Comprehensive Single-family Home Deep Energy Retrofits with Prefabricated Panel-Block Wall Insulation

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Project Summary

OBJECTIVE, OUTCOME, & IMPACT

Develop and demonstrate a prefabricated insulated panel-block (PB) exterior wall insulation system and digital processes on 5 smaller buildings that 1) adds ~R-24; 2) semi-skilled laborers install in 60 person-hours with no on-site cutting; 3) at a cost of <$10/ft^2. Reducing site HVAC energy by 28%, the system could save ~0.8 quad/year in cold, very cold, and mixed climate zones.

TEAM & PARTNERS

Technology Development: Progressive Foam, Steven Winter Associates.
Deployment: Green Building Alliance (GBA), Rising Tide Partners, VEIC.
Commercialization: GBA, Massachusetts Clean Energy Center, VEIC, Vinyl Siding Institute.

STATS

Performance Period: 7/2020 – 11/2026

DOE Budget: $5,438k, Cost Share: $1,360k

Milestone 1: Finalized PB and trim designs.

Milestone 2: Achieved target scan-to-BIM accuracy.

Milestone 3: Recruiting 5 pilot buildings nearly complete.

Sources: DOE-EIA (2020), Fraunhofer, PNNL (2022), NREL ResStock.

Problem

- One- to four-family homes account for >90% of heating and cooling energy in in cold, very cold, and mixed climates (~3.9 quad site energy)
  - Approximately half of buildings have *negligible* or R-7 wall insulation
- Walls account for ~40% of HVAC energy consumption in colder climates (including infiltration)
- Outside of the multi-family sector, insulated vinyl siding (~R-2) is most common
- Deep exterior wall insulation retrofits, e.g., +R-20, are very costly (>$20/ft^2) due to extensive high-skill site work around terminations – death by a thousand cuts
- Consequently, negligible uptake of significant exterior wall insulation retrofits occurs despite technical energy saving potential of ~0.8 quad/year (site)
  - Additional value for reducing heat pump design loads
- Developing a high-performance exterior insulation system + *process* that greatly decreases quantity and quality of site labor required could greatly improve the economics, adoption, and realized energy savings – of exterior wall retrofits

Sources: DOE/EIA (2020), PNNL (2022),

Alignment and Impact

Impact: Achieving *installed* costs <$10/ft^2, i.e., similar to conventional *uninsulated* vinyl siding, to scale deployment of high-performance exterior wall insulation

- Particularly valuable for LMI households in older, unimproved housing stock

Alignment with DOE Goals: Reduces heating and cooling energy consumption and loads to:

- Facilitate building electrification by reducing
  - whole-building kWh and kW, heat pump capacities required (cost, electric capacity)
  - ability for HPs to meet loads using existing ducts
- Increase building flexibility and resilience during outages
- Reduce renewable electricity generation and grid infrastructure required to achieve 100% renewables and a net-zero economy
- Reduce inhabitant energy costs and Improve inhabitant comfort and acoustics

Alignment and Impact

End-of-Project Deliverables:

- Processes to digitize the exterior wall insulation retrofit process developed
- Highly insulated exterior facade, +R-24, deployed on five (5) 1- to 5-family buildings using the digital processes
- Evaluation of digital processes and energy performance
  - Installation of PB system in ≤80 person-hours on 2,000 ft^2 building
  - Clear pathway to achieving installed cost of ≤$10.00 ft^2 (wall area)
  - 60 to 80% reduction in HVAC+DHW site energy (with electrification; stretch goal)
- Commercialization Plan, Technology-to-Market Plan, Updated Pitch Deck

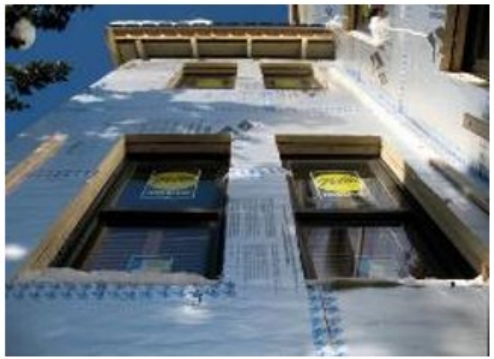
Impacts:

- Support pursuit of venture capital for start-up company to commercialize
- Technology de-risking – investors want technology *platforms*

Approach

Exterior Wall Retrofits: State-of-the-Art

- Detached Homes: 4’x8’ insulation board sheets and trim custom-cut on site, Larsen Truss
  - Prior DER pilots and practitioners found SOA for detached homes was time- and labor-intensive → costly and disruptive
  - Workers custom-cut insulation to fit wall penetrations, build extension boxes for windows, cut and apply air and vapor barriers and sealants, tape insulation joints, etc.
  - Far too costly and requires too much skilled labor to scale = negligible uptake
- Multifamily Buildings: Larger panels (e.g., EnergieSprong) prefabricated off site
  - Most applicable to buildings with very basic facades, challenging to use cranes around many buildings

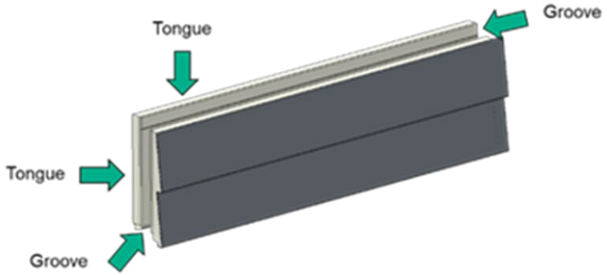


Sources: Byggmeister (2009), Neuhauser (2011), PNNL (2022), Wotzak (2009).

Approach

Basic building block: Prefabricated Panel Block (PB)

- Standard full size = 1’ x 4-8’ x 4”
- Pre-cladded with attractive exterior
- Adds R-24 insulation (polyiso)
- Light weight (<5 pounds)
- Net shape production
- Tongue-and-groove feature to manage water intrusion and air leakage
- Installs over existing siding using screws
  - WRB installed over existing cladding



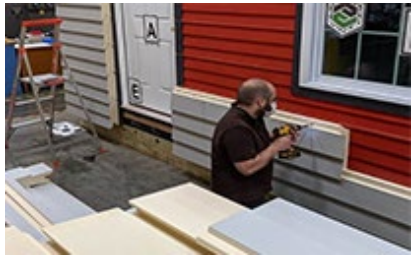
Approach: Process Summary

We digitize the design, production, and installation processes to customize wall retrofits to each building.

1.

Laser Scanning Generates Façade BIM

2.

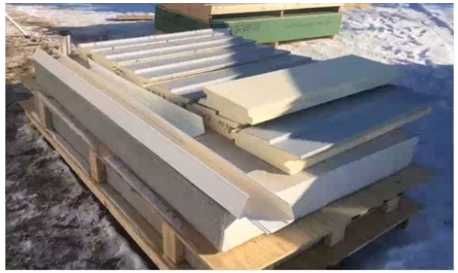


Panelization algorithm solves for optimal PB Set for each building

3.

PB CAD files feed CNC PB + Trim Fabrication Kitting Process

4.



Palletized PB kit shipped to site

5.

Augmented Reality (AR) guides on-site install over existing cladding + Quality Control

Image Sources: Fraunhofer USA, QYPC, U.Minnesota.

Approach

Key Attributes of our approach:

- Offsite design and fabrication to minimize on-site labor = Minimize Disruption and Cost
- Empower – not replace – semi-skilled workers using AR to increase their productivity and provide quality control
- Work with small contractors' business models – Capital-lean approach
- Process digitization: Rapid performance gains and cost decreases foreseeable

Traditional re-siding
- **Low** material cost
- **High** labor cost
- **No** energy savings

Pre-fab Lightweight PBs
- **Higher** material cost
- **Lower** labor cost
- **High** energy savings

Approach: Project Plan

- Develop full digital process flow: Scan-to-BIM (S2B), Panelization, and AR Experience
  - Scanning Barriers: Scanning yields many artifacts, Heterogeneity of target buildings, limited tagged point-cloud datasets available to train neural network (NN) to segment scanned facades
  - Risk mitigation: Scan ~40 buildings and manually tag objects; test full process on mock-up wall and several buildings
- Develop full set of trim solutions to address common terminations
  - Barriers: Dozens of different terminations, heterogeneity of target buildings, some buildings lack overhangs, cost
  - Risk mitigation: Leverage prior DER solutions, Mock-up walls to test and refine solutions, third-party review and feedback, water intrusion testing
- Test on Mock-up wall and then apply digital process flow to five test buildings
  - Validate accuracy of building dimensions, object tagging by NN, dimensions of PB set generated
  - AR experience renders correct PBs in correct locations, in correct installation order
- Design and install custom PB set on five pilot buildings in Boston and Pittsburgh:

  Scan → Panelize → Fabricate → Install using AR experience

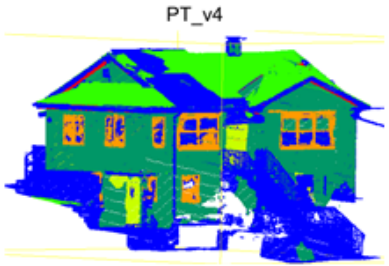
Approach: Commercialization

- Successful commercialization depends on creating a financially viable business model that is attractive to investors or licensees, as well as achieving contractor and homeowner acceptance
- Our proposed commercialization approach: Seek venture capital to fund start-up
  - Company would own digital processes and design
  - Team with polyiso and vinyl siding manufacturers on production
- Value propositions for this ~$30 billion/year opportunity:
  - *Homeowner:* Lower energy costs, superior comfort + acoustics, at a similar price to vinyl siding
  - *Siding Installers:* Increased worker productivity, higher margins
  - *Investors:* 10-year IRR of 50% from operations alone
- Target initial market: Colder climates with older housing stock, higher energy prices, and strong EE programs → Northeast
- Successful demonstration of viable digital processes essential to de-risk technology

Progress and Future Work

Scan-to-BIM: Challenges & Workflow

- Very challenging – extract information from ~300 million points, must be robust for wide range of length scales and feature characteristics, 100+ edges per building
- Fraught with “phantom” and missing points, outliers
- Scanned ~40 buildings, manually segmented 15
- Trained neural network to accurately segment point cloud
- Developed algorithms to extract dimensions and edge types of key building features

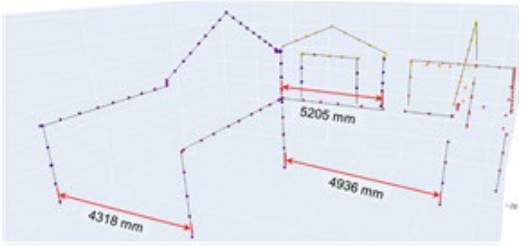


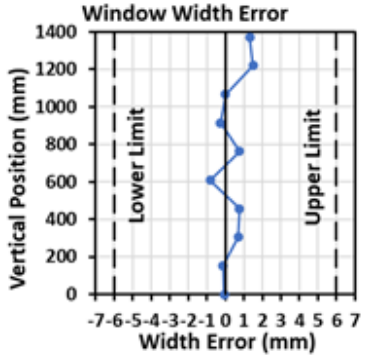
Scan → Processing → Segmentation → S2B → Panelization

Progress and Future Work

Scan-to-BIM: Dimensional Accuracy

- Tested wide range of candidate algorithms to accurately identify edges of different building elements
  - Mostly for segmented point clouds
- Key is having algorithms that accurately identify building elements and their edges
  - Found that different algorithms work better for different elements
  - Windows most challenging due to trim
- Have honed algorithms by testing on several digital assets to meet ±¼“ goal



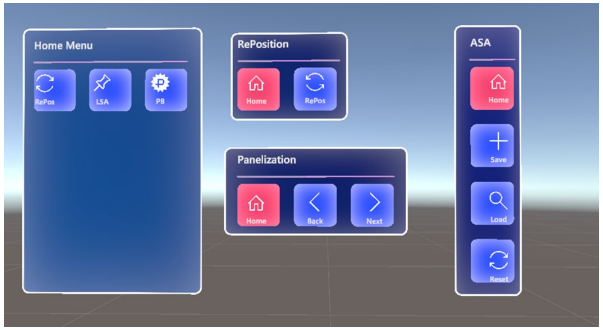


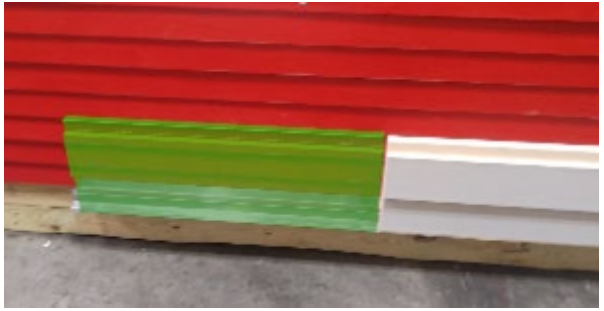
Progress and Future Work

Augmented Reality (AR) Experience

We have developed several key aspects:

- Local spatial anchors to align virtual and real worlds (basic and fine alignment)
- Local state object to specify PB parameters for accurately rendering PB holograms
- QR codes for PB tracking
- Unified home menu to support workflow
- Working to integrate AR with overall digital workflow, i.e., outputs from panelization

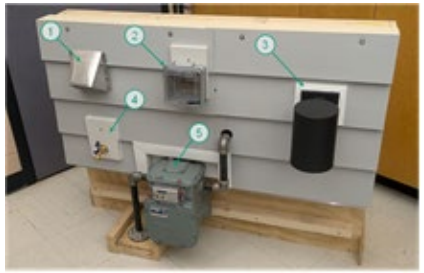




Progress and Future Work

Finalized Trim Designs

- Numerous different terminations – want to address all with pre-fabricated solutions
- Developed wide range of design details, tested on mock-up walls, refined as needed
- Developed material cost models to support design decisions (additional cost reductions expected at scale)



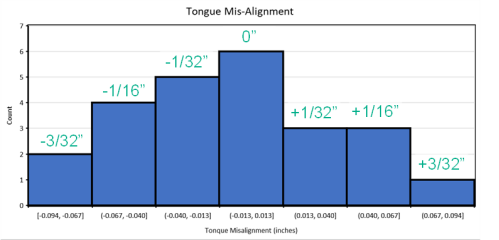
	The Standard Home						
	Opaque Wall Area	Soffits	Outside Corners	Inside Corners	Windows	Doors	Start Strips
Measurement	1,500 ft²	200 ft	100 ft	50 ft	250 ft	50 ft	200 ft
Cost Estimate, Per Unit	$3.59/ft²	$3.89/ft	$4.12/ft	$1.48/ft	$2.82/ft	$2.82/ft	$1.78/ft
Cost Estimate, Total	$5,385	$778	$412	$74	$705	$141	$356

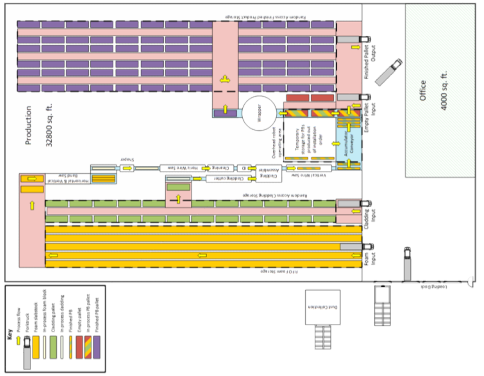
Option 5

Progress and Future Work

PB Fabrication

- Worked with foam vendor to improve production accuracy by modifying set-up and cutting paths
- Working with Progressive Foam to develop process to adhere vinyl siding cladding to foam and cut to shape
- Cost of low-volume PB production for demonstration buildings proving higher than budgeted – shift HVAC retrofit costs to PB production
- Conceptual factory design for ~5k homes/year and manufacturing cost model shows much lower cost





Progress and Future Work

Preparing for 2025 Retrofits

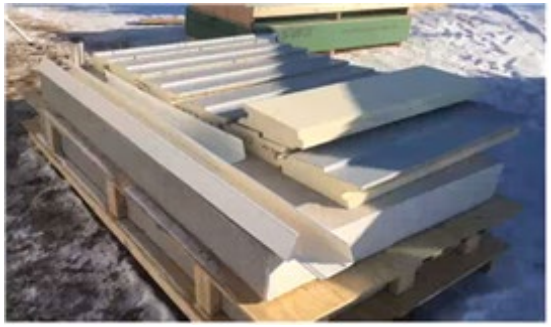
2024 (by 11/30)

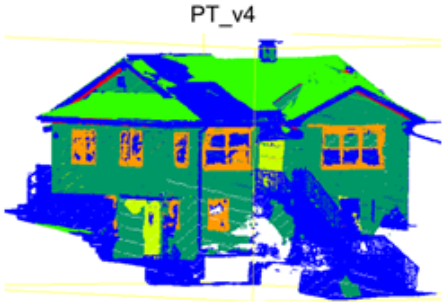
- Apply digital process (except PB fabrication) to five test buildings
- Finalize five retrofit buildings for 2025 pilot

2025

- Select contractors to install PBs
- Scan buildings and fabricate full PB + trim sets
- AR-assisted installation of PB system
- Monitor field performance

Thank you





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Reference Slides

Project Execution

	BP1 (2020-22)						BP2 (2022-23)				BP3 (2023-24)				BP4 (2024-25)				BP5 (2025-26)			
Planned budget	$625,220						$1,872,558				$1,887,487				$1,587,892				$825,169			
Spent budget	$625,220						$1,872,558				$1,420,000 (est.)				$0				$0			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22
Past Work: Key Milestones & GNG Shown																						
Q6 G/NG: DER including PBs + other ECMs has clear pathway to 75%+ site EUI reduction					◆																	
Q6 G/NG: Cost model shows viable pathway to ≤$6.00/ft2 installed cost at volume production				◆	◆																	
Q6 G/NG: PBs installed on mockup wall with acceptable fit, in ≤4 hours.				◆	◆																	
Q10 Milestone: Demonstrate AR anchor soln.									◆	◆												
Q10 Milestone: Window S2B accuracy ±10 mm									◆	◆												
Current/Future Work: Key Milestones, GNG																						
Q14 G/NG: Demonstrate virtually S2B->Panelization->AR process on 5 homes, ±6mm														◆								
Q14 G/NG: 5 buildings selected for retrofits.														◆								
Q18 G/NG: Retrofits implemented at 5 buildings using digital processes, monitoring.																		◆				

Note: This project spans 7 DOE FYs and comprises >60 milestones, limiting what could be shown in this format.

Team

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Improving the Built Environment Since 1972

HF

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Deployment & Commercialization

Green Building Alliance

Rising Tide PARTNERS
Restoring Communities Preventing Displacement

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MASSACHUSETTS CLEAN ENERGY CENTER