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Developing a Composite Vacuum Insulated Panel (VIP) Insulation/Vinyl Siding Technology for Retrofitting Residential Walls

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Buildings and Transportation Science Division

DEVELOPING A COMPOSITE VACUUM INSULATED PANEL (VIP) INSULATION/VINYL SIDING COMPOSITE TECHNOLOGY FOR RETROFITTING RESIDENTIAL WALLS

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Executive summary

Retrofitting an existing wall assembly to make it more energy efficient is a difficult technical challenge. Common approaches include cavity fill techniques, adding continuous foam or fibrous insulation, or adding an insulated cladding or siding product.

Filling wall cavities with loose-fill insulation is the most common practice, but conventional "drill-and-fill" techniques result in damage to the interior gypsum board. Performing the task from the exterior side requires removing and replacing the cladding system and adds appreciable cost. Even after completion, the wall system is under-insulated by today's standards, achieving an R-value of only approximately R10.

Continuous insulation (CI) can be applied to the outside of the exterior sheathing, but it also adds appreciable cost to the project. The 2018 International Energy Conservation Code (IECC) requires CI thicknesses of 1 or 2 in. on residential building walls with traditional 2 x 4 framing. Additional CI would be required if the existing wall cavities were uninsulated. The addition of this amount of CI requires that all the architectural details be retrimmed.

Insulated siding—vinyl siding with manufacturer-installed rigid expanded polystyrene foam plastic insulation permanently adhered to it—forms a layer of CI around a home. The international standard for insulated vinyl siding (ASTM D7793) requires a minimum thermal resistance rating of R2. The added amount of R-value currently available in insulated vinyl siding on the market is very small.

This report summarizes a research project to produce vacuum-insulated panel (VIP)/vinyl siding that would represent at least a five-fold thermal improvement from currently available insulated siding products. It has sufficient R-value to meet the CI requirements of the 2018 IECC in all climate zones and has a much thinner profile that will facilitate its application to existing residential homes without the need for expensive retrimming of the architectural details.

Acknowledgements

This work was supported by the Building Technologies Office of the U. S. Department of Energy under Contract No. DE-AC05- 00OR22725 with UT-Battelle, LLC. The authors would like to thank the DOE's Dale Hoffmeyer for his support of this project. We are grateful to Douglas Smith, Ron Esparza, and John Jones of NanoPore LLC, as well as Chris Johnson and Patrick Olvey of Royal Building Products, for their efforts and support in making the vinyl siding and composite siding material boards needed for this project. We want to acknowledge the efforts of Liza Bowles and Christine Barbour for their assistance in organizing and facilitating the user sessions. We also thank Som Shrestha of ORNL for helping with the energy savings analysis and Chrissi

Antonopoulos of Pacific Northwest National Laboratory (PNNL) for her help in developing cost data for this technology.

Introduction and background

This project attempted to seize an opportunity to take a giant leap forward in commercializing a technology that would address a key opportunity to achieve energy savings in the existing residential housing stock. It is typically very difficult to increase the R-value of the thermal envelope in existing residential housing as doing so from the inside is disruptive and can be cost-prohibitive, and there have not been good solutions to increase thermal envelope performance from the exterior through adding continuous insulation due to the additional work required to fit existing architectural features to the new wall thickness and to reclad the facade. A high thermal resistivity or R-value per inch product that can be used in these applications offers an excellent solution.

Retrofitting an existing wall assembly to make it more energy-efficient is probably the most difficult technical challenge facing the building industry. Common approaches used today include cavity fill techniques or adding an insulated cladding or siding product. Filling wall cavities with loose-fill insulation is the most common practice, but conventional "drill and fill" techniques damage the interior gypsum board that is difficult to repair and completely conceal. Performing the task from the exterior side requires removing and replacing the cladding system and adds appreciable cost to the project. Typically, this retrofit does not meet the minimum existing building code requirements, resulting in an insufficient thermal performance upgrade.

Today's state of the art in terms of energy-efficient cladding is insulated vinyl siding. Insulated siding—vinyl siding with manufacturer-installed rigid expanded polystyrene foam plastic insulation permanently adhered to it—forms a layer of continuous insulation around a home. The international standard for insulated vinyl siding, American Society for Testing and Materials ASTM D7793 (ASTM, 2020), requires a minimum thermal resistance rating of R2. The added amount of R-value that currently available insulated vinyl siding offers is small and does not allow building owners to dramatically improve the energy performance of their wall assemblies by its addition. It does, however, help with air sealing. Adding additional R-value is possible through installing two inches of foam but creates considerable expense in architectural detailing and creates a less than desirable appearance. The cost of this approach depends on the home design and can vary appreciably depending on the number of architectural features incorporated in the building's design.

The proposed vacuum-insulated vinyl siding technology developed during this project represents a 4- to 5-fold thermal improvement from currently available insulated siding products. It has sufficient R-value to improve thermal performance significantly and has a much thinner profile than traditional mass insulation that will facilitate its application to existing homes without the need for expensive re-trimming of the architectural details. Our initial target was to provide this product for \$5 - \$6/ft², which would give the homeowner a good Return on Investment (ROI) and a better option than currently exists in the market. For comparison, existing insulated vinyl siding sold today costs \$2 - \$3/ft².

In 2016, an engineering prototype of the proposed insulated siding was developed. The siding consisted of 0.5-inch modified atmosphere insulation (MAI) panels attached to a flat vertical siding and covered by 0.5-inches of extruded polystyrene board (see Figure 1). MAI is a low-cost vacuum insulation that can achieve R35/inch. The engineering prototype achieved R11.7. In 2017, a factory-manufactured engineering prototype using a more common “double 6” siding profile will be created and tested. The goal of this project was to improve the design and to seek user feedback regarding its viability as a retrofit cladding product and reports on the research activities over the past three years.

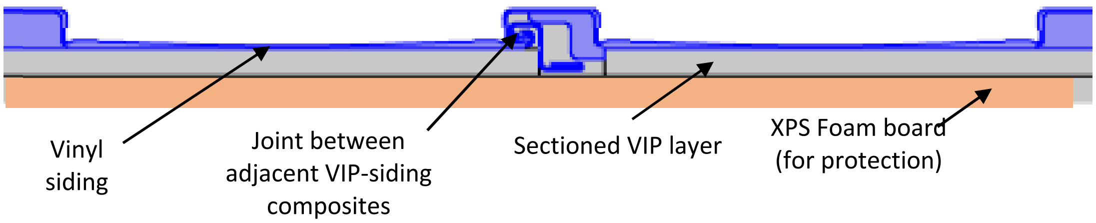


Figure 1: Cross section of insulated vinyl siding evaluated in 2016. This configuration yielded almost R12.

What are VIPs and MAIs

Vacuum Insulation Panels (VIPs) are ultra-thin, high-performing insulants that can be up to 20 times more effective than traditional mass insulation products. VIPs provide energy efficiency and space benefits for buildings, appliances, and refrigerated transportation systems, including those used to ship COVID-19 vaccines (VIPA, 2014).

The first VIP was made in 1930 from a porous material enclosed in rubber. In the 1950s, a glass fiber core was inserted into a welded steel panel. Nanostructured materials began to appear in the 1960s, and the development of VIPs intensified with the first VIPs made of precipitated silica beginning to appear in the 1990s.

Vacuum insulation panels provide a high insulation value in a thin cross-section which is achieved by packaging the core material in a gas impermeable membrane and evacuating it to very low pressures below ambient (Figure 2). The core material and pressure will determine the level of thermal performance possible. Insulation values can range from R30 to greater than R100 per inch (Alam et al., 2011). Figure 3 shows the insulation value of vacuum insulation panels compared to commercial insulation materials used in residential and commercial construction.

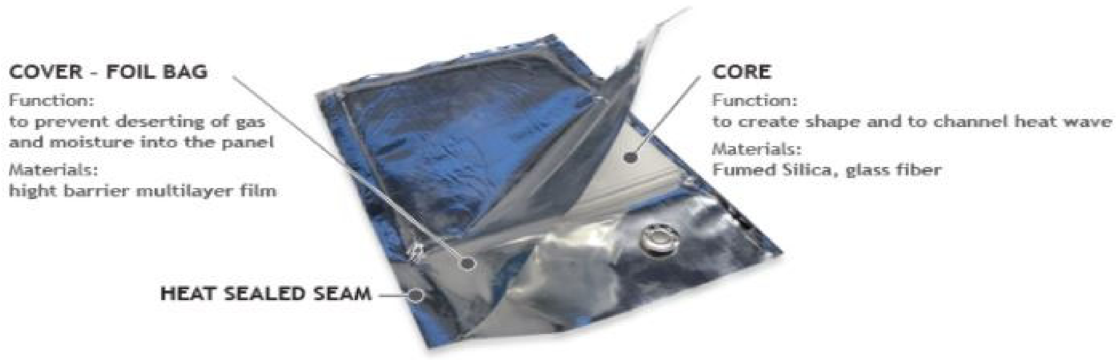


Figure 2: Components, materials, and functions of VIPs (courtesy of VIPA International).

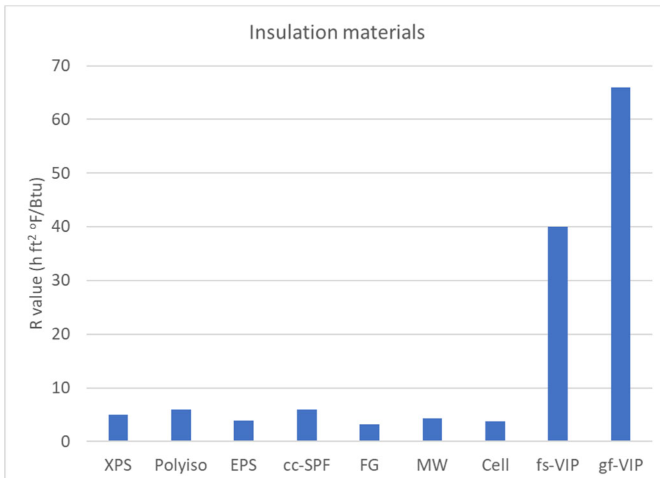


Figure 3: The insulation value of commercial insulation materials compared to vacuum insulation panels. Legend: XPS - Extruded polystyrene; Polyiso - Polyisocyanurate board; EPS - Expanded polystyrene; cc-SPF - closed cell spray polyurethane foam; FG - fiber glass batt; MW – mineral wool; Cell – blown in cellulose; fs-VIP – fumed silica vacuum insulation panel; gf-VIP – glass fiber vacuum insulation panel.

Fumed silica, glass fibers and rigid plastic foams are the predominant core materials used in commercially available vacuum insulation panels, each with a unique set of performance characteristics. Figure 4 shows the thermal conductivity for the different core materials as a function of pressure (Heinemann, et al., 2005). The major distinction between core materials is the dependence of thermal conductivity on pressure. For glass fibers and plastic foams, the thermal conductivity behavior has two characteristics or properties. First, pressures less than 1mbar are required to achieve high insulation values. Second, the insulation value is strongly pressure dependent at values greater than 1 mbar and decreases rapidly with increasing pressure. For VIP cores made with glass fiber insulation, values approaching R100 per inch are possible at very low pressures (0.001 mbar or less). In fact, some manufacturers report values of R100 per inch on their technical data sheets. However, preserving the vacuum level required to maintain such a high insulation value remains an issue or concern.

The thermal behavior of vacuum insulation panels comprised of fumed silica cores are distinct from those made of glass fibers and plastic foams. Figure 4 clearly reveals the feature that distinguishes VIPs with fumed silica cores from other core materials, and that is the pressure-independent thermal conductivity up to 10 mbar. It's this behavior that makes these vacuum insulation panels attractive as insulation materials in residential and commercial construction compared to VIPs with other core materials. The other difference is the value of the thermal conductivity at ambient pressures. At 1000 mbar, the thermal conductivity for VIPs with fumed silica cores is significantly lower compared to other core materials. At ambient pressure, which represents a complete loss of vacuum, the thermal conductivity of the fumed silica core is just below 20 mW/mK, which is lower than any traditional mass-type insulation. The closest performer is polyurethane foam with a thermal conductivity just below 30 mW/mK. The other traditional insulation materials have thermal conductivities greater than 30 mW/mK.

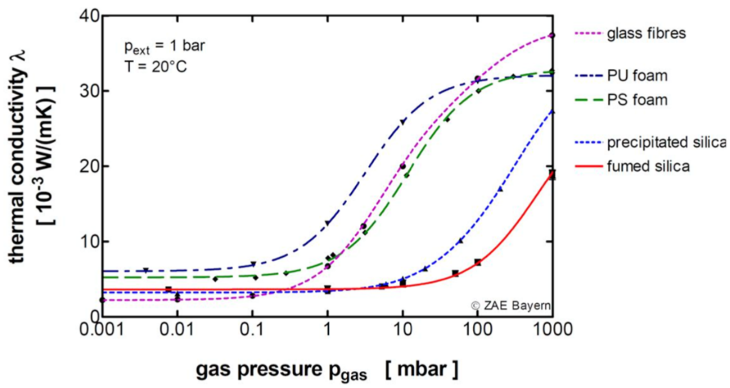


Figure 4: Thermal conductivity of vacuum insulation panels as a function of pressure for different core materials (courtesy of ZAE Bayern).

Barrier films allow the transmission of gas and water vapor at very low rates. For example, Avery Dennison's Proprietary Surface Technology (PST) metalized laminated barrier film has a water vapor transmission rate of 0.035 g/m^2/day @ 100°F and 90% relative humidity (Hanita Avery Dennison, 2018). Though the rate is low, it's sufficient to result in loss of vacuum of the VIP over extended periods of time at time scales characteristic to the lifetime of residential and commercial buildings. Working with industry and academic partners, the European Union (EU) funded research that led to the development of an industry standard, EN 17140, to quantify the performance of manufactured vacuum insulation panels (European Committee for Standardization, 2021). That standard includes a proposed accelerated aging test method for the purpose of calculating service life.

A vacuum insulation panel (VIP) is the only existing technology that can enable the development of composite insulation materials with R-values of 12 per inch or greater. Although VIPs have existed for many decades, their adoption in buildings has been limited with their high cost and integration into the building envelope being the major hindrances. Protecting the VIPs during transportation and handling, as well as when they are installed in the envelope, are also issues that need to be mitigated to successfully deploy VIPs in building envelopes.

A recently developed, lower-cost variant of vacuum insulation, called modified atmosphere insulation (MAI), was initially used in this research (Desjarlais et al., 2019). MAI is created using a different processing method compared to VIPs, which can possibly lead to significant cost reductions. However, to achieve the desired R-value of the composite insulated siding, it was critical that MAI possess the same thermal performance as regular VIPs. This report provides some background information on the MAI technology, its distinguishing features, and its thermal performance.

The cost of VIPs is primarily driven by the manufacturing process (up to 75% of the total cost). Initially, the composite siding contained MAIs. MAI is processed at ambient pressure, using standard vertical form-fill/seal machines of the type used to package potato chips. Regular VIP processing includes pressing fine powders into boards, which must then be cut, dried, evacuated, and sealed in a vacuum. MAI avoided these process steps by replacing the air in the fluidized powder core with a low-conductivity vapor (steam, for example). Once the core is sealed within the barrier films and cool-formed to its final shape, the vapor condenses and creates a vacuum. It was estimated that the cost of MAI panels would be appreciably less than traditional VIPs. The MAI technology is protected by several patents held by our partner NanoPore (Smith, 2017). With the sale of NanoPore and the passing of their owner Dr. Douglas Smith, MAI panels were no longer available, and the project switched to traditional VIPs.

What is the impact of success?

Developing high R/inch insulation systems for building envelopes is a high-priority research area for the Buildings Technology Office (BTO) of Department of Energy (DOE). With an average age of almost 40 years old, a major portion of our housing stock has poorly insulated walls and needs exterior cladding replacement. The objective of this project is to target that market and develop an insulated vinyl siding finished prototype that achieves R10 while attempting to minimize the overall thickness of the cladding for existing housing. The proposed vacuum-insulated siding represents a 4 to 5-fold thermal improvement from currently available insulated siding products.

The BTO Residential Building Integration (RBI) Program aims to support the development of cost-effective technologies that can contribute to carbon-neutral buildings by 2050. This project is responsive to this objective; it seeks to build on the popularity and cost competitiveness of vinyl siding by developing and demonstrating a version that would increase the R-value of wall systems by R10. It offers an economical path forward to address the retrofit of existing residential walls that are under-insulated by today's standards.

The expected outcomes of this project would include:

1. A market assessment to determine the market potential and cost premium that a customer would be willing to pay and market adoption acceleration plan;
2. Finalized design of the insulated vinyl siding after hands-on exposure and feedback from builders and contractors;
3. A year-long field exposure experiment designed to address application issues such as nailing and cutting, thermal cycling, performance under high temperatures as well as performance issues such as R-value retention; and
4. The development and use of an accelerated test protocol to investigate R-value retention over the service life of vinyl siding.

The US Census (American Community Survey, 2015) indicates that there are 135 million houses in the US and that the median age of homes is approximately 40 years. To estimate the potential energy savings of having an R10 vinyl siding product, we divided the retrofit market into two segments based on the age of the home. We assumed that those homes built after 1990 (30 percent) had an average performance equal to the International Energy Conservation Code (IECC) 2006 standard (IECC, 2006). Homes built prior to 1990 (70 percent) were assumed to have an average performance based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90A-1980 (ASHRAE, 1980). The energy benefits of adding R10 insulated siding to residential walls were estimated via EnergyPlus simulations of standardized buildings in Climate Zones 2 (Houston, TX) and 5 (Chicago, IL).

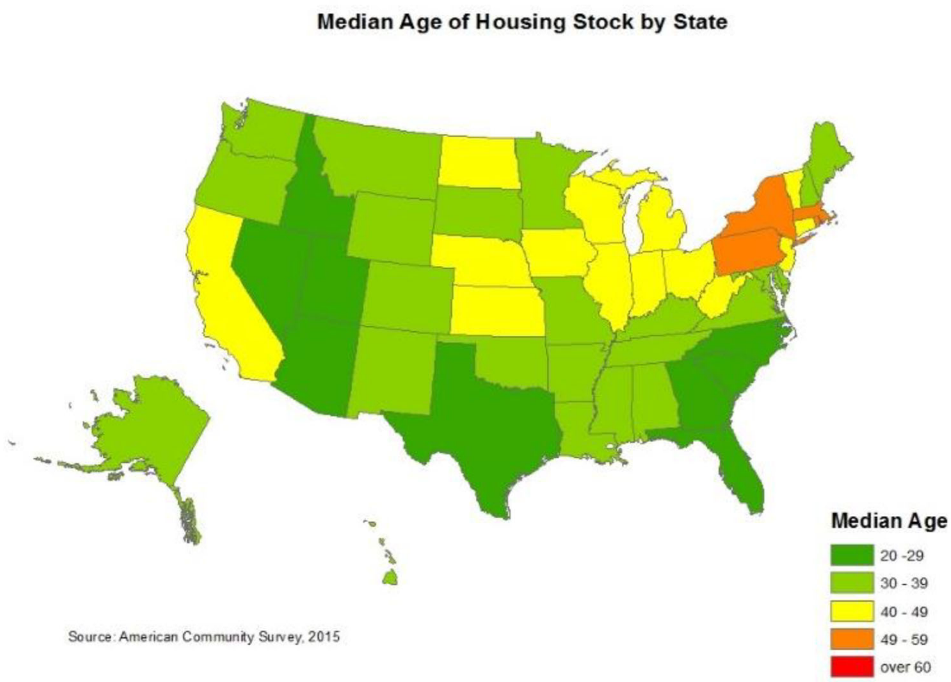


Figure 5:Median age of housing stock by state. http://eyeonhousing.org/2017/01/age-of-housing-stock-by-state/ (American Community Survey, 2015).

Per the BTO Market Definition Calculator, the energy use totals for residential wall-generated heating and cooling loads for new and retrofit houses in climate zones 1-5 total 1600 TBtu. On average, retrofitting the walls in the two climate zones show approximately a 9% reduction in heating and cooling load compared to the IECC 2006 baseline and 28% compared to ASHRAE 90A-1980. In total, the anticipated energy savings benefits of deploying R10 vinyl siding would be approximately 360 TBtu.

The estimated annual savings were 3.03 MWh of electricity and 79.1 Therm of natural gas. Assuming the national costs of 12.64 cents/kWh and \$12.36/1000 ft^3 of natural gas (*100* ft^3*=1.03 Therm*) are used to calculate reductions in energy cost, these yield annual savings of \$0.06/ft^2 of wall area for Chicago that initially conformed to IECC 2006. If the baseline case was assumed per ASHRAE 1980 standard, the energy cost reduction due to added R10 insulation would be \$0.27/ft^2 of wall area per year. Similar savings were estimated for Houston (CZ2) weather.

The National Association of Realtors cites siding replacement as one of the best long-term investments for homeowners, with vinyl siding showing an 85% cost recovery or the percent of the investment that would be recovered due to increased property value (Cost vs. value 2016). Thus, cost-effective exterior cladding and insulation retrofit systems not only yield energy savings but also add value in terms of future resale, a critical decision factor for homeowners.

Recent adoptions of more aggressive energy codes (IECC, 2018) are accelerating the use of continuous insulation by mandating its use in northern climate zones when constructing with traditional framing geometries. This code recognizes insulated siding as a form of continuous insulation, which can be used to offset some or all the continuous insulation requirements prescribed by the code. These higher R-value levels of continuous insulation create "safer" walls hygrothermally.

Initial prototype development and evaluations

When developing the original prototype, the project team pursued the following guidelines for the new insulation /cladding system:

1. The technology needed to be multifunctional, acting as both cladding and continuous insulation);
2. The technology needed to be as thin as possible with an original target of being no more than 1¼ inches thick);
3. The technology was required to have an R-value of at least R10 to meet the 2018 IECC continuous insulation requirements for all climate zones; and
4. The technology must be like the existing insulated vinyl cladding as possible.

An image of traditional insulated vinyl siding is depicted in the top left corner of Figure 6. EPS foam is wire cut to match the profile shape of the vinyl siding and adhered in place. To replicate this with a VIP, a press was manufactured so that the fumed silica core could be shaped to match the vinyl siding profile. This is shown in the bottom left corner of Figure 6. A pressed fumed silica core was produced (top right image of Figure 6) , placed inside a barrier film (bottom right image of Figure 6), and evacuated to produce a VIP that matched the siding profile. For our original prototype, we used a "double 6" vinyl siding profile. This profile has a vertical coverage of approximately 12 inches and would allow us to produce and use a wide VIP that would be 12 inches high by approximately 24 inches long. The 24-inch length was selected so that a VIP failure would be limited in terms of the surface area impacted by the failure. The VIPs were then butted together and adhered to the vinyl siding. A variety of adhesives were used and will be discussed in a later section of this report. Approximately 125 square feet of the product was produced in the laboratory to be used for a systems thermal performance test and to provide samples to the industry experts who were going to evaluate the technology.

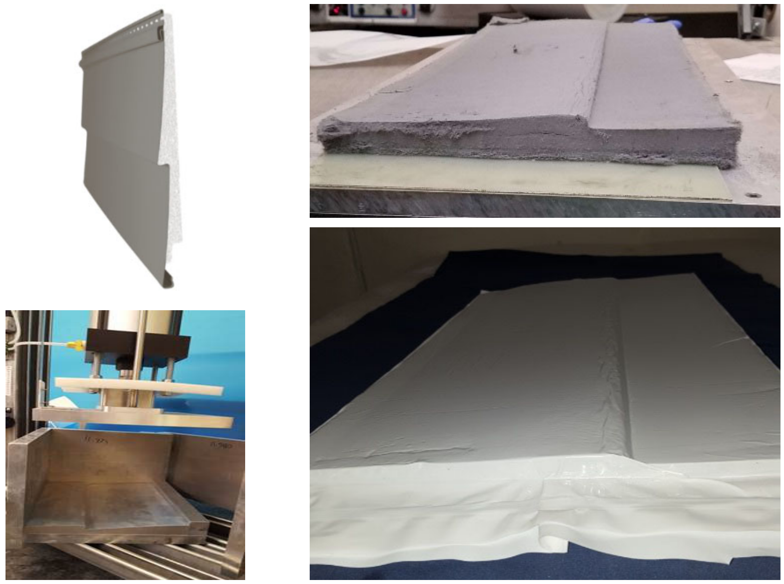


Figure 6: Images of the traditional insulated vinyl siding and the original VIP prototype.

Adhesive evaluations

A potential issue for these composites is the difference in thermal expansion coefficients (CTE) of the VIP panels and the vinyl siding. The CTE of these materials can vary by a factor of 10, and the thickness between the barrier film and vinyl siding varies by a factor of 200. Experiments were performed in Albuquerque, NM, to subject the test panels to the extreme diurnal solar load cycles that provided as large a temperature difference (ΔT) as the siding would typically experience under virtually any installation conditions. In this location, the surface temperatures can vary by over 90°F in a twenty-four-hour period, which will cause the outer layers to be in compression during the night and tension during the day. These temperature variations cause changes in the lengths of the barrier films and vinyl siding that stress the adhesive bond.

The VIP/vinyl siding was compared to a traditional insulated siding of expanded polystyrene (EPS) with both insulation materials adhered to the siding with a hot melt adhesive. Both sets of siding were installed on a south-facing wall, which captures the solar irradiance and results in high daytime surface temperatures of the VIP/vinyl and EPS/vinyl composites. Initial experiments utilized hot-melt adhesive to connect the components together. One section of the panel was also painted black to enhance the effect of the solar radiation by decreasing the vinyl siding's solar reflectance. This first experiment failed within the first week as the increased surface temperatures (over 150°F) allowed the hot-melt adhesive to remelt, causing the vinyl siding to lose rigidity and warp away from both the EPS and VIP insulation layers. The panels on the black painted siding completely detached from the siding, leading to extreme warping (See Figure 7).

A second experiment was undertaken that utilized a polyurethane reactive (PUR) adhesive to mitigate the delamination encountered due to the elevated temperatures created by the solar radiation. Unlike regular hot melt, PUR will solidify through moisture in the air to form a bond that will not remelt. A PUR applicator gun with an adjustable spray nozzle was used to apply the PUR adhesive. This allowed for more coverage area than the extrusion applicator that was used in the first experiment. This kind of application process is dependent on temperature and humidity to ensure the best possible bond. The PUR adhesive was applied only to the VIP composite, as we did not have enough adhesive to use on the EPS siding at the time. The second experiment did not include the black painted siding as the available solar radiation in Albuquerque, NM, was sufficient to increase the vinyl surface temperatures to reasonable mid-afternoon sunlit levels.

Figure 7: Initial adhesive exposure experimental setup (left); delamination and warping of siding (right).

The VIP and EPS composites were instrumented with temperature sensors on the front of the vinyl siding and the support board behind the insulation. That allowed for the measurement of the temperature differences across their cross-sections. Ambient temperature was recorded directly in front of the test panels. The solar radiation was also monitored using a pyranometer mounted on a crossbar. We collected data from this second experiment for seven months. This time frame provided data in both the winter and summer conditions, giving valuable information about the durability of the panels and the possible negative side effects from extreme thermal cycling. The test wall was monitored for signs of warping and delamination during this period. During the experiment, it was noted that there was minimal warping of the siding. This observation led to a modification to the experiment at the four-month mark. At that point in time, the top VIP panel was cut in half to test what would happen to the siding with decreased thermal performance if a VIP panel failed. This provided information for real-world installation where siding would need to be cut around windows and doors.

Visual inspection of the test wall showed some bumps in the siding that would be indicative of areas not being fully adhered. It should be noted that there were more bumps present on the EPS composite, which is due to the use of hot melt instead of PUR adhesive. After taking the test wall apart, it was apparent that some regions of the EPS had become completely detached. The VIP sections were all strongly adhered to the vinyl, including the VIP panel that had been cut in half (see Figure 8). There were still some issues with getting full coverage with the PUR adhesive due to the applicator gun. This problem can likely be resolved in an inline process required for mass production as the proper equipment would likely mitigate the bumps developed in this experiment.

Figure 8: Siding autopsy with PUR adhesive. Panels are still fully adhered to siding.

Testing of the thermal cycling of the VIP composites showed that with the proper adhesive (PUR), warping/buckling of the VIP/vinyl siding could be avoided. Although the vinyl siding and the VIP panels have different CTEs, the stress of the thermal cycling was not enough to break the adhesive bond between them. It is essential to get full coverage of PUR hot melt, as well as good contact between the VIP panels and vinyl siding to avoid warping. During this experiment, it was also shown that the VIP panels were able to maintain the internal vacuum for the duration of the test.

VIP performance

Laboratory tests of small-scale MAI and VIP panels were performed according to ASTM International test standards. The small-scale samples were 12 in. square by 1 in. thick. The tests measured the overall thermal conductance (and resistance) of the samples. These tests were done in a heat flow meter (HFM) that operates according to ASTM C518 (ASTM 2017), which measures the steady-state thermal transmission properties of materials. In a nutshell, an HFM consists of two plates that sandwich the test specimen. The temperature of each plate can be independently controlled, and each plate is equipped with a heat flux transducer (HFT) to measure the heat flow entering or exiting the plates. By measuring the temperature difference across the sample, the heat flow, and the sample thickness, the thermal resistance of the sample can be determined following Fourier's law, assuming one-dimensional heat flow. Figure 5 depicts the typical thermal resistance per inch of thickness of the MAI and VIP panels as a function of temperature and pressure. An R per inch of approximately 36 is measured at room temperature. This R-value drops to approximately 32 hr-ft^2°F/Btu at 140°F. If the VIP panels were installed behind a dark-colored vinyl siding, it is anticipated that its temperature might increase to about this level during the early afternoon on walls having significant solar exposure. At approximately 1 mbar, the VIP panels have an R-value per inch of approximately 40. This R-value drops slightly until approximately 10–15 mbar and then drops quickly until it stabilizes at ambient pressure at an R-value of 8. Note that if the VIP panels are produced with an internal gas pressure of 1 mbar, leakage can occur into the panel and only a modest loss of

R-value will be measured. This “plateau” in the R-value vs. pressure curve allows for some panel aging to occur without significant performance loss. Finally, at ambient pressure, the VIP panel still outperforms all traditional insulations because of the nanoporous nature of its core.

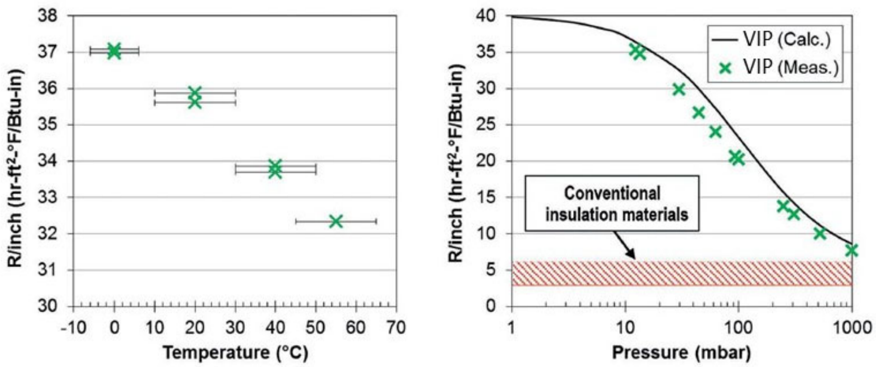


Figure 9: Thermal resistivity (R/inch) of VIPs as a function of temperature and pressure that were used in this research project.

GHB testing

A guarded hot box (GHB) operated according to ASTM C1363 (ASTM, 2019) was used to measure the steady-state thermal resistance of the full-scale VIP/vinyl siding composites. Figure 10 shows the hot box that is used to characterize full-scale walls and assemblies. Test assemblies are installed in a specimen frame mounted on a moveable dolly. The specimen frame has an overall aperture of 12 ft. wide by 10 ft. high. However, typical test specimen dimensions are 8 ft. square, while the remainder of the aperture is filled with 6-in. rigid expanded polystyrene (EPS) insulation with a thermal resistance of at least 24 hr-ft^2˚F/Btu. The specimen frame/test assembly is inserted between two “clam-shell” chambers of identical cross-sections. These chambers are designated as the climate (cold) and metering/guard (hot) chambers. The metering chamber is 8 ft. squared by 1.3 ft. deep, and its aperture defines the test area. The climate chamber can achieve a low temperature of 10°F, and the metering chamber can achieve a high temperature of 110°F. The walls of the metering chamber are constructed with 3-in.-thick aged, extruded polystyrene (XPS) foam with a thermal resistance of 14.8 hr ft^2˚F/Btu. Further, the guard chamber is also equipped with heaters to minimize the temperature difference with the metering chamber. The combination of foam insulation on the metering chamber and the guard chamber heaters essentially eliminates any heat loss from the metering to the guard chamber. During operation, the temperatures of the climate and metering chambers are set at the desired levels, and the system is allowed to attain steady state. Steady state is defined by the measured variables staying within the prescribed tolerances of ±0.5°F for temperature and ±1% for power and showing no monotonic changes. During the tests, the data (temperatures, power supply, etc.) are collected every 30 seconds. Once a steady-state is established, data from the last 12 hours of the steady-state period are used for analyses.

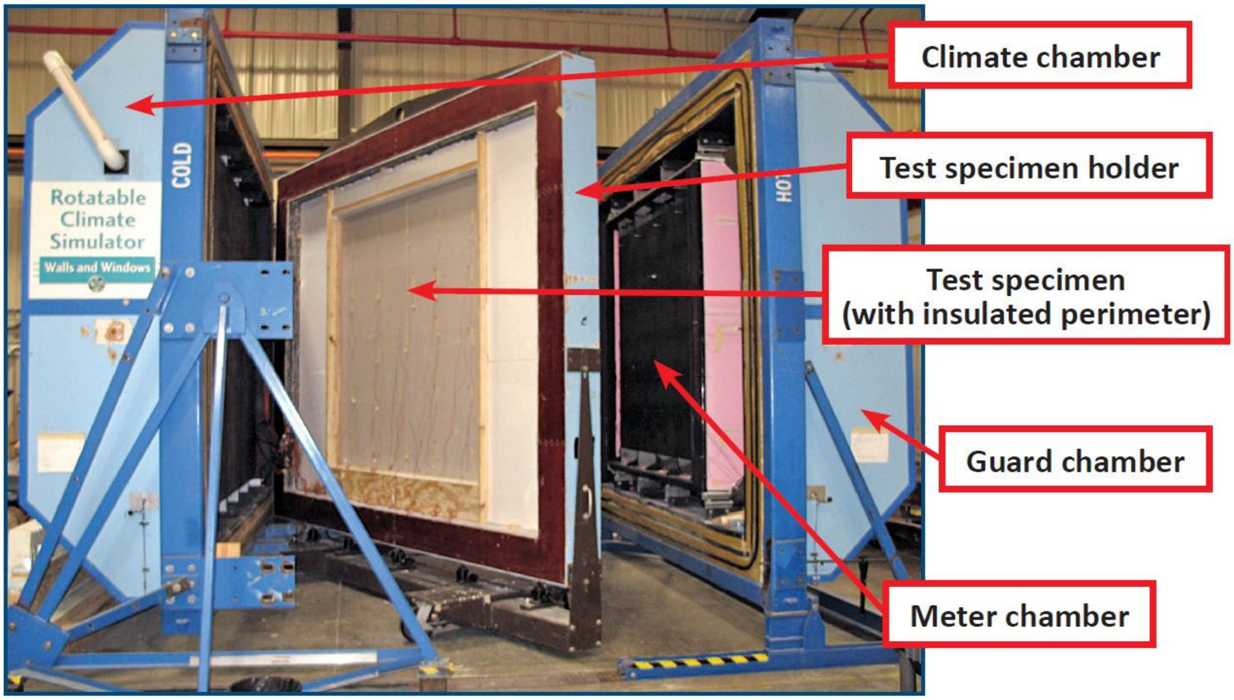


Figure 10: Guarded Hot box used for evaluating the VIP/vinyl siding composite.

The test wall construction from the exterior side inward was as follows: VIP/vinyl siding, 0.5-in. extruded polystyrene foam (XPS), 0.5-in. oriented strand board (OSB), 2 x 4 studs with empty cavities, and 0.5-in. interior sheathing (gypsum board). See Figure 11. The VIP/vinyl composite was facing the cold (climate) side of the hot box that was maintained at 50˚F; the gypsum board was facing the warm (meter) side of the hot box that was maintained at 100˚F.

Three arrays of 20 thermocouples were placed on the vinyl surface, the interface between XPS and OSB, and the gypsum surface. The thermocouples were installed on identical locations on the three surfaces; in other words, at any given location, the thermocouples on the three surfaces were along a straight line to enable the calculation of the temperature differences across the surfaces.

Eight pieces of siding were used to construct the wall. Within each piece, there were four VIP panels; three were of dimensions 24 x 10.62 in., and one was 22 x 10.62 in. Thus, the overall VIP coverage within the wall was 87%. On the cavity side, the area fraction of the frames or studs was 13.7%. Ten thermocouples were placed on VIP sections without joints or studs, while five sensors were attached over the joints between the siding pieces and the stud locations. The area fractions were used to calculate the area-weighted temperature differences between the different surfaces.

It is noted that the VIP and non-VIP areas will impact the calculated temperature differences for the whole wall. Similarly, for the vinyl-to-XPS section, the thermocouples on the stud locations will have an impact on its weighted-average temperature difference. Thus, there is some uncertainty in calculations of R-value resulting from the uncertainty in the temperature difference calculations.

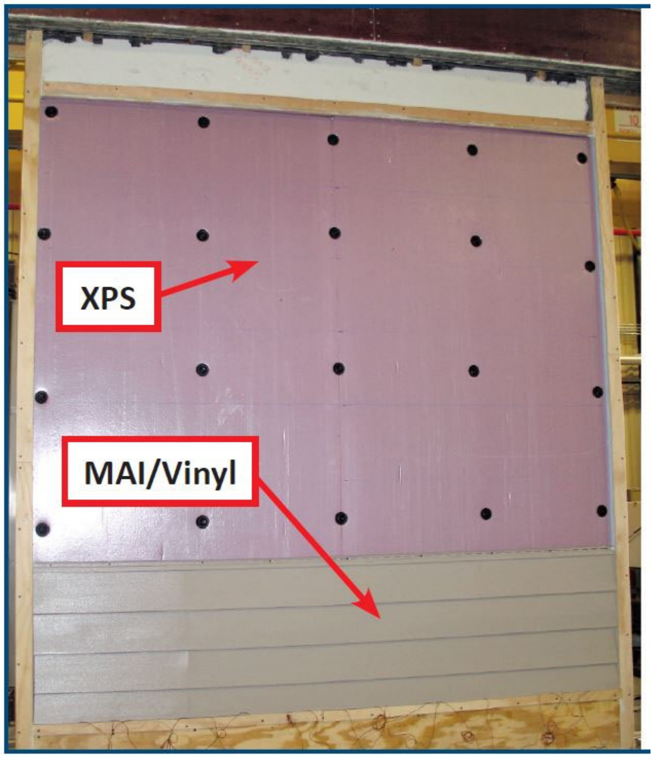


Figure 11: Construction of the GHB test specimen.

With instrumentation installed at critical locations, the R-value of different portions of the test wall can be derived separately (Figure 12). Knowing the temperature differences across the entire assembly and the stud cavity (OSB/gypsum), their individual R-values can be calculated. The measured R-value of the VIP/vinyl and XPS layer was 12.9 hr-ft^2˚F/Btu, if taking the difference between the whole wall and the OSB-to-gypsum section. Assuming R-5/in. for XPS, the R-value of the VIP/vinyl portion is in the range 10.4 hr ft^2˚F/Btu.

Power input meter chamber (Btu/hr)	189.7		
Total wall area (ft^2)	64.0		
	Vinyl	**XPS/OSB**	**Gypsum**
Average air temperatures (˚F)	50.1		100.1
Average surface temperatures (˚F)	51.3	89.6	96.8
	Whole wall	**Vinyl/XPS**	**OSB/Gypsum**
Area weighted ΔT (˚F)	45.5	38.3	7.2
R-value (hr-ft^2-˚F/Btu)	**15.4**	**12.9**	**2.4**

Figure 12: Summary of guarded hot box results on first prototype.

South Carolina NET facility exposure

A field test was initiated in October 2018 in a natural exposure test (NET) facility at Charleston, South Carolina. The NET facility is a single-story, conditioned building, which exposes side-by-side roof/attic and wall assemblies to natural weathering. Figure 13 shows the southeast and southwest walls of the NET facility; the southeast wall is parallel to the long axis of the building and contains several openings for test walls. This orientation exposes the test walls to a maximum amount of wind-driven rain. These openings can accommodate test walls with state-of-the-art and prototype building envelope technologies for evaluation under real building and weather conditions. Typical test wall dimensions are 9ft. high by 4ft. wide, and they are usually instrumented with temperature, relative humidity, and heat flow sensors. The data is collected and monitored over several months and even years to evaluate the long-term performance of building envelope systems and technologies.

Figure 13: Natural Exposure Test (NET) Facility in Charleston SC.

Two test walls were built for this study: one with the VIP/vinyl composite siding and the second one with EPS vinyl siding. The test walls were constructed using interior sheathing (0.5-inch gypsum board), wood framing (studs), cavity insulation (fiberglass batts) exterior sheathing (0.5-inch oriented strand board or OSB), 0.25-inch extruded polystyrene foam (XPS) with taped joints, and the insulated vinyl siding. The studs were 3.5 inches deep and 1.5 inches thick, and the fiberglass batts had a nominal thermal resistance of 13 hr ft^2 ˚F/Btu. The taped XPS layer was assumed to be the air control layer. No specific vapor control was incorporated into this configuration as this climate zone 3 location can perform with a vapor-open design. The addition of vacuum panels does decrease the air permeability of the vinyl siding to some extent. However, the composite siding is attached in a manner similar to traditional uninsulated vinyl siding. This loose connection to the sheathing allows for thermal expansion of the siding as well as providing some air permeability. One purpose of the field testing was to evaluate the extent of thermal loss due to this airflow around the insulated siding. The test walls contained thermistors, combination T/RH sensors and HFTs at different interfaces and across the cross-section. The sensors are scanned at 60 s intervals, and the time-averaged data were recorded at an hourly rate. A schematic of the test walls is depicted in Figure 14. Three sets of data were collected; on the EPS vinyl siding, on the VIP/vinyl siding, and on a VIP panel that had been purposely damaged during installation.

The interior space of the NET is maintained at a temperature range between 70 and 75°F with a relative humidity of approximately 50%. The panels were installed in the Fall of 2018, and measurements were recorded hourly. Figure 15 shows the two panels installed side by side. The cross-sections of the double six vinyl siding elements are shown in Figure 16. Figure 16(b) shows the VIP installed on the backside of the vinyl siding as indicated by the wrinkled barrier

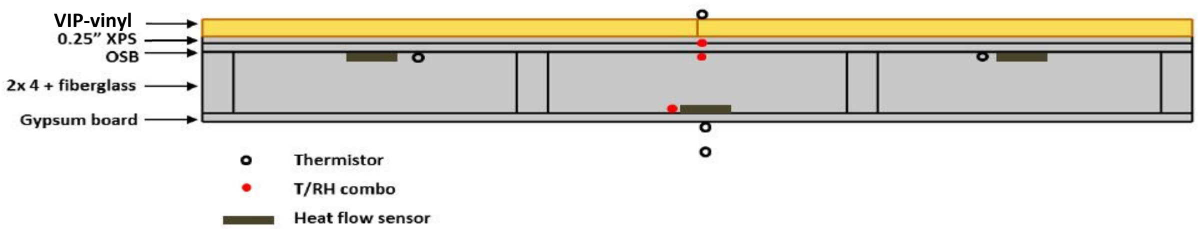


Figure 14: Schematic of test walls showing instrumentation layout in the natural exposure test facility.

film. The wrinkles are the result of the core being evacuated. The difference in pressure between the VIP core and ambient air imposes a load on the VIP, which gives rise to the wrinkled film. The wall assembly with vinyl siding insulated with VIPs includes vacuum insulation panels in two conditions, intact and damaged. The barrier film for the purposely damaged VIP was punctured, resulting in a complete loss of vacuum. That simulates damage in the field caused by handling and installation. Figure 17 is an infrared thermal image showing the difference in temperature between the damaged and intact siding vacuum insulation panels. Note that the VIPs along the right side of the panel were damaged during installation increasing the number of damaged VIPs to approximately half of the number installed.

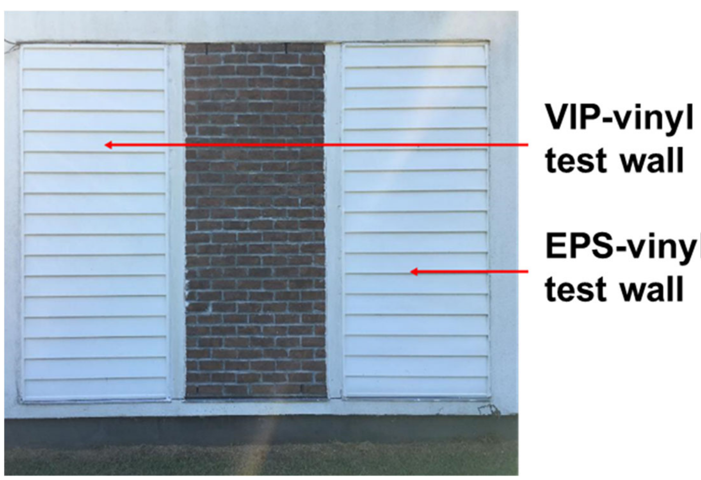
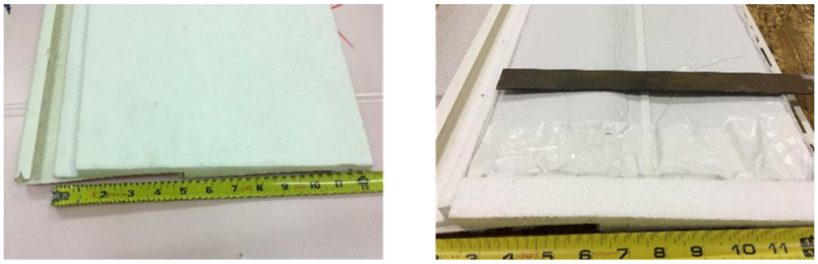


Figure 15: Test panels with insulated vinyl siding. The vinyl siding on the left is insulated with VIPs (R35). On the right side is the same siding insulated with expanded polystyrene foam (R3).



(a) (b)

Figure 16: (a) Double six vinyl siding insulated with expanded polystyrene (R3). (b) Double six vinyl siding insulated with vacuum insulation panels (R35).

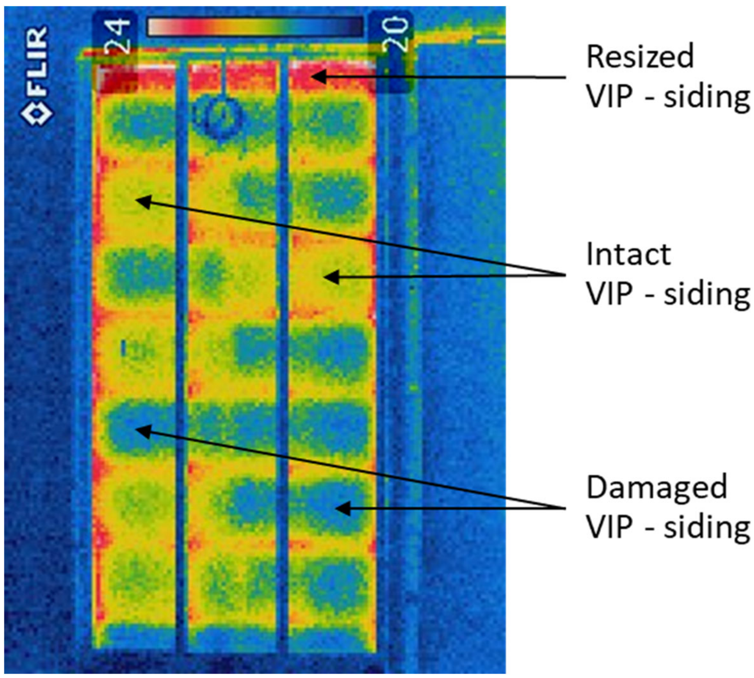


Figure 17: Thermal image of the wall panel with vinyl siding insulated with VIPs. The image highlights differences between intact and damaged vacuum insulation panels. To simulate a damaged VIP, the barrier film was intentionally punctured, resulting in the loss of vacuum.

Heat gains and losses were calculated based on the measurements from the heat flux transducers. Figure 18 depicts the monthly panel heat gains as a function of time. The vinyl siding insulated with expanded polystyrene shows the greatest peak heat gain with values around 175 Btu/ft^2. Peak heat gains for the vinyl siding with damaged VIP show a slightly lower heat gain. The most significant decrease in heat gain is the vinyl siding with the intact VIP. The maximum peak heat gain during the winter months is slightly higher than 100 Btu/ft^2, representing a reduction of 50 percent compared to vinyl siding insulated with expanded polystyrene. Figure 19 shows similar data for the panel heat losses as a function of time. The trend for heat losses was similar to heat gains; vinyl siding with expanded polystyrene shows the greatest peak heat loss, followed by the vinyl siding with damaged VIP at approximately 200

Btu/ft^2. The peak heat loss for vinyl siding insulated with vacuum insulation panels is just over 100 Btu/ft^2, again representing a peak reduction of almost 50 percent.

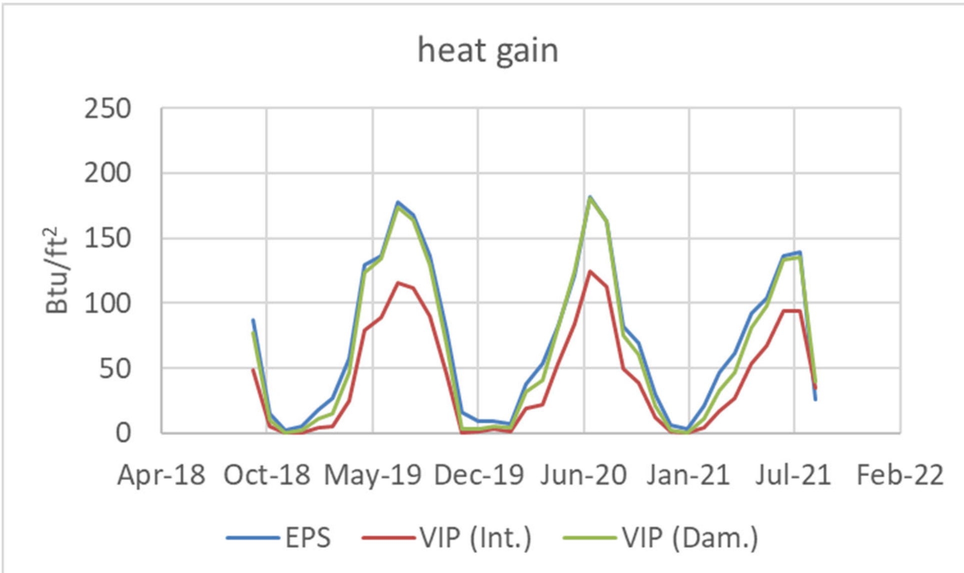


Figure 18: Panel heat gains during the exposure for vinyl siding insulated with expanded polystyrene, vacuum insulation panels (VIPs) and damaged VIPs.

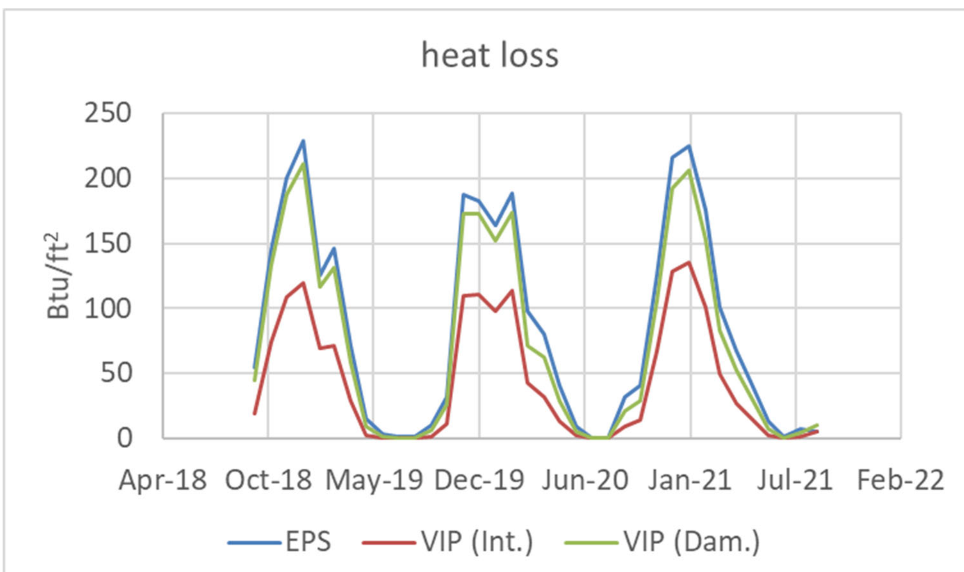


Figure 19: Panel heat loss during the exposure for vinyl siding insulated with expanded polystyrene, vacuum insulation panels (VIPs) and damaged VIPs.

To understand the effect of aging, measurements of percent heat gain and loss reductions were compared at yearly intervals for the vinyl siding with VIPs. The percent reductions for heat loss and gain were calculated by comparing the VIP siding heat loss to the EPS siding heat loss. Figure 20 shows the percent reduction in heat gain during the summer months. In 2019 the percent decrease, or average percent decrease during the months of June through September was approximately 34 percent. The average percent decrease over the same period the subsequent year was approximately 33 percent. The month of September was the only month during that period that saw a percent increase over the prior year. The percent reduction in heat loss during the winter months was also calculated and shown in Figure 21. The average percent reduction in 2019 was approximately 47 percent. In 2020, the average percent reduction decreased to 44 percent. The average percent reduction in 2021 for the months January through March was approximately 43 percent. In aggregate, thermal performance is decreasing, on average, approximately 1 to 3 percent per year. It is important to note that the yearly changes are due to a possible change in thermal performance as well as changes in the meteorological conditions.

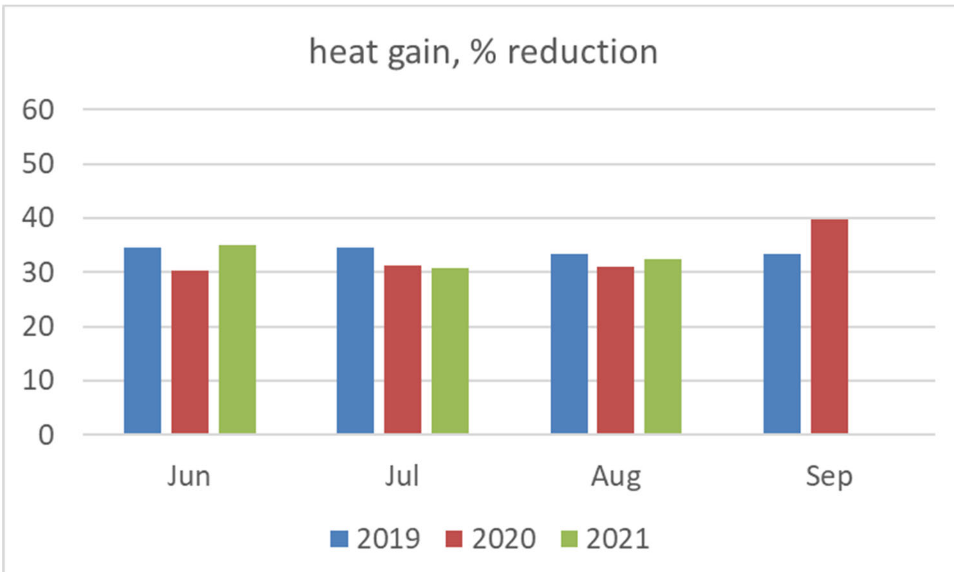


Figure 20: The heat gain reduction of vinyl siding insulated with VIPs compared to the same siding insulated with expanded polystyrene foam.

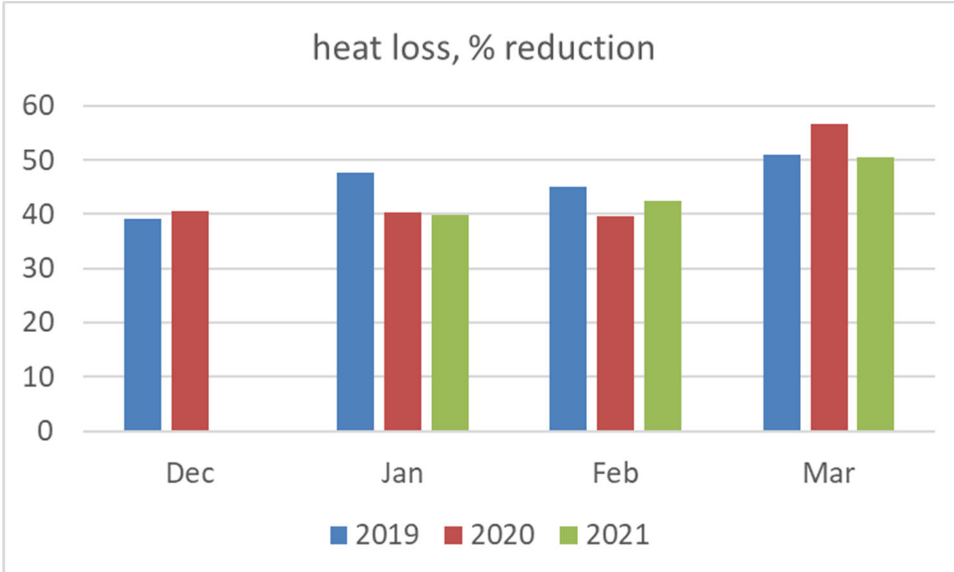


Figure 21: The percent reduction in heat loss of the wall panel with vinyl siding insulated with vacuum insulation panels compared to the same siding insulated with expanded polystyrene.

VIP/vinyl siding composite aging studies at ORNL

Vacuum insulation panels use different types of barrier films depending on the application and cost requirements or constraints. The barrier films can be categorized as polymeric or metalized. In both cases, the films are made up of multiple layers laminated into one sheet. To improve or increase resistance to gas and water vapor transmission, metal foils are sandwiched between polymer films. Though the metalized barrier films significantly lower gas and water vapor transmission, their cost is significantly higher compared to polymer films.

Exposure studies were carried out under three different conditions to assess the performance of polymer and metalized barrier films on the long-term performance of vacuum insulation panels used as insulation behind vinyl siding. Vinyl siding samples were constructed using vacuum insulation panels as insulation, and rigid plastic foam was installed as spacers and perimeter edge protection. The panels were exposed to three conditions: room temperature or laboratory conditions; 75^{o}F and 80% relative humidity; and exterior conditions at Oak Ridge, TN. The thermal conductivity was measured as a function of time in accordance with ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. The R-value was calculated and then plotted as a function of time. These measurements were performed on a composite comprised of a 0.75-inch-thick VIP surrounded with EPS foam and attached to vinyl siding. The R-values reported in this section do not represent the thermal performance of just the VIP.

Figure 22 compares the R-value at room temperature and relative humidity. At time zero, the measured R values are approximately 17 hr ft^{2} ^{o}F/Btu. After almost 800 days of exposure, the R values for the VIP with polymeric film (EVOH or ethylene vinyl alcohol) and the VIP with the metalized film (PST or Proprietary Surface Treatment) are about 12 and 16 hr ft^{2} ^{o}F/Btu, respectively with the metallized film outperforming the polymeric film by approximately 20 percent. This difference is greater when the samples are exposed to the outdoor environment of East Tennessee, see Figure 23. The measured R values for the VIPs with polymeric and metalized films are 9 and 14 hr ft^2 ^{o}F/Btu, respectively, representing a percent difference just over 40 percent. The greatest difference is for samples exposed to high relative humidity. Figure 24 shows the R-value after almost 800 days of exposure to 75^{o}F and 80 percent relative humidity. The measured R values for the VIPs with the polymeric and metalized film are 7 and 15 hr ft^2 ^{o}F/Btu, respectively, representing a percent difference of over 70 percent highlighting the impact of vapor transmission on the performance of these materials. Depending on the number of layers in the barrier film, the water vapor transmission rate difference between multilayer metalized and polymeric films can be at least one order of magnitude. It is worth noting that the percentage difference in insulation value for the VIP with polymeric film between room temperature and 75°F and 80% relative humidity is approximately 60 percent when compared to less than 10 percent for the VIP with metalized film for the same conditions. Based on these results, a decision was made to use only VIPs with metalized films. The sensitivity of the polymer films to moisture transmission makes them unsuitable for applications within the building envelope.

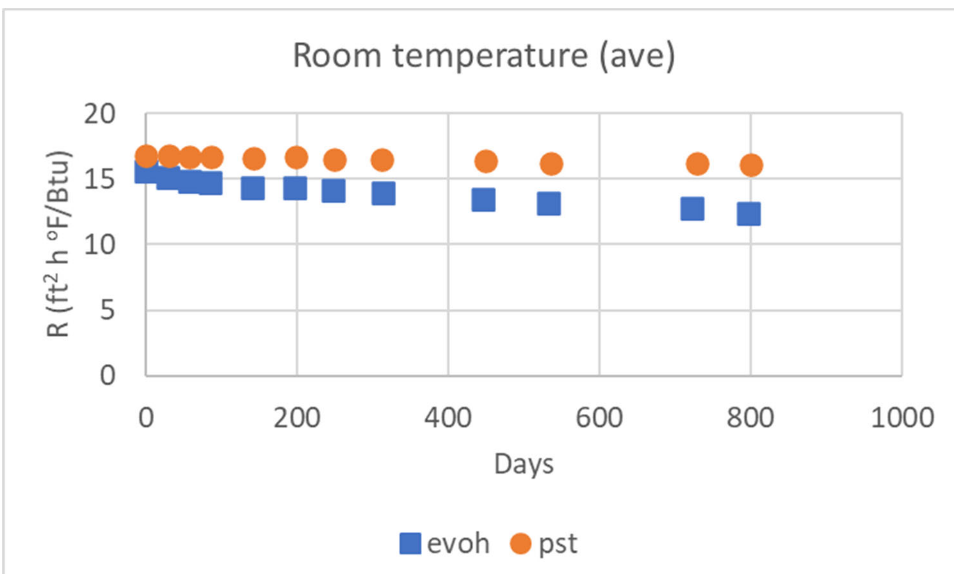


Figure 22: R-value as a function of time in days for VIP/vinyl siding composite panel exposed to laboratory temperature and relative humidity conditions. The R value is an average (ave) of two samples.

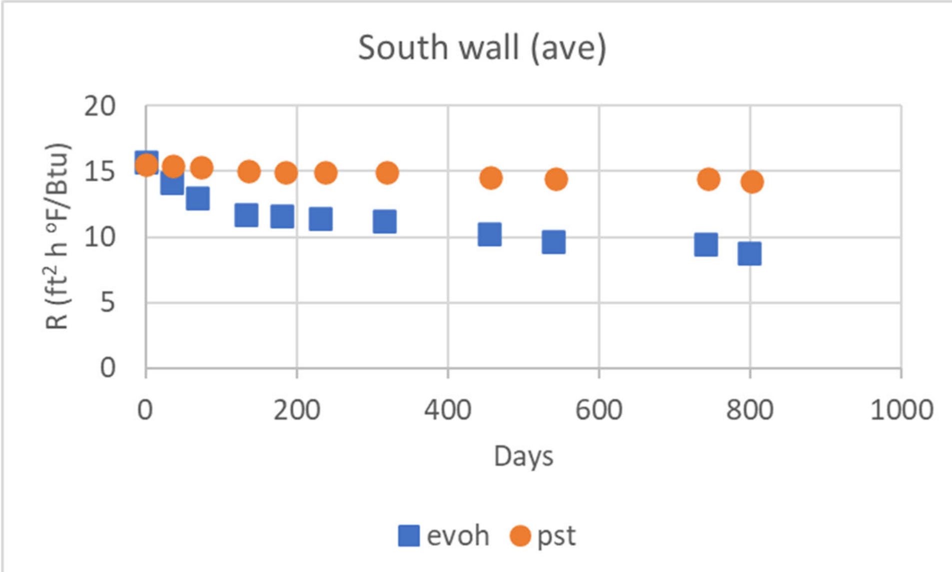


Figure 24: R value as a function of time for a VIP/vinyl siding composite panel exposed to an ambient temperature and high relative humidity laboratory environment of 80%RH and a constant temperature of 75°F. The R value is an average (ave) of two samples

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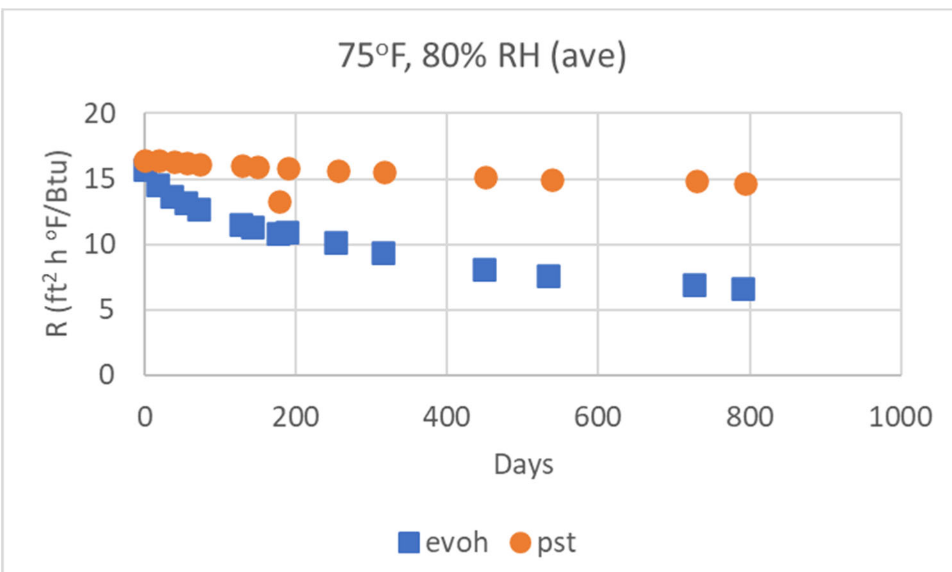

As mentioned earlier, the European Union-funded research that led to the development of an industry-standard, EN 17140, Specification for "Thermal insulation products for buildings - Factory-made vacuum insulation panels (VIP)" to quantify the performance of VIPs (European Committee for Standardization, 2021). That standard includes a proposed accelerated aging test method for the purpose of calculating thermal performance over the VIP's service life that is estimated to be 25 years due to aging associated with air and moisture intake and thermal bridging due to barrier film. Two VIP test specimens are stored at 122°F and 70%RH for 180 days. At 0, 60, 120 and 180 days, the thermal conductivity is measured in accordance with EN 12667:2001 (like ASTM C518), and the average of two samples of the same thickness is determined. These values will later be used to calculate the center of panel conductivity at 25 years following the standard.

We have initiated these experiments on VIPs with metalized films but will not complete them by the end of this fiscal year. An addendum to this report will be issued to include this information.

First series of user workshops

The evaluation of prototypes was performed with user feedback to direct changes in the design and manufacturing of VIP/vinyl siding composites. The project team conducted several user events to gain feedback from builders and contractors in several settings using mock-up demonstrations of the VIP/vinyl siding composite prototypes. The project team constructed prototype mock-ups. These mock-ups were intended to finalize design choices and test the range of installation approaches anticipated in the field, dealing with windows and doors, penetrations, flashing and fastening details, etc.

The project team held four demonstration events inviting builders and contractors to view a wall constructed with the VIP/vinyl siding composite prototype. Attendees were able to view and handle the product. The project team then facilitated a discussion to gain feedback from attendees related to installation, robustness, handling, on-site storage, design, and feasibility.

Our team (Oak Ridge National Laboratory (ORNL), Royal Building Products, and Newport Partners, partnered to test and demonstrate a VIP that can be adhered to vinyl siding providing an average insulation value of R10 which is well beyond the typical R-2.7 of current insulated vinyl siding. With half of the homes in the U.S. built before 1980 and before today's more rigorous energy codes, we used primary research methods and asked stakeholders if a high-R insulated vinyl siding applied from the outside of an existing home would be of benefit to this large market.

We conducted a series of workshops with specialty siding installers, contractors, distributors, remodelers, builders, and architects to gather information on their current practices related to vinyl siding and insulated vinyl siding to understand the current market; and to explore their perceptions and opinions of the VIP/vinyl siding composite prototype. Workshops were held in August and September 2019 in Columbus, OH (OH), Clifton Park, NY (NY), Maple Lawn, MD (MD), and Deer Park, NY on Long Island (LI). Figure 25 details the location, date, and participants in each of the voice of the user sessions.

LOCATION	DATE	PARTICIPANTS
Royal Building Products, Columbus, OH (OH)	July 25, 2019	3 Manufacturer Sales Reps; 1 Distributor; 2 Contractors; 1 Siding Installer
CRBRA, Clifton Park, NY ALBANY REGION (NY)	August 21, 2019	5 Suppliers; 2 Architects; 1 Builder; 3 NYSERDA reps
MBIA, Maple Lawn, MD BALTIMORE / WASHINGTON (MD)	September 9, 2019	5 Installers, 2 Manufacturer Sales Reps; 4 (1 each)Builder, Remodeler, Rater, Distributor, 2 Manufacturer Sales Reps
United Way, Deer Park, NY LONG ISLAND REGION (LI)	September 24, 2019	5 Installers; 3 General Contractors; 3 Weatherization and Home Performance; 2 United Way; 3 (1 each) Engineer, Building Supply, Manufacturer Sales Rep

Figure 25: Details pertaining to the user sessions reviewing the original prototype.

Vinyl siding

We began each session by exploring current practices to better understand the replacement siding market. Traditional vinyl siding is attractive because it is inexpensive, lightweight, low maintenance, and has many design options. Vinyl siding, especially the thicker, more expensive products, meet current design trends for darker siding colors and accents, which are trending in all markets.

> *"Vinyl siding is easy and fast to install, costs the least and is low-maintenance. Plus, there are a lot of design options and colors." (LI)*

According to the participants in all markets, the greatest issue with vinyl siding is the proper installation by skilled labor. A nationwide construction labor shortage further impacts this. In Columbus and Albany, participants noted that homeowners and builders are waiting weeks to get siding installed. They can sell jobs, but they can't get the product installed.

> "*There are probably 12 installers in our region. 3-4 of them install HardiePlank. We're not even talking about good installation. They don't read the instructions*." (NY)

In Long Island**,** where they have high housing and labor costs and vinyl siding is not allowed in the covenants of some communities, vinyl siding is considered an inexpensive solution for homeowners.

> "*Vinyl siding is just cosmetic, a quick fix to the house to make it look better."* (LI)

Vinyl siding is not typically used for higher-end homes that are designed by architects. The higher-end markets typically feature wood, fiber cement, and shake siding. In Maryland, where there is a large new home market with siding on 3 sides with a brick or stone façade, participants see homeowners moving away from vinyl to fiber cement cladding.

Residing is common, and vinyl siding appears to have an advantage related to cost and appearance. Ideally, a contractor will remove siding, add housewrap and reside (MD & LI). In

Columbus, an installer mentioned that they always install siding over the existing siding (OH). In Albany and LI, they will re-side over asbestos or clapboard after adding a backer board for a flat nailing surface. Since it is "*$30,000 to remediate asbestos, they will use 2 1/2" nails to go over-top* (LI)" the asbestos.

In Maryland, the most important part of residing is making "*the surface look flat and not follow flaws in the wall.*" They suggested that vinyl siding is a better option for residing because "*fiber cement follows the wall exactly revealing any wall issues underneath, but vinyl can be floated to hide the flaws underneath.*"

Energy efficiency and codes

Participants across locations agree that energy efficiency is increasingly important to reduce utility bills and meet increasing energy codes. Participants in colder climates acknowledged that with new energy codes, there will be a need for higher R-value systems. *"70% of buildings were constructed before code and will need solutions for increased R-value."* (NY)

In Maryland, a milder climate, contractors noted that for retrofits, energy efficiency is "*just windows for most people. They might know heat pumps. Foam is expensive*." They suggested that newer homes are already built better, so the savings related to energy efficiency aren't as significant.

Contractors on Long Island (LI), a marine climate, had mixed thoughts on energy efficiency. They acknowledged that utility bills are an issue, but you *"don't need to meet code for siding, windows or roofing (unless you change the roof sheathing) only for permanent work…and people don't want to pull a permit because then they need to bring everything up to code*." However, they noted, some communities always require permits and new codes impact remodeling. Contractors agreed that homeowners "*should do siding and windows [together], but half won't do it, only the middle to upper income.*" One contractor stated that he currently uses graphite polystyrene rigid foam insulation to increase the energy efficiency of existing homes.

Insulated vinyl siding

Workshop participants were familiar with insulated vinyl siding, but most did not use it because of the higher cost compared to traditional vinyl siding. They agreed that it has a better appearance and the rigidity required for darker colors, which are currently trending, but it is "*double the price of vinyl siding due to material and installation costs."*

According to a representative from Royal Building Products, the insulated vinyl siding makes up approximately 3 percent of the total siding market, but as the leading manufacturer of insulated vinyl siding, Royal Building Products has a substantial share of the market. A summary of comments associated with style and market trends is given in Figure 26.

Currently, insulated vinyl siding is not just installed for its R-value but also for its rigid appearance and stability. Adding insulation to increase energy efficiency in existing homes was not common among participants with whom we spoke, but they agreed that codes are increasing and that it will become more important in the future. In new homes, participants typically meet code requirements with wall sheathing systems that incorporate built-in exterior insulation.

CURRENT PRACTICES: Styles and trends

Darker colors and accents are trending in all markets.

DESIGN	Columbus	Albany	Baltimore / DC	Long Island
Double Hollow Core Dutch Lap	Dutch Lap is 60% of market.	6" is more like cedar board	4" / 6" 40 colors and profiles 60-70% of market	Dutch lap is 55% of the market and double 4, 4 ½ clapboard look is 45%. This reverses about every 4 years.
Board & Batten (B&B)	Growing IVS B&B growing	Growing in custom but only 5% of a home – gables Come in 10' so need transition break	And shake for gables, wider, flatter	They might use cedar shake vinyl on the front and regular everywhere else.
Insulated Vinyl Siding (IVS)	+ Appearance Used for rigid appearance not R-value Competes with Hardie Plank because customers are less price sensitive;	Very small part of market	Stiffening More rigid Doubles the siding budget	+ Need for darker colors because of the sun. - Double the price. - Will move to HardiePlank
Darker colors	Growing; richer look	Growing; cost more	Green, blues, grays; darker is a premium; thicker	Needs to be rigid due to the sun. Double the price.
Single Course			Looks better	Single 7' and double 6-7" with IVS

Figure 26: Summary of current vinyl siding styles and trends.

Large volume specialty contractors finance the sale of insulated vinyl siding, but smaller contractors do not commonly use it because it is more expensive and requires additional installation work. Ideally, contractors install windows and siding at the same time, but it's often too expensive for their customers.

The current insulated vinyl siding market is dominated by "in a day sale," where potential customers are pressured to buy that day and receive financing. Unique and Champion in Columbus, OH, only use insulated vinyl siding. They provide good, better, and best solutions to meet a combined R19 envelope. Power Home, King Quality, and Allure, the largest siding contractors on Long Island (LI), sell and finance insulated vinyl siding. They are high volume and can do 1-3 houses in a day with a crew of 12-15 installers.

Workshop participants believe that insulated vinyl siding "doubles the price" of a project. There is not enough increase in R-value or air loss benefit to make a case for the cost, and many homeowners would rather spend their money on visible items like countertops.

> *"Tried it when it first came out, R-values were too minimal to make a case for using it due to cost."* (LI)
>
> *"We have tried to push people to insulated vinyl siding, but they would rather spend money on something they can see. Counter tops, tubs."* (LI)

Figure 27:Summary of current vinyl siding styles and trends.

> *"Minimal sales, it is not worth it. If people are willing to pay more, they switch to Hardie."* (LI)

> *"90% of people don't want to pay extra. 70% of the market is low at $8/sf; 20% at $12 per; 10% is higher at $20/sf, but then you are looking at a different product."* (LI)

Smaller contractors perceive installation as more difficult because it requires more than one person to carry on a job site, and the thicker panels require different fastening and detailing around windows, doors, soffits, and gables.

A distributor in the Albany (NY) area said they used to sell Craneboard. Insulated vinyl siding was introduced in 1996 by a collaboration between Progressive Foam and Crane Performance Siding (progressivefoam.com), so it has a 20-plus year history. The distributor noted: *"We sell 3-4 [insulated vinyl siding] jobs per year. It's full box quantities. We can't sell it if there is a problem. It's a volume issue*." It is also a site storage issue, according to some participants.

Reactions to first VIP/vinyl siding prototype

Stakeholder reactions to the first prototype were mixed. Across all groups, they felt that the VIP/vinyl siding prototype had the same strengths (appearance and rigidity) and weaknesses (cost and installation) as traditional insulated vinyl siding. Stakeholders were astonished by the R-value per inch compared to insulated vinyl siding, even when cut. They felt that even at R8 (R-value when punctured), the VIP/vinyl siding product would contribute to meeting the energy code since it is "*triple what's out there*." However, the reduced R-value when the VIP is penetrated caused confusion and concern since, according to participants, 10 to 25 percent of siding is cut or ripped on location.

Some stakeholders were concerned that field cutting the product would "*raise OSHA concerns like HardiePlank,*" because of the silica content. Others suggested that you just wear face protection, and it would not be an issue. There were questions about resealing field cuts to avoid moisture penetration and the stability of the product once moisture entered.

The workshops in Columbus, OH, and Albany, NY, started with a somewhat detailed product presentation in which participants were allowed and encouraged to ask questions. In Maryland and Long Island, participants were given the product samples early on and shared their reactions to the product without having seen the presentation.

After watching a video introduction and handling the VIP/vinyl siding prototype, participants performed a SWOT analysis:

- Strengths – what do you like about it?
- Weaknesses – what concerns do you have?
- Opportunities – how do you see this product meeting a market need?
- Threats – what needs to be changed to make the product viable for the existing housing market?

According to some distributor participants, the prototype's differentiating strength is its high R-value and opportunities for meeting code requirements such as continuous insulation. The weaknesses were primarily related to cutting and puncturing the product resulting in a lower R-value and increased labor cost to install the product. Handling and packaging were also concerning.

Most of the perceived threats were related to unanswered questions and included:

- Are there OSHA requirements for cutting silica?
- What is the installation time, costs, and training? Will it cost more? How do we sell it and make a profit?
- Does insulation stay attached during expansion and contraction?
- What about vapor and moisture? How will it integrate with rainscreens or drainage planes for airflow?
- What about buckling and gaps between the panels? How do you connect, join, and overlap ends?
- How long does the seal last? What is the warranty? The VIP insulation needs to last as long as the vinyl siding.

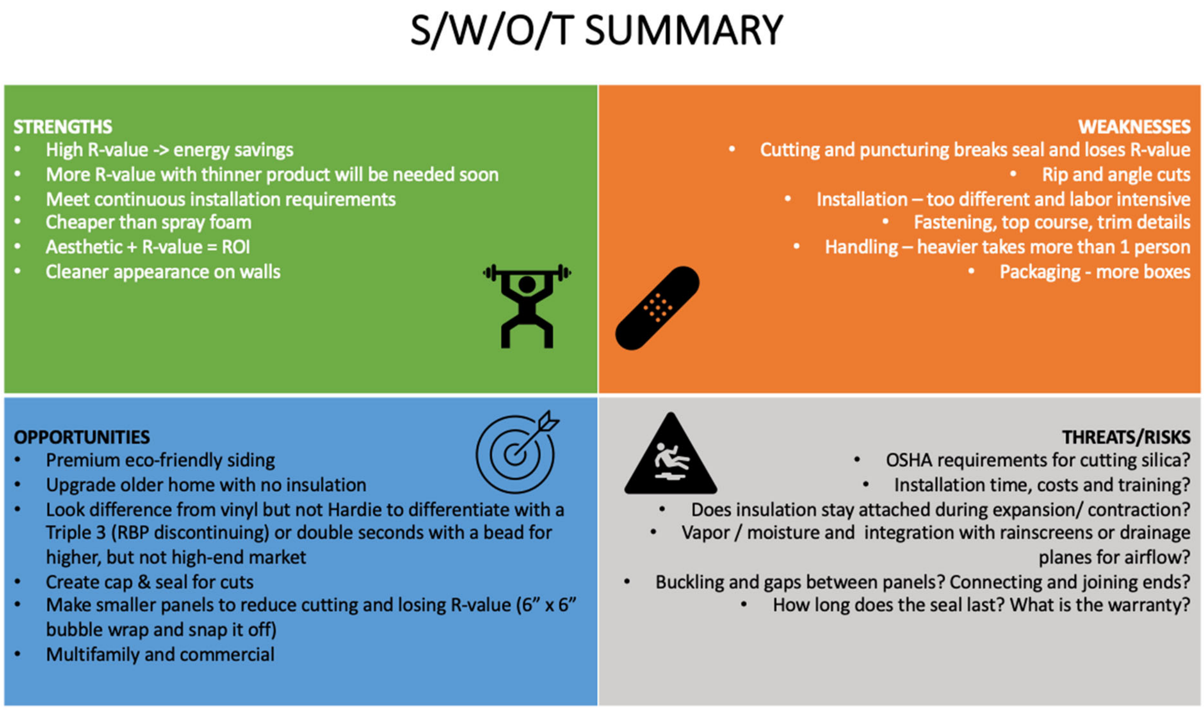

Figure 28: Summary of feedback received from the SWOT analysis.

Despite their concerns, participants identified several opportunities for a combined insulation and siding product as an eco-friendly upgrade to existing homes. They suggested that with improvements such as smaller panels to reduce cutting and to differentiate the aesthetic from traditional vinyl siding, the product could work in a "higher-end" market. They also see a market in multifamily and commercial buildings.

Designing and commercializing a product takes many iterations. Although there was optimism for the potential of a high R-value siding for existing homes, participants were not ready to install, sell or design the first prototype. They were impressed with the R-value and liked the appearance and rigidity since it works with on-trend dark colors, but they were concerned with installation costs, field cutting, and delivery. After reviewing the technology, participants were asked to rate the likelihood of specifying the technology on projects. They were asked to assign a score between 0 and 10, where 0 indicates that they would not specify the technology and a