss.

Relative Humidity

Typical construction in cold climates relies on interior air/vapor retarders to keep warm humid interior air from getting into the walls and condensing on the cold sheathing. Air/Vapor retarders are typically 6 mil polyethylene plastic installed directly behind the interior gypsum board. CCHRC did not install any air/vapor retarders in these tests, choosing instead to see how moisture migrated through the wall (CCHRC did not humidify the south lab so the RH on the warm side of the large wall was well below typical, averaging 18%).

The RH at the sheathing plane behind the ½ inch (12 mm) VIPs installed with the milled XPS channels was monitored. Over the course of the testing it did not get above 70% and there was no cause for concern in this study. Additionally, the plywood was well below freezing for much of the time which makes it difficult for mold to grow. Ice did form behind the in-fill design that used only sill sealer and XPS blocks to hold it in place; there were no RH sensors in this cavity. The ice was discovered when one of the panels was touched and crystals could be heard falling. Care should be taken to seal the VIPS so that there is minimal vapor movement to the very cold sheathing behind the VIPs. In locations with higher RH, sealing the VIPs without a vapor retarder in place may not be sufficient (further study is recommended). Figure 28 shows the temperature and the relative humidity of one stud cavity.

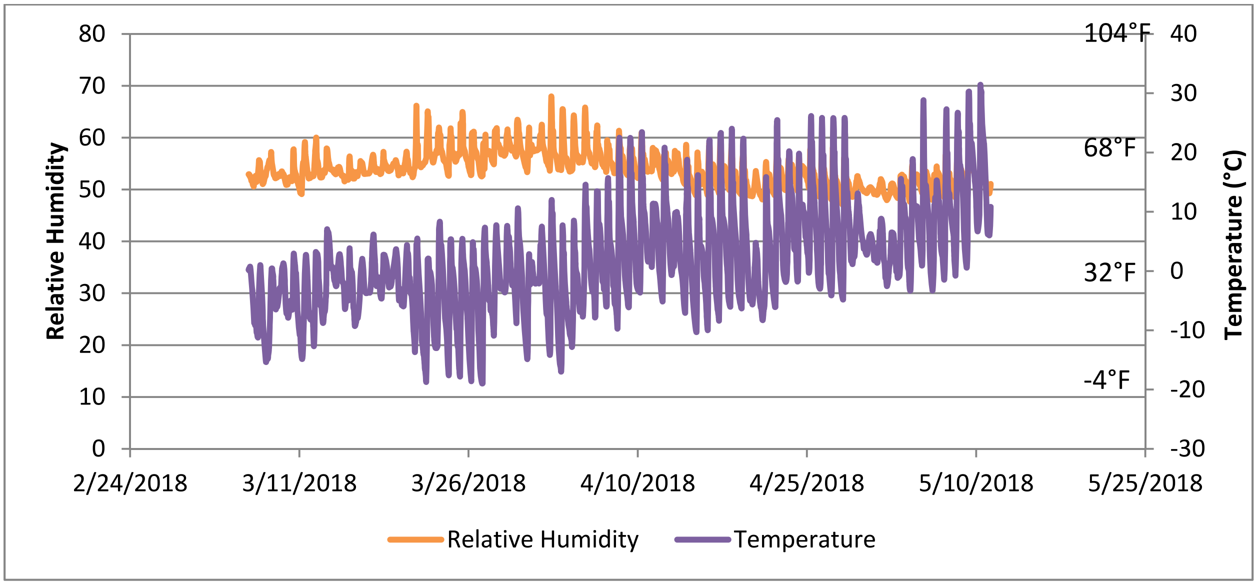


Figure 28. Relative humidity and temperature of the wall cavity behind VIPs. This section of VIP in-fill design was well sealed on the edges. The in-fill design that was not well sealed had some ice buildup behind the VIP.

Infrared Photos

CCHRC took infrared (IR) photos of the large wall on a cool 36°F (2°C) morning. The photos were taken from both sides of the wall and show where the heat loss is the greatest. The photos also show that some of the VIPs have failed allowing greater heat loss. Figures 29 through 32 show IR photos of the large wall.

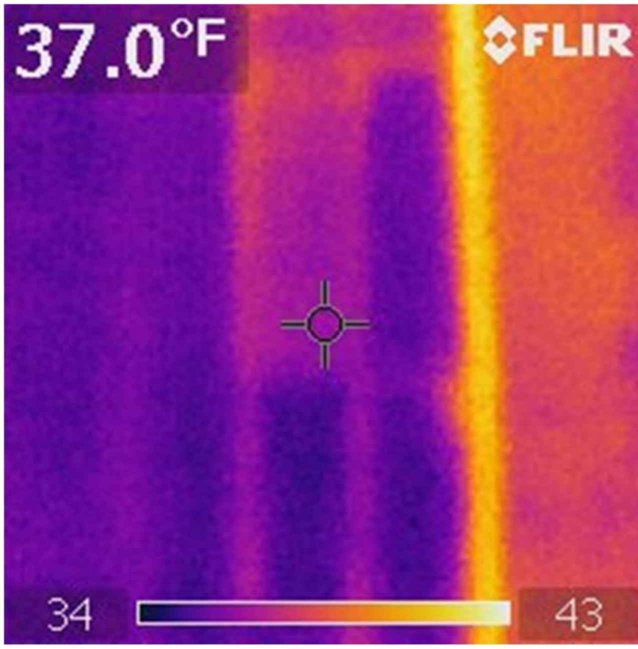


Figure 29. An outside view of the in-fill wall. The bright yellow line is where the wall joins the existing wall. The VIPs are visible as the deep purple. The lighter purple rectangle at the top is a broken VIP. The studs are also visible as the light purple. (range: 1.1°C to 6.1 °C)

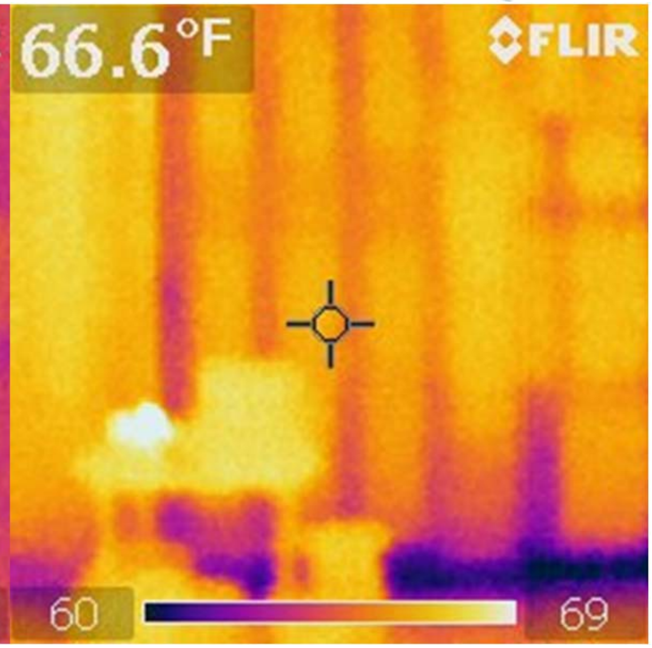


Figure 30. The in-fill wall from the inside. This is after the interior finish wall boards were installed. The studs are still visible as red lines. (range: 15.6°C to 20.6 °C)

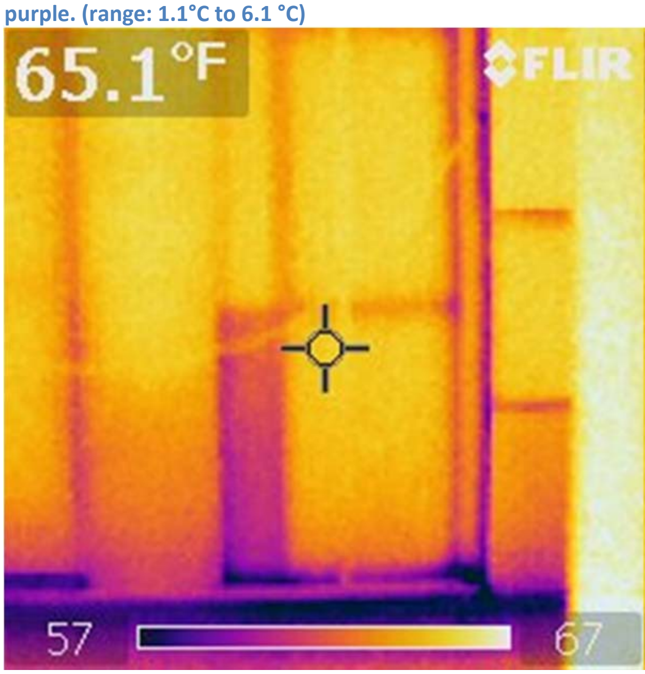


Figure 31. The retrofit wall from the inside. There are 2 of the finish panels on the left side of the photo. The joints between the 1 inch (25 mm) VIPs are visible as the reddish lines just above the cursor. The purple rectangle toward the bottom is part of a broken VIP. (range: 13.9°C to 19.4°C)

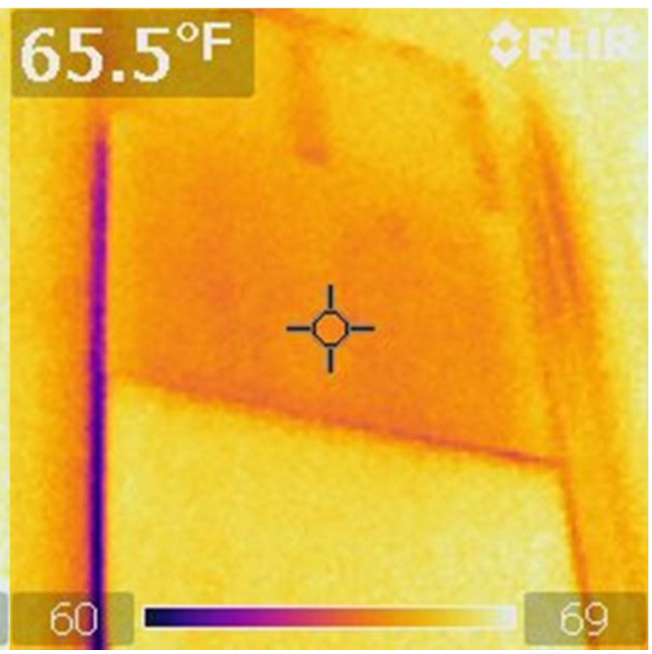


Figure 32. The top two panels of the continuous interior VIP wall from the inside. The upper panel is about 9F° (5C°) cooler than the lower panel. While not completely failed this panel seems to have less vacuum than the others. (range: 15.6°C to 20.6 °C)

R-value

Measuring the heat flow through the VIPs in-situ was more challenging than expected. The flow was so low for the 1 inch (25 mm) VIPs that the heat flux transducers could not always read a clean signal. The hourly data was compiled into weekly data (for the MTL) and daily data (for the large wall) in order to produce readable data.

The MTL had 1 inch (25 mm) VIPs outside of the stud wall with no insulation inside the studs. The VIP and sheathing R-value was calculated over 5 months. Figure 33 shows the R-value in the MTL over time. The average R-value was 72 (13 RSI). The R-value was higher than the expected R-60 (10.5 RSI); the higher numbers tended to coincide with lower temperatures.

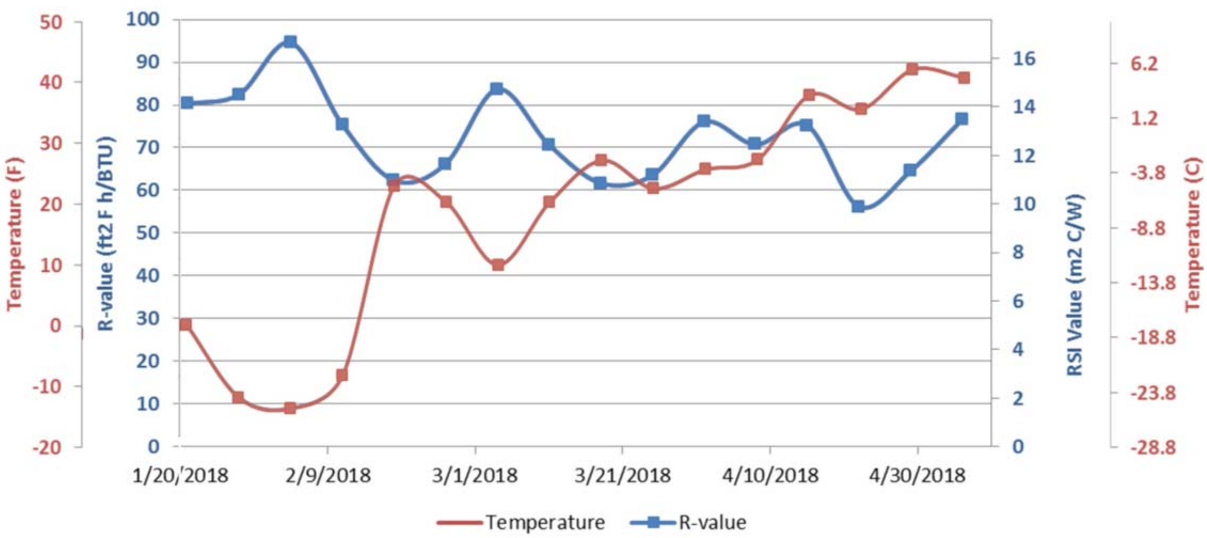


Figure 33. Weekly averages of the MTL VIP wall. The R-value improved with dropping outside temperature. This is because radiation is the dominant form of heat transfer in a vacuum and the colder outside temperature slows heat transfer by radiation.

The R-value data from the large wall was not as variable as the MTL so daily averages were calculated. Data collection started the first week of March with unfinished walls. The finish wall boards were added to the wall the last week in March.

The 1 inch (25 mm) VIP had a variable R-value but still readable until the finish wall boards were added (Figure 34). The average R-value of the 1 inch (25 mm) VIPs and the plywood (without the finish wall boards) was R-66 (12 RSI). After the wall was finished the data is too noisy to use (even the weekly averages are chaotic). The ½ inch (12 mm) VIPs produced fairly consistent data on the large wall before the finish wall boards were added. The ½ inch (12 mm) VIP wall (with the plywood included) averaged R-28 (5 RSI).

One of the broken ½ inch (12 mm) VIPS was monitored as well. The average R-value of the broken VIP and plywood section of the wall was 5.7 (RSI 1) without the finish wall boards.

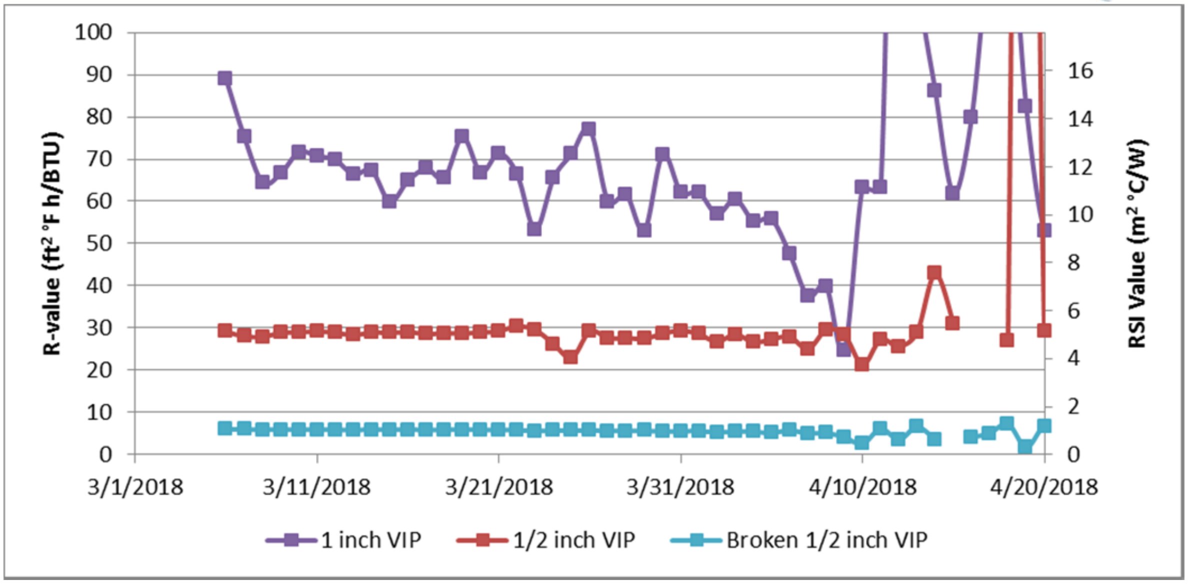


Figure 34. Daily R-value for the large VIP wall. The addition of the interior finish wall boards changed the conditions around the sensors and decreased the heat loss to a point that the sensors had difficulty getting accurate readings.

Adhesives

CCHRC worked with a variety of adhesives. Adhesives were evaluated for adhesion to plywood and the Mylar facing of the VIPs, but also the ability to remain functional at cold temperatures and the ease of installation. Notes on the adhesives are presented in Table 1. The notes are based on the experience of the CCHRC VIPs installers.

Table 1. Adhesive installation notes.

Adhesive	Installation Notes
3M-High Strength 90 Spray Adhesive	Excellent initial tack held VIP tight and flat; resisted manual lifting; suitable for vertical application; instant grab; strong fumes requires ventilation for safe application; low VOC product is available at a premium cost
Touch-n-Foam Polyurethane Foam Adhesive	Failed to bond
TiteBond-Greenguard Construction	Weak bond
ECHO tape DC-R218A	Double sided pressure sensitive bi-axial tape – was the fastest and cleanest adhesive; bonded tenaciously to all materials; excellent initial bond-held the panels tight and flat; suitable for vertical application
ChemLink – Duralink 50	Thick consistency seemed to have an initial tight flat bond resisting lifting at the corners; not suitable for vertical application due to cure-time
ChemLink – MI	Good bond once set; not suitable for vertical application due to cure-time
ChemLink – Metalink	Good bond once set; not suitable for vertical application due to cure-time
Liquid Nails Fuze it	Moisture curing polyurethane based adhesive – caused difficulty achieving good bond in Fairbanks dry climate; not suitable for vertical application due to cure-time

The final step in this project was to remove panels from the wall to see if the adhesives were still pliable and look for any chemical degradation that may have happened over the 5 month test. The test may have been too short to see any chemical degradation. Removal notes are presented in Table 2.

Table 2. Adhesive removal notes.

Adhesive	Removal Notes
3M-High Strength 90 Spray Adhesive	The panel popped off the wall with little effort, there was no residue on the VIP, this adhesive may need longer analysis
ECHO tape DC-R218A	The panel pulled off with some effort, the VIP was not damaged
ChemLink – Duralink 50	Still bonded flat, the VIP failed to pull off the wall at all
ChemLink – MI	Still bonded flat, the VIP failed to pull off the wall at all
ChemLink – Metalink	Did not adhere flat to the plywood, pulled off the wall slightly in places
Liquid Nails Fuze it	Did not adhere flat to the plywood, pulled off the wall slightly in places

Discussion

Even with the widely varying data, the VIPs meet their advertised thermal performance consistently. The ½ inch (12 mm) VIP was consistently an R-28 to R-29 (4.9 to 5.1 RSI) for the month of March; the advertised value is R-30 (5.3 RSI), less than a 1% difference. VIPs have not been used much in residential construction because they are too expensive; however the price seems to be getting close to what the residential market can bear. One of the biggest drawbacks with the VIPs is their fragility; 4 of the 27 VIPs installed in the large wall broke at some point during installation, a failure rate of 15%.

The continuous exterior insulation walls had the best protection for the VIPs. Continuous exterior application of VIPs to the exterior sheeting has several advantages over the other application techniques. Insulation placed on the exterior of the building assembly provides protection against thermal bridging of structural materials. Exterior application accommodates multi-story construction without thermal breaks between floors. Placing the insulation to the exterior allows for installation of the electrical, plumbing, and mechanical systems on the interior side of the wall cavity without fear of damage to the VIPs or the need for additional furring or an interior wall.

The exterior application technique used in the MTL test wall was the least complicated and most viable application method based on standard building techniques and material application. The VIPs were installed between milled foam strips which provided a location for fastening furring strips to support a rain screen siding system. The foam strip system does not provide as complete insulation coverage as the continuous exterior application with a curtain wall but it does address the major design and build issues associated with the curtain wall method. The XPS foam strip system provides a thermal break between the siding and wall and allows the rain screen to be constructed using standard building techniques. While the curtain wall method creates a very complete insulation envelope it also creates structural design and construction challenge especially with the fastening to the outer wall.

The CCHRC test walls were designed so that the VIPs were protected once construction was complete. This meant the VIPs were not accessible from the inside or the outside of the wall so that occupants cannot puncture them accidentally. However, most of the failure happened during construction.

CCHRC brainstormed ideas to improve/protect the VIPs during construction. The thin Mylar covering of the VIPs was easily punctured with staples, metal shavings, screws, and other items that are typically found on a job site. It seems that there are many ways to make the covering more robust. Encasing the VIP in 1/4 inch (6 mm) EPS foam might be the quickest most cost effective option. Alternatively the VIP could become the central part of the prefabricated wall system like a Structurally Insulated Panel (SIP) or a Stressed Skin Panel System.

The finish wall boards are a very interesting product. We were not able to test them well in this study as they arrived late and were not part of the original project. The finish wall boards are light and similar to the U.S. gypsum board finishing boards. They are not beveled at the edges, which means they are not optimum for current U.S. mudding and taping finishes. They have an interior metal plate that is difficult to puncture but can be done while attempting to hang items on the wall. The metal plate also makes it impossible to use a traditional stud finder which is typically used when adding interior wall décor. The finish wall boards do improve durability of the VIPs during construction; they are less susceptible to random construction site punctures. One of the installed panels did lose vacuum during installation when the metal plate warped while being screwed to the wall. In locations that will not see so much destructive user activity, like ceilings and floors these panels could be a useful added layer of insulation.

Conclusions

Overall the product works well with a variety of adhesives. The largest challenge is the fragility of the material. Any encounter with a sharp object can puncture the Mylar coating which causes the panel to lose thermal performance. Careful construction practices and/or more robust packaging can mitigate this problem. CCHRC recommends evaluation and testing of potential manufacturing process that incorporate the VIPs into a larger package like a SIP that would protect the VIPS in wall applications.

The finish wall boards were not studied as well as the raw VIPs. Further analysis of the finish wall boards is suggested. Analysis should include looking at them in ceiling and flooring applications.

Getting the VIPs from the packaging to the wall is still a delicate process and at this point the best suggestion is to keep them packaged until the last minute. Do a sweep of the area of extraneous sharp points before removing them from their packaging. And take them from the package and stick them directly to the wall. A spray adhesive or double sided tape that adhere immediately are the best options to hold the VIPs in place and away from potential sharp points. Packaging the VIPs in a more protective manner, like encasing them in ¼ inch (6 mm) EPS would improve durability greatly.

In their current configuration, the VIPs will be the most protected when used as exterior insulation. The exterior insulation method shown in Figures 1, 2, 6, and 7 is the most recommended construction method for working with the Mylar VIPs and traditional residential construction methods. If the building is configured in a way that a self-supporting curtain wall is an option, the exterior insulation method from Figure 19 is an excellent option with less thermal bridging between VIPs.

The VIPs have excellent thermal performance for their size. In fact they seem to perform better as they get colder, which is an advantage in a heating dominated climate. Further study in a more controlled environment is suggested to verify this.