Industrialized Weatherization

Efficiency Vermont R&D Project:

Comprehensive Deep Energy Retrofits with Prefabricated Panel Block Wall Insulation

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Executive Summary

The Efficiency Vermont R&D program supports demonstration projects that encourage innovation and drive the evolution of services in strategic areas that can benefit from targeted investments. Retrofitting the existing building stock and developing local workforces are strategic initiatives under Efficiency Vermont's *Triennial Plan 2021 - 2023*. Further, Vermont law specifies principles for meeting State energy policy targets, in terms of the achievement of greenhouse gas reductions.[1] Within that framework, the *2022 Vermont Comprehensive Energy Plan* has established a goal to weatherize 120,000 homes by 2030. This project offers a possible prototype for effectively achieving the 2030 weatherization goal.

Efficiency Vermont's Home Performance with ENERGY STAR® program guides standard weatherization services involving a comprehensive home evaluation, custom recommendations for energy upgrades by a trained professional, and quality assurance evaluations of the completed installation.

This project's primary objective is to evaluate a super-insulated wall retrofitting process using prefabricated panel block wall insulation—a form of industrialized weatherization or industrialized construction—developed by the Fraunhofer USA Center for Manufacturing Innovation.[2] The work begun in 2023 and reported here evaluated the panel block (PB) technology's potential in terms of market appeal and acceptance, and will help shape Fraunhofer's Tech-to-Market Plan. In turn, this process will also help Efficiency Vermont understand the suitability and market potential of the PB system and deep energy retrofit process for Vermont households and businesses. The data will also inform future Efficiency Vermont energy efficiency and decarbonization programs.

As a result of the data obtained in 2023, the Efficiency Vermont R&D team has evaluated the PB technology designed to (1) minimize site work; (2) enable computer-aided manufacturing mass customization; (3) empower workers to be more efficient; and (4) ensure high-quality retrofits, in a capital-lean way that is compatible with the business model of most small business contractors.

This report offers recommendations to improve the technology-to-market approach and technical specifications for the PB technology for effective weatherizing, to define optimal building characteristics, and about the role the State can play in accelerating the achievement of its weatherization goal through the scaled deployment of this technology. The report also acknowledges the Fraunhofer PB solution is still in development. Full implementation and mass

[1] 30 V.S.A. §202a: To meet Vermont's energy service needs in a manner that will achieve the greenhouse gas emissions reductions requirements pursuant to 10 V.S.A. § 578 and is consistent with the Vermont Climate Action Plan adopted and updated pursuant to 10 V.S.A. § 592.
[2] Fraunhofer USA, an applied research and development organization, received a 5-year award from the U.S. Department of Energy (DE-EE-000906) to pilot and install exterior-block deep energy retrofit technology in five residential buildings. One of the pilot buildings will be in Vermont.

adoption (if the technology can prove itself in the Vermont environmental and business climates) are many years away.

Introduction

Efficiency Vermont has become a partner with Fraunhofer USA on a 5-year federally funded project that tests the market uptake, production characteristics, and energy effectiveness of deep energy retrofits completed with prefabricated insulated panel blocks in climates deemed to be *cold* and *very-cold* by the U.S. Department of Energy's Climate Zones classifications.

More than a year ago, the Fraunhofer Center for Manufacturing Innovation at Boston University approached Efficiency Vermont to scope a demonstration site in this state. The primary aim for the Fraunhofer project in Vermont is to socialize the project and its technology among contractors and other trade practitioners, via Efficiency Vermont staff. Efficiency Vermont's role in 2023 was to engage local stakeholders to broaden and accelerate mutual understanding of the project, deepen Fraunhofer's knowledge of the technology's market appeal to the local market, and expand Vermont stakeholders' perceptions of the new technology and the digitized workflow that drives successful installation.

Through an ongoing 5-year award from the U.S. Department of Energy (DOE), Fraunhofer will complete five deep energy retrofits (DERs) using the PB technology and an HVAC electrification package. Two of the buildings are in Massachusetts; two others are in Pittsburgh, Pennsylvania; and one will be in Vermont. The Fraunhofer project began December 2021 and will end in December 2026.

The target building type is 1- to 4-family homes. The DER construction package targets energy use reductions of at least 60 percent and up to 80 percent for whole-home heating, ventilation, and air-conditioning (HVAC), and domestic hot water (DHW) site energy consumption. Fraunhofer's DOE-funded project team also involves Steven Winter Associates, Gradient, Progressive Foam, the Massachusetts Clean Energy Center, and Rising Tide Partners.

This report describes the first year of the Efficiency Vermont R&D work with Fraunhofer and examines the "tech-to-market" and technical characteristics of the project to date. This report also describes the initial feedback on the early stages of the Vermont project.

Background

In 2020, DOE launched the Advanced Building Construction (ABC) Initiative to invest in new technology that enables high-performance new construction and retrofit strategies that can be deployed quickly with minimal onsite construction. The buildings must be affordable to building owners and appealing to occupants and investors. The initiative also offers a proving ground for innovators' abilities to scale the use of the technologies, to meet national goals for decarbonization.

The current project continues work Fraunhofer completed under its Phase 1 of a DOE ABC award (DE-EE-000906) to design, install, and test a panelized block (PB) exterior-wall insulation prototype. The prototype integrates high-resolution facade scanning automated generation of retrofit façade design, computer numerically controlled (CNC) machining of PB exterior-wall insulation, and augmented reality (AR) into installation technologies. DOE deemed Phase 1 to be successful, which has led to the current Phase 2 project involving Efficiency Vermont and the field installation at the Vermont site.

Method

This research engaged Vermont subject matter experts (SMEs) that included representatives from 3E Thermal, Capstone Community Action, the Energy Action Network, and Efficiency Vermont. They provided feedback on the following topics, to support Fraunhofer's implementation of its DOE ABC project's Phase 2:

- Gauge the perceptions of energy efficiency program implementers and construction professionals about the market appeal of a DER construction package using PB retrofits and digitized workflows
- Gather feedback on the technical installation characteristics of the PB retrofits and digitized workflows
- Gather feedback on the PB business model
- Identify eligible buildings to be evaluated, with one to be chosen for the retrofit

The SMEs attended small-group meetings aligned with their expertise and availability. In those meetings, the SMEs learned about the Phase 1 design, products, and installation process, and responded to the following questions:

1. Is there a market appeal for PB retrofits and digitized workflows?
2. What are the market barriers?
3. What are the strengths and weaknesses of the technical approach of the PB retrofits and digitized workflows?
4. What are important considerations to create a viable PB business model?
5. Can we identify eligible buildings to be evaluated and chosen for the retrofit?

SMEs also attended a field visit to evaluate typical Vermont buildings that met the draft selection criteria.

Results

Technology-to-Market Feedback

Prefabricated PB construction is an emerging technology. As the project moves into its second year and beyond, based on the feedback from the SMEs, the Efficiency Vermont R&D team recommends to Fraunhofer the following points on their Technology-to-Market plan.[3]

1. **Clear and coordinated messaging.** New technology loses its initial appeal if implementers and other market actors perceive it to be infeasible, be too complex, or cost too much. Perceived feasibility by implementers, supply chain partners, and external stakeholders could be a barrier to adoption. To sustain interest in advancing emerging technology, clear and coordinated messaging is important to reduce confusion and create a fuller understanding of new technology.

2. **Evaluating market potential.** The R&D team recommends scoping market potential accurately before promoting the new technology. This will require an investigation of local market building typologies and market characteristics. Many Efficiency Vermont reviewers of the PB product considered Fraunhofer's building envelope improvement protocol a concern or a risk for Vermont buildings because its new and untested which raised concerns about indoor air quality, moisture management and durability. A significant challenge in Vermont is its very diverse housing stock, which will inhibit a one-size-fits-all strategy to scaling the technology among housing developers and homeowners.

3. **Informing regulatory agencies.** Traditional weatherization retrofits can involve renovations and additions; in such events, the State generally requires permits under the Residential Building Energy Standards. Most towns have building permit requirements if an owner changes the building's footprint or use. In some cases, an exterior retrofit could trigger a review or investigation by historic preservation officials if a building is in a historic district or on a historic registry. The R&D team therefore determined that excluding historic buildings from early PB installations would reduce the risk of delays or stoppages.

In addition to these building permit regulations, the R&D team determined that the new technology would need to undergo testing of its response to ignition and the spread of fire. The R&D team also concluded sharing product information with regulators and a local fire marshal should result in Fraunhofer's deeper understanding of fire regulations and of concerns from other relevant agencies and organizations.

4. **Engaging the supply chain.** The R&D team recommends engaging a supply chain stakeholder group for input on the technology's feasibility as it relates to the Technology-to-

[3] Under DOE definitions, Technology-to-Market planning involves commercializing innovative technologies via partnerships among small organizations, industry, universities, DOE National Laboratories, investors, and nonprofit organizations. DOE also cites its Energy Transitions Initiative as a component of Tech-to-Market work. Energy Transitions involves support to states, municipalities, and communities that are transitioning to clean-energy systems. For more information, see slides 10 and 11 in DOE's FY 2017 Budget Overview.

Market Plan. A market evaluation, early in this project (see **2. Evaluating market potential** in this section), can identify candidate buildings' typologies, local demographics, and other characteristics that can inform supply chain needs. Building typology especially will play a significant role in determining probable success with Fraunhofer's planned system. Obtaining clarity from Fraunhofer about ideal building typologies for the PB technology, and solutions to common obstacles from these installations, will be valuable for choosing appropriate scoping and installation methods for the Vermont DER project.

5. **Engaging contractors.** The R&D team recommends engaging a contractor stakeholder group for input on the technology's feasibility as it relates to the Technology-to-Market Plan. The PB installation requires substantial knowledge of Fraunhofer's proprietary technology, which involves scanning equipment to generate computer-aided design (CAD) drawings. Contractors who do not yet have AR skills will need to acquire them to guide the installation. It is likely that the cost of equipment and the necessary comfort with new technology are barriers for Vermont contractors, as is the technology itself. Because of these factors, the R&D team recommends Fraunhofer build in steps for hearing from the contractor base about their challenges in acquiring these new skills.

6. **Evaluating costs.** Efficiency Vermont is not yet aware of existing research or comparisons of estimated project costs and demonstrated energy savings associated with the Fraunhofer technology to current standard cold-climate construction practice. Different cost factors pertain in the Fraunhofer solution. For example, if PB is substantially more costly for implementers, even though the benefits to occupants might be immediately evident, DOE-specified job cost averages for low-income weatherization projects might affect the quantity of projects that can be completed. For this reason, it is important for Fraunhofer to document costs of project installations and make that data available.

The R&D team also notes that there is an absence of price comparisons to other solutions already in the marketplace, in terms of value streams and down-sides to this model. Price comparisons will be necessary to attract retrofit contractors and payers to using the PB product.

Technical Feedback

To review the technology for practical application in Vermont, the R&D team assembled a group of SMEs to provide feedback about the DER construction package made up of the PB prototype Fraunhofer completed under Phase 1 of the DOE ABC award. Fraunhofer will use this feedback to refine the design and technical approach for Phase 2.

Water-resistant barrier (WRB) installation details. The SMEs questioned whether a stapled and taped WRB (for example, Tyvek) is the best material choice, and whether the Phase 1 testing that resulted in an 80 percent reduction in air leakage on the prototype would be achieved when installed on an actual building. The SMEs recommend that Fraunhofer consider adhered-membrane WRB (using a product such as Blueskin) for better air sealing, and acknowledge that there is an increased material cost associated with its use. In October 2021, the material cost of the Fraunhofer Tyvek WRB solution was approximately a third of the cost of Blueskin, at $0.45 per square foot; the Tyvek wrap cost $0.15 per square foot.

In terms of installation costs of just the WRB, Fraunhofer estimated $0.31 per square foot to install Tyvek, and somewhat lower costs to install Blueskin because it does not involve taping. However, Blueskin is prone to a half-conical curling or opening (fishmouthing), which could increase installation cost.

If a stapled and taped WRB is used, the SMEs recommend securely taping the WRB on the perimeter of the building, the seams of the material, and to the windows to reach Passive House Institute US (PHIUS) levels of tightness, targeting 1 air change per hour under 50 pascals of pressure (ACH50), and measuring ACH50 at multiple stages of construction to provide feedback and improve installation techniques.

The SMEs also expressed an interest in Fraunhofer's using a lower-embodied carbon insulation material in the PB fabrication, such as the wood fiber board product, TimberBoard (TimberHP) for the insulation component.

Windows. The Phase 1 PB prototype assumed no replacements of existing windows, but assumed the installation of interior storm windows. The SMEs agree interior storms improve window performance without incurring the substantial cost of window replacement. This method eliminates living space disruption by keeping the work on building's exterior.

However, there were other considerations that might affect this assessment. If a window replacement were to occur after the DER is complete, the SMEs believe the PB installation would be disrupted, with no guarantee that it would be returned to the specifications of the completed DER. This, they reasoned, would compromise air sealing, watertightness, and overall durability of the DER. Under ideal conditions, the windows would be replaced in the existing frame during PB installation, assuming they would last for the life of the DER. The optimal solution would be to insert a new window, replacing the old one, in the existing frame. SMEs discussed window placement in terms of "outie", "mid-way", and "innie" windows which could be reflected in local contractor preferences, as well.

The SMEs also felt window replacement should be offered as an upgrade to a basic PB package, and that a strong window trim and sealing solution is crucial to avoid water damage.

PB insulation. Porches, enclosed porches, and small roof areas over exterior doors (stoops) can be problematic for insulation. That is, they are often uninsulated, will prevent continuous insulation with PBs, and likely offer a direct air path between the joists separating the first and second floors.

Nevertheless, occupants frequently want to keep their stoops to protect their front doors and the transition space between indoors and outdoors. The SMEs noted that removing or dismantling the roof to allow PB installation in place of the missing sheathing is the preferred approach. But they also acknowledged that it might be cost prohibitive. An alternative method would be to open the underside of a porch or stoop roof to install insulation and seal it at an exterior wall plane, since the PB system cannot be installed behind the porch roof. For uninsulated enclosed porches, the PB system could be wrapped around the enclosed porch, effectively bringing that space within the thermal enclosure, but incurring greater cost. It would also preserve the space.

Mechanical systems. The Fraunhofer Phase 1 design suggested the installation of ductless mini-split heat pumps (DMSHPs) in buildings without existing ducts. The SMEs are very familiar with this technology and have concluded that such an installation would provide sufficient comfort in cold weather, given the other benefits of the PB system on occupant comfort.

The SMEs believe hybrid mechanical systems—those that maintain functional fossil fuel systems while adding heat pumps—are an appropriate solution for Vermont housing. A hybrid mechanical system effectively has two redundant heating systems, and can give building owners confidence that there will be sufficient heat if weather exceeds design conditions. A hybrid mechanical system can also allow right-sizing of the heat pump to better match the load of the building across most of the heating season. Such a system also allows the retained fossil system to supplement during the relatively short time when the building is near or at design load.

Ventilation systems. One energy professional noted that the Fraunhofer exhaust-only ventilation strategy is insufficient to provide control of, and ensure, good indoor air quality. The SME suggested instead that the standard mechanical package contain distributed, balanced energy recovery ventilation. This would draw approximately 50 watts of power.

The SMEs considered the possibility of high-quality ventilation with the use of "local" or "decentralized" balanced ventilation. The SMEs expressed concern that such systems might not be suited to a cold climate and could introduce cold air, resulting in locally uncomfortable conditions. Systems that allow spot energy recovery ventilation, however, could make possible the blowing of cold air when it was not wanted.

Health benefits. The SMEs felt that the PB system would effectively encapsulate lead paint on existing exterior surfaces, and therefore would add value to a project. They recommended creating mitigation measures to minimize dispersal of lead paint during installation, as part of the PB installation process. Once installed, the PB would prevent additional lead paint chips from falling to the ground.

Contractor potential. Despite the SME assessment that the Fraunhofer PB system is beyond the scope of the current Vermont contractor market's capacity, the SMEs agreed that general contractors who are enthusiastic about using new building methods should be located and trained in the technology. Efficiency Vermont staff identified a possible partner for undertaking the Fraunhofer project demonstration.

Other observations. Applying spray foam to basement walls is common in Vermont and can account for reducing space heating loads by approximately 30 percent. The SMEs recommend Fraunhofer consider spray foam application or a lower-embodied carbon insulation and air sealing system for basement walls. Stone and rubble foundations might need spray foam, but others could do with board foam or even carefully detailed fiber insulation.

Conclusion

This R&D team fulfilled its research objectives of gathering and reporting feedback on the challenges of planning for a Technology-to-Market introduction of PB retrofits into the building market in cold climates. That is, the project has:

1. Collected perceptions and other field information from Efficiency Vermont staff and SMEs about the market appeal of PB retrofits and their associated digitized work flows
2. Obtained feedback on the technical features of PB retrofits and the work flows
3. Gathered targeted feedback on the PB business model
4. Begun the work of finding eligible buildings for their suitability in receiving a PB retrofit

Advised Next Steps from the Field

The R&D team recommends the PB installation demonstration project have the following characteristics:

- The building must be very simple in design.
- The site does not have historical preservation status.
- The building has a minimal or no porch, and does not have a stoop roof.
- It is a building in need of re-siding or has deteriorating lead paint on the siding.
- An experienced general contractor is on board for the project and willing to apply an innovative technology.
- The homeowners and contractor are open to receiving Fraunhofer's and Efficiency Vermont's technical assistance to support all phases of the project, from design to installation, and to post-occupancy monitoring from a trusted partner (an Efficiency Vermont staff person or an Efficiency Excellence Network contractor).
- The homeowners or rental occupants are open to training in operations and maintenance of the installed whole-building energy system.

Context for Vermont

The R&D team believes the State's clean-energy goals cannot be met without a forward-thinking strategy for testing innovative retrofit solutions. This R&D project has furthered local stakeholder understanding of the energy savings and environmental benefits, risks, and practicalities of launching a scalable solution such as that being tested in Vermont by Fraunhofer USA.

To that end, the R&D team initially has concluded from its experience in 2023 with Fraunhofer that—with the obtained feedback from Efficiency Vermont staff, contractors, and other SMEs—

further participation in the implementation of the Vermont site will result in a housing retrofit solution that will:

- Increase the speed, quality, and energy efficiency of housing in need of deep energy retrofits
- Drive down the costs of such projects, relative to current practices, increasing the potential for vulnerable households to improve exterior wall building envelope conditions
- Offer beneficial opportunities to transform the careers of construction trade allies

Finally, because the Fraunhofer PB solution is still in development, full implementation and mass adoption (if the technology can prove itself in the Vermont environmental and business climates) are many years away. However, the technology could well prove to be financially feasible, relative to the GHG reductions it can produce. If that occurs, Efficiency Vermont will then be able to design and offer a feasible incentive structure that can result in high rates of uptake and corresponding benefits that accrue to building owners, occupants, and local economic development—while meeting the relevant goals presented in the *Comprehensive Energy Plan.*