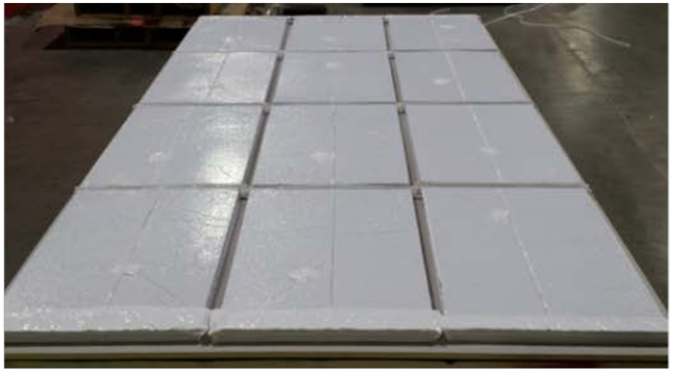
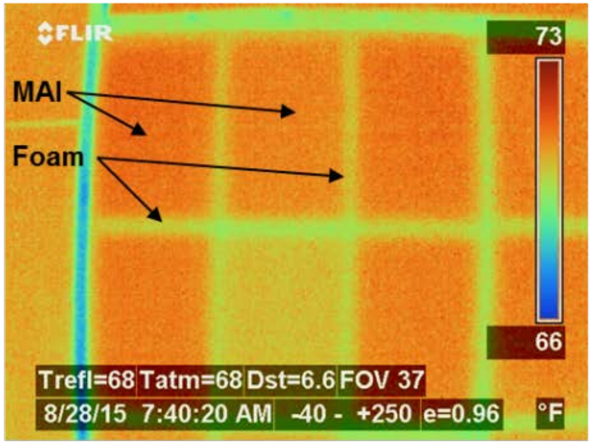
R25 Polyisocyanurate Composite Insulation Material

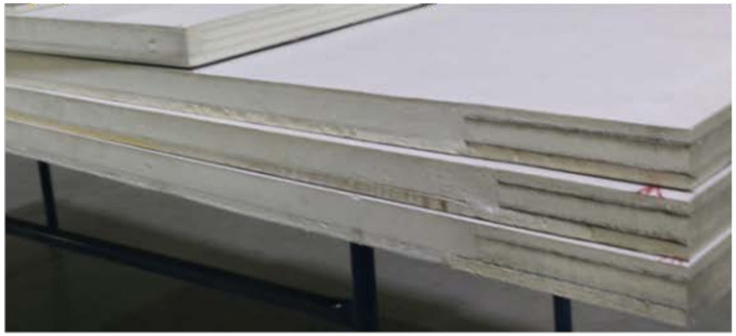
2016 Building Technologies Office Peer Review



Modified Atmosphere Insulation (MAI) panels on high-density (HD) foam substrate



Foam application on manufacturing line



Finished composite insulation boards

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Project Summary

Timeline:

Start date: Oct 1, 2014

Planned end date: Sep 30, 2017

Key Milestones

1. First full-scale MAI-polyiso composite measured to be R-10/inch; 9/30/15
2. Verify R-value of improved MAI-polyiso composite produced on the production line to be R-12/inch ; 9/30/2016
3. Optimized cost of commercial composite panels with R-12/inch; 6/30/2017

Budget:

Total Project $ to Date:

- DOE: $1,101,756
- Cost Share: $177,812

Total Project $:

- DOE: $1,237,500
- Cost Share: $310,000

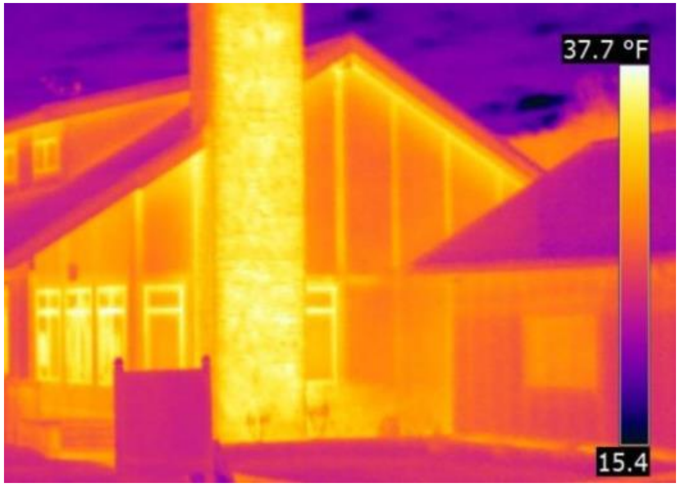
Key Partners:

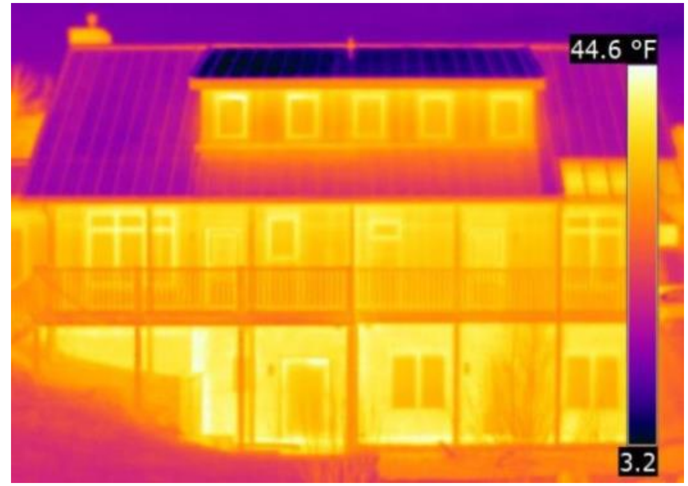
Firestone Building Products Company
NanoPore, Inc.

Project Outcome:

Develop a 2-inch thick composite foam insulation board with R25 (hr-ft^2-F/Btu), with a cost premium of \$0.30/ft^2. This addresses the MYPP goal of creating low-cost, advanced insulation materials.

Purpose and Objectives





Problem Statement: Address the EERE BTO's mission to develop low-cost, high-performance advanced insulation materials for building envelopes (*Table 8 under section 2.3 of BTO's Multi-Year Program Plan or MYPP*).

- Per BTO's 2014 Roadmap, adding R24 to existing walls has a 2030 technical potential of 1,101 TBTUs.
- Need 4 inches or more of current insulation materials vs. 2 inches of the new composite insulation.

Purpose and Objectives

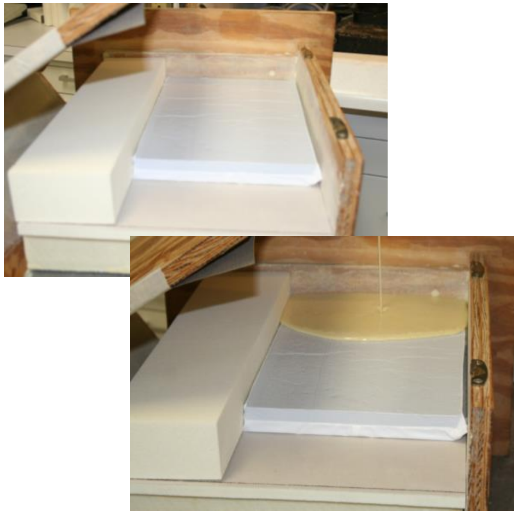
Target Market and Audience: The target market is residential walls and low-slope commercial roofs, both retrofit and new construction.

- In 2010, the primary energy consumption attributable to commercial roofs and residential walls was 2,810 TBTUs (per 2014 BTO Roadmap).

Impact of Project:

1. Major output: Development of R12/inch composite insulation with MAI cores encapsulated by polyiso foam, produced on a manufacturing line.
2. Near-term outcomes (end of project):
   a. Verified thermal performance (R12/inch) of the insulation boards.
   b. Techno-economic analysis evaluating $0.30/ft^2 cost premium target.
3. Mid-term: Field-demonstration and evaluation of long-term performance.
4. Long-term: Incorporation of the new composite insulation into regular production by foam manufacturer(s) and market adoption.

Approach



Lab-scale foaming experiments

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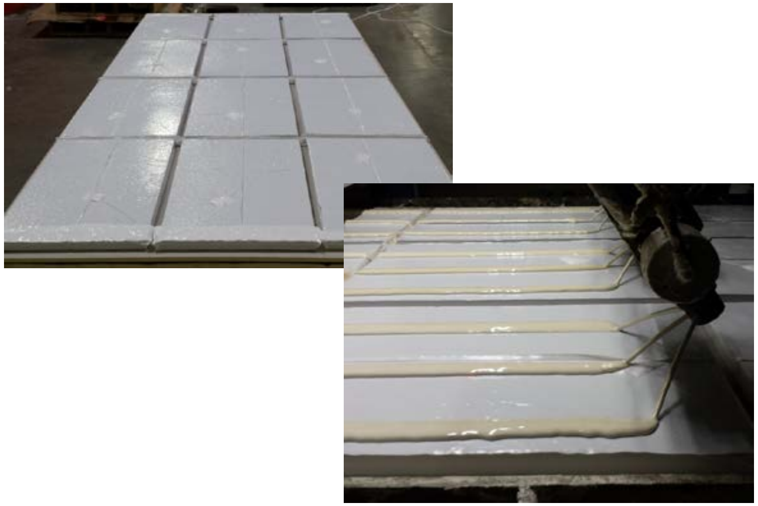

Plant production of composite boards

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Thermal performance testing per ASTM C1363

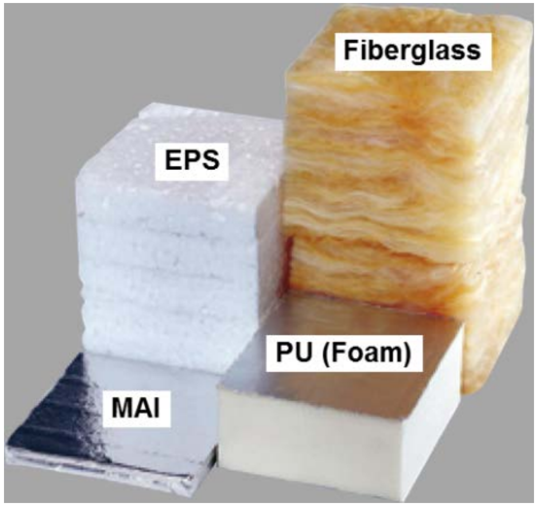
Key Issues:

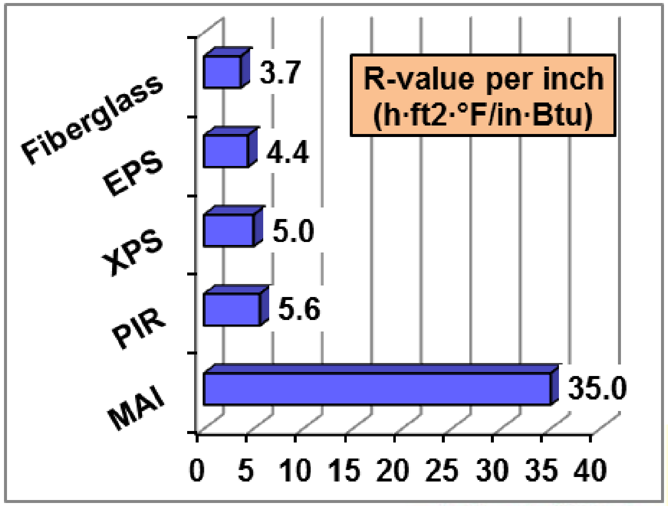
- Damage to MAI panels by exothermic foam expansion during encapsulation.
- Complete foam encapsulation of the MAI panels (without air pockets).
- Moisture-related issues arising due to addition of the composite insulation.
  - Barrier films of the MAI panels act as additional air/vapor barriers for building envelopes.

Approach

Distinctive Characteristics:

- Use of MAI (40% lower cost than regular vacuum insulation panels or VIPs).
- Polyiso (PIR): Highest R/inch of all commercial insulation materials, with demonstrated toughness and durability in construction environments.
- New composite insulation: Combining the features of MAI panels (very high R-value) and polyiso (high R-value and durability).
- Encapsulation of MAI panels in polyiso foam protects them during transportation and handling, installation, and use.

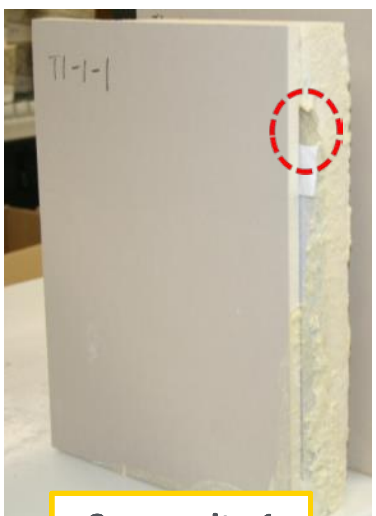




Progress and Accomplishments

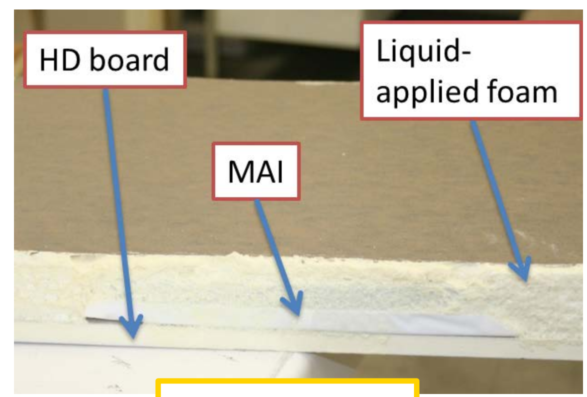
Laboratory-scale experiments: Foam encapsulation of MAI panels

- MAI panels with metallized and all-polymer barrier films were tested.
  - Polymer barriers significantly reduce thermal bridging around MAI panels.
- The foam encapsulation of MAI panels was satisfactory, except one test.
  - Caused by lab foaming conditions; not expected in plant production.
- MAI panels withstood the exothermic foam expansion.
  - No measureable dimensional changes to MAI panels.
  - Barrier surface temperature rise (<90°C) less than damage threshold (110°C).



Composite 1

Composite 2



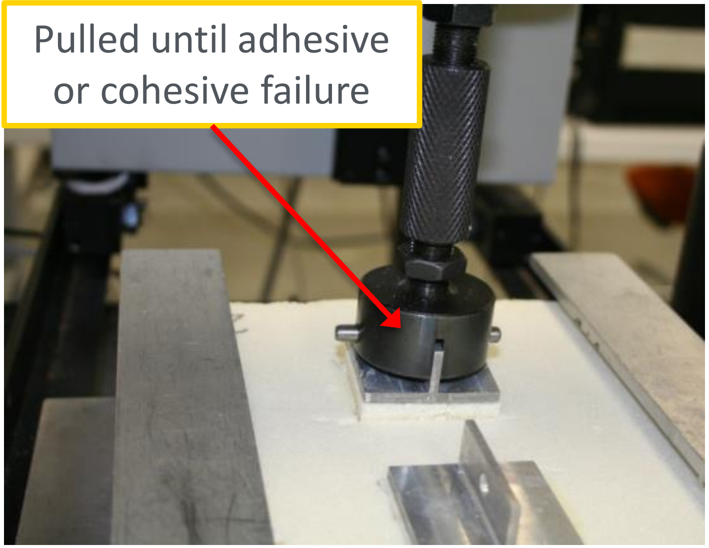
Composite 3

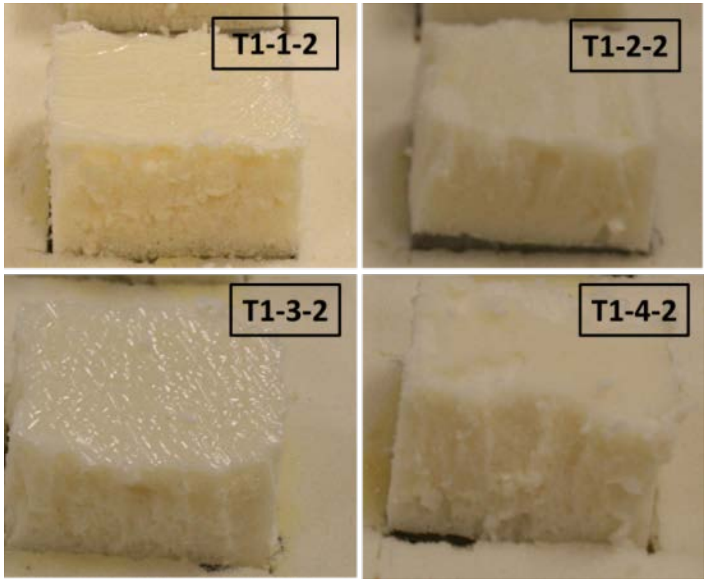
Progress and Accomplishments

Laboratory-scale experiments: Foam adherence to MAI barrier films

- Metal plates attached to foam surface and cured for 3 days.
- Foam cut around the metal plates and pulled until adhesive (foam-MAI barrier) or cohesive (foam) failure.
- All barriers passed the minimum required adhesion force of 4 psi.

MAI barrier ID	Adhesion (psi)	Failure mode
T1-1 (PE)	6.8	Adhesive
T1-2 (PET)	31.2	Cohesive
T1-3 (BOPP)	5.1	Adhesive
T1-4 (nylon)	17.9	Partial cohesive





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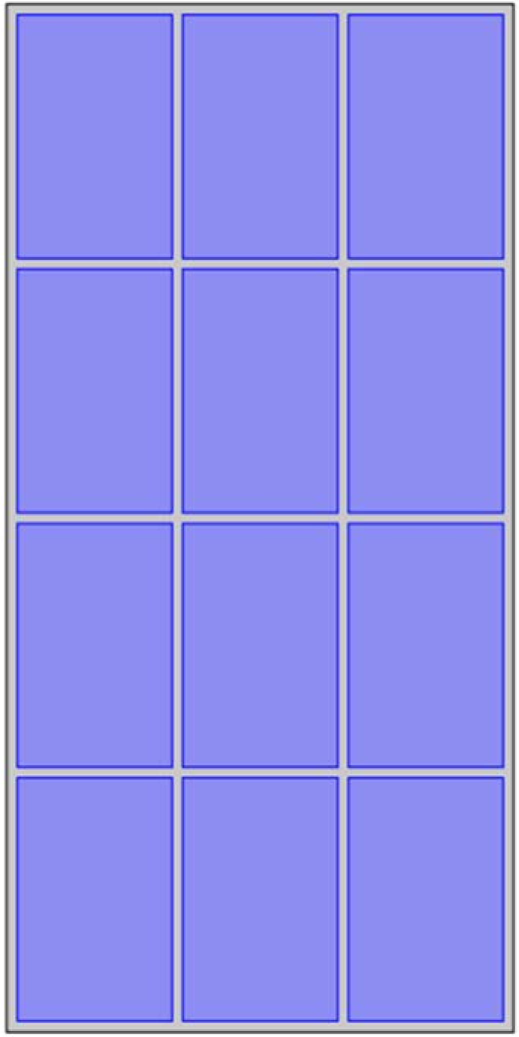
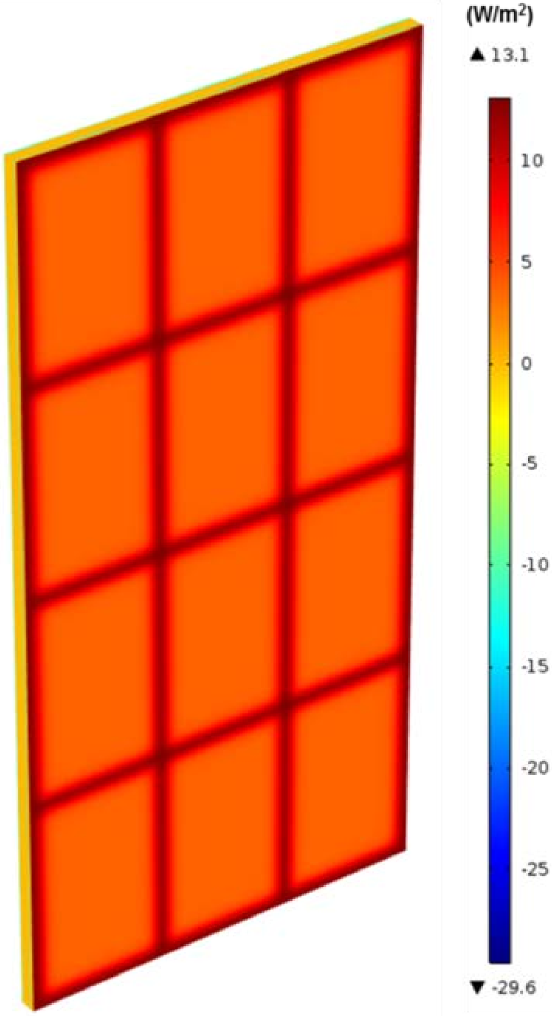
Progress and Accomplishments

Design of MAI-Polyiso Composite Boards Based on Thermal Modeling

- First-generation 4’ x 8’ composite design
- 4x3 array of MAI panels (22.75” x 14.7”)
  - 1 inch gaps for mechanical fasteners
  - 86.9% MAI coverage
- Estimated R-value of the 2-inch board: 25.5 hr-ft^2-°F/Btu (*R12.7/inch*)

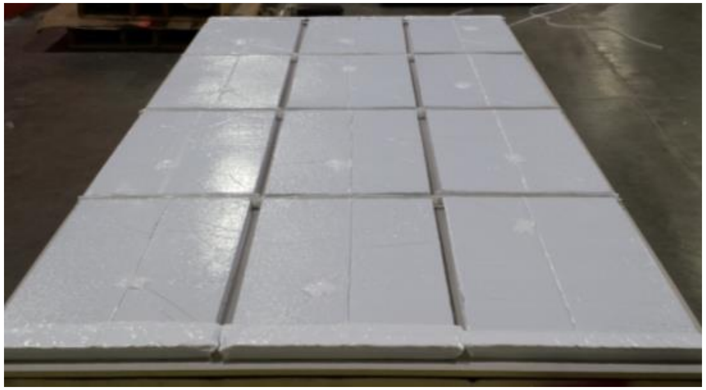




Simulated heat flows through a MAI-foam composite board.

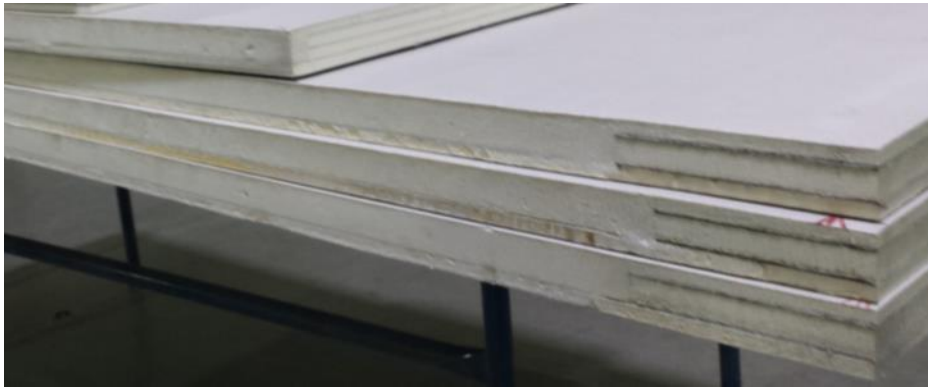
Progress and Accomplishments

- July 2015: Three first-generation composites produced in a manufacturing plant.
  - *No major changes needed to the assembly line; critical consideration with respect to cost premium of the new composite insulation*.

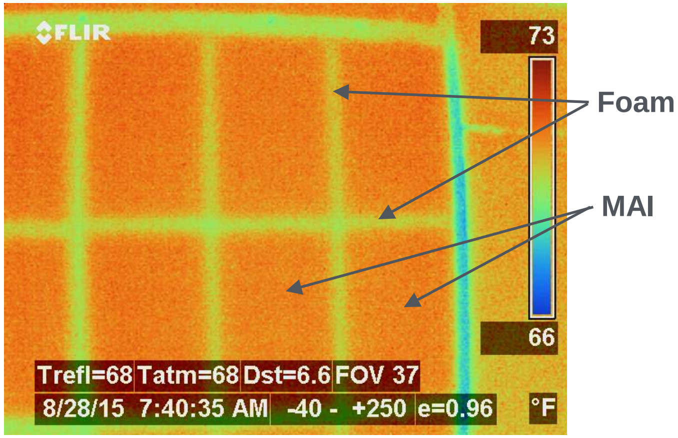


MAI panels attached to high-density (HD) foam substrate

MAI-HD board fed through foaming line



Finished composite insulation boards



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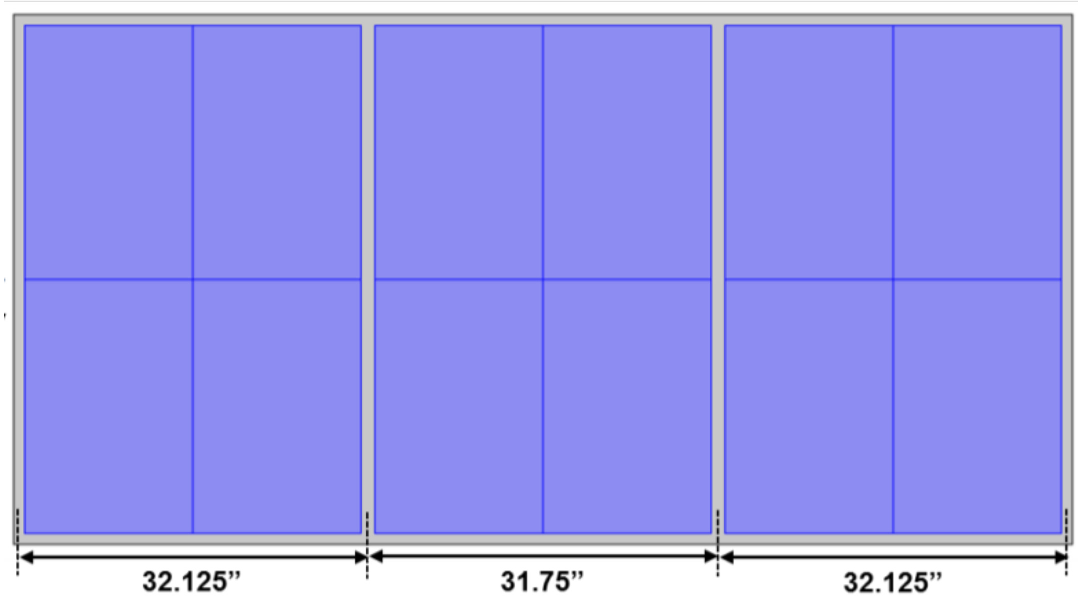
Progress and Accomplishments

- September 2015: Guarded hot box tests (ASTM C1363) yielded R21.6 for the 2-inch composites (*R10.8/inch*).
  - Year 1 Go/No-Go target: R10/inch
- Autopsy of one board performed after the hot box test.
  - No discernible changes in MAI shape and dimensions.
  - One area had poor foam fill, with implications on measured R-value.

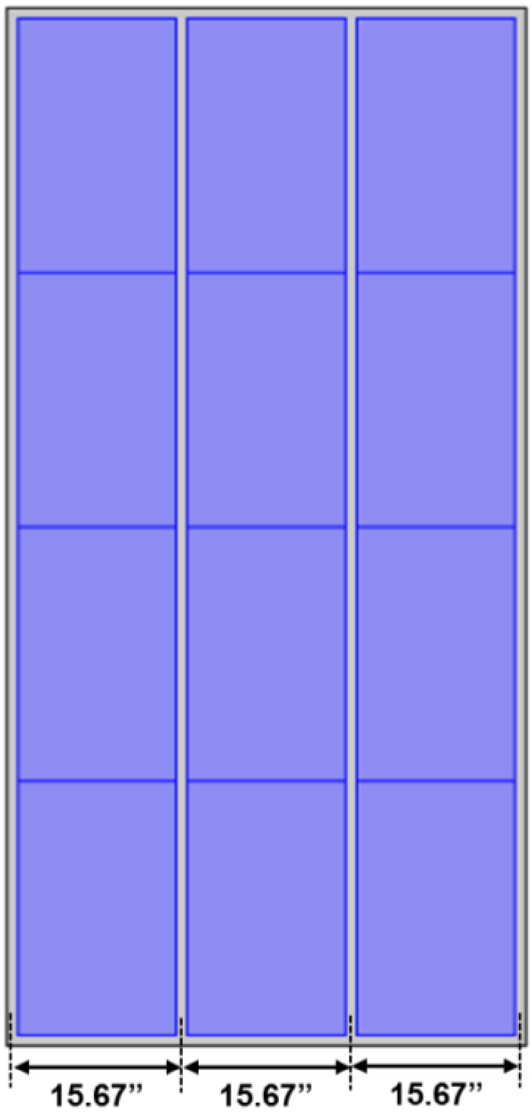
Poor foam fill

Progress and Accomplishments

- Second generation composites: Higher MAI coverage to achieve R12/inch.
  - 89.8 - 91.3% vs. 86.9% in FY15
- Modeling indicates increases in overall R-values of 1.3 – 2.1 hr-ft^2-°F/Btu
  - *ΔR/inch of 0.7-1.1*



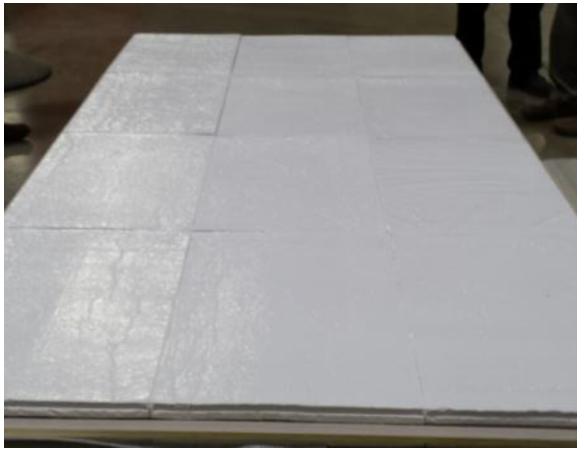
Skipping alternate studs on walls

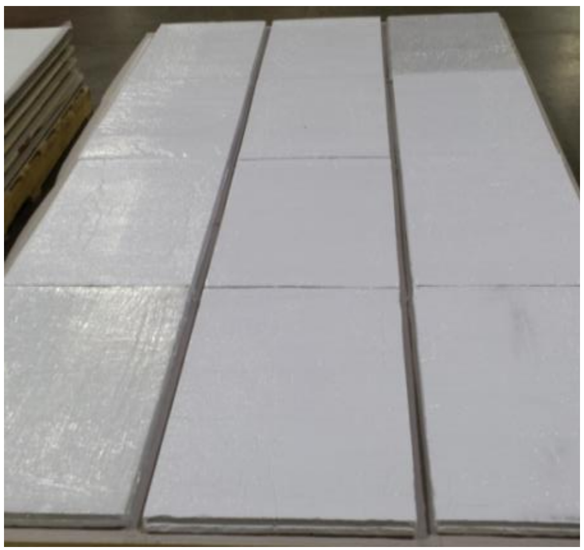


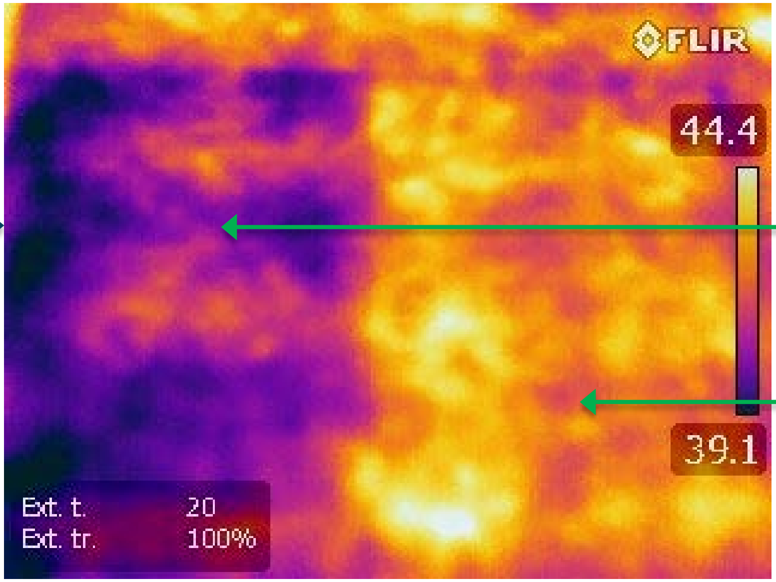
Eliminating foam gaps along the width

Progress and Accomplishments

Second-generation composite production (March 3, 2016)







- Potential online quality control using IR imaging
- Thermal diffusivity ($k/\rho c_p$): Damaged MAI >> Intact MAI
  - Cools the 'warm' spray-applied foam faster.

Progress and Accomplishments

Techno-economic Analysis

- September 2015: Interim report detailing methodology and strategy.
- Identifying external factors impacting demand for new composite insulation.
  - e.g. competitive products, energy cost, building codes, etc.
- Evaluation of production efficiencies and material cost reductions needed to achieve the desired $0.30/ft^2 cost premium.
- Initial analysis report due in April 2016 (based on Year 1 project results).
  - Phase 2 analysis report: December 2016.
  - Final analysis report: June 2017.

Hygrothermal Analysis

- Hygrothermal modeling indicated no adverse moisture-related effects due to addition of MAI panels.

Progress and Accomplishments

Market Impact: Potential market impact is listed as the project is still in R&D stage.

- Based on numerical simulations of standard residential and commercial building models, the new R25 insulation board has a 2030 primary energy savings potential of 1319 TBTUs.
- The techno-economic analysis, due by June 2017, will determine cost premium and/or pathways to desired cost premium and the market demand.

Awards/Recognition: N/A

Lessons Learned:

- Handling of MAI-HD boards (before the foaming process) – Improper handling can lead to detachment of MAI panels from the HD substrate.
- One composite produced during July 2015 contained 2 failed MAI panels (out of 12); Quality control process is needed during eventual mass production.
  - Simulations indicate 15% reduction in R-value due to 2 failed MAI panels.

Project Integration and Collaboration

Project Integration: The project is a collaboration between ORNL, Firestone Building Products Company and NanoPore, Inc. Dr. Jim Hoff of Tegnos Research Inc. is performing the techno-economic analysis.

- Firestone has been in the polyisocyanurate industry for 25 years and is the largest manufacturer of commercial roofing materials in the world.
- NanoPore has been developing nanoporous materials and advanced insulation (including VIPs) since 1993 and has more than 100 patents.
- Dr. Jim Hoff has 30+ years of executive experience in the building materials industry and is a former Vice President at Firestone Building Products.

Communications:

- Manuscript titled '*Development of High Performance Composite Foam Insulation with Vacuum Insulation Cores*' submitted to **Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference**.
- 'Flipping the switch,' R&D Magazine Article, February 2015, http://www.rdmag.com/news/2015/02/flipping-switch

Next Steps and Future Plans

- Develop accelerated aging test protocol for MAI panels (June 2016)
- Verify improved composite boards to be R12/inch by testing in ORNL's guarded hot box (Sept. 2016)
- Detailed techno-economic analysis and cost optimization (June 2017)
- Field-testing of thermal performance of composite boards in ORNL's natural exposure test (NET) facilities (Oct. 2016 – Sept. 2017)

Additional Tasks (beyond current scope):

- Demonstration of new composite insulation in actual or simulated retrofit applications.
  - Identify installation challenges, design changes required, etc.
- Long-term testing in actual buildings to ascertain lifetime thermal performance of the composite insulation.

REFERENCE SLIDES

Project Budget

Variances: N/A
Cost to Date: 89% of the budget (including cost to date and encumbered costs)
Additional Funding: N/A

Budget History					
FY 2015 (past)		FY 2016 (current)		FY 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$542,961	$113,378	$431,006	$140,602	$264,032	$56,154

Project Plan and Schedule

- Changes in ORNL's subcontracting process resulted in delays at the beginning of the project in providing funds to the industry partners, causing the initial milestones to slip.
- There are Go/No-Go decision points at the end of each Fiscal Year:
  - FY15 - First full-scale MAI-polyiso composites measured to be R10/inch (9/30/2015)
  - FY16 - Improved MAI-polyiso composites measured to be R12/inch (9/30/2016)

Project Schedule		
Project Start: 10/1/2014		Completed Work
Projected End: 9/30/2017		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

Task	FY2015				FY2016				FY2017			
	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Bench-top prototype with MAI panel encapsulated with foam												
Methodology and strategy for techno-economic analysis												
First full-scale MAI-polyiso composites measured to be R-10/inch												
Hygrothermal analysis of envelope assemblies with MAI panels												
Design for improved MAI-polyiso composite (using modeling)												
Current/Future Work												
Accelerated aging test protocol for MAI panels												
Improved MAI-polyiso composites measured to be R-12/inch												