Development of High Performance Composite Foam Insulation with Vacuum Insulation Cores

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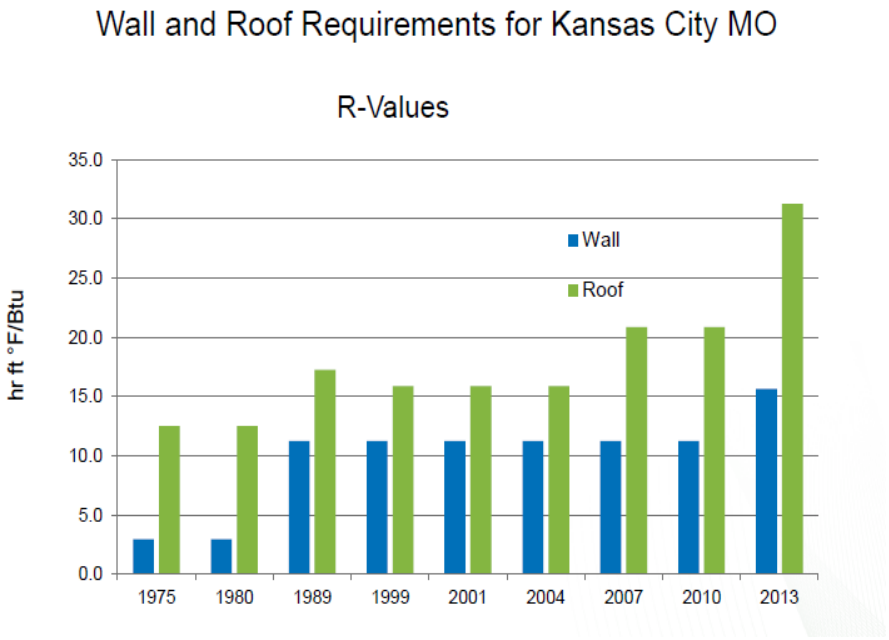
Agenda

- Background
- Lab scale evaluation
- Manufacture scale evaluation
- Results

Background

- 40% of all primary energy and 75% of all electricity used in the US is from building.
- ASHRAE Standards increase insulation requirement for both wall and roofing
- Retrofitting wall and roofs needs thinner insulation system to be economically and technically viable
- DOE's roadmap for building envelope indicates that developing insulation material with ≥R12/in is high priority



Primary Energy Savings from Residential Wall Retrofits (assuming 2 inches of insulation) (1 Quad = 1000 TBtu)

Thermal Insulation Technology Performance Target	Market Size (TBtu)	Technical Potential, 2030 (TBtu)	Unstaged Max Adoption Potential, 2030 (TBtu)
Residential Building Sector			
R-6/in	1,610	836	267
R-8/in	1,610	951	304
R-12/in	1,610	1,101	352

Source: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf

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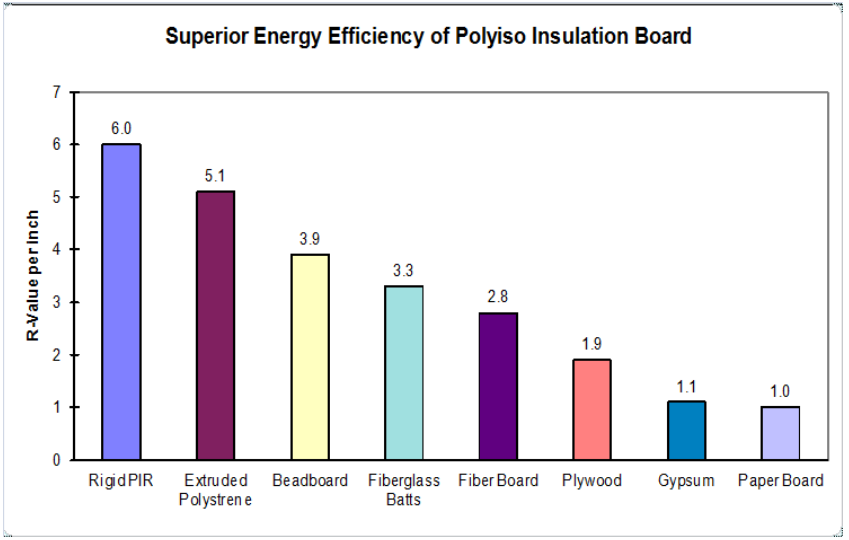
Polyisocyanurate (Polyiso) Product

- **R value 5.7-6.0 per inch of thickness**
- Excellent fire resistance
- Excellent Chemical resistance
- Dimensional stability
- Moisture resistance
- Compressive strength
- Low environmental impact :
- Virtually no GWP (global warming)
- Zero ODP (Ozone depletion)
- Long service life
- Regional material



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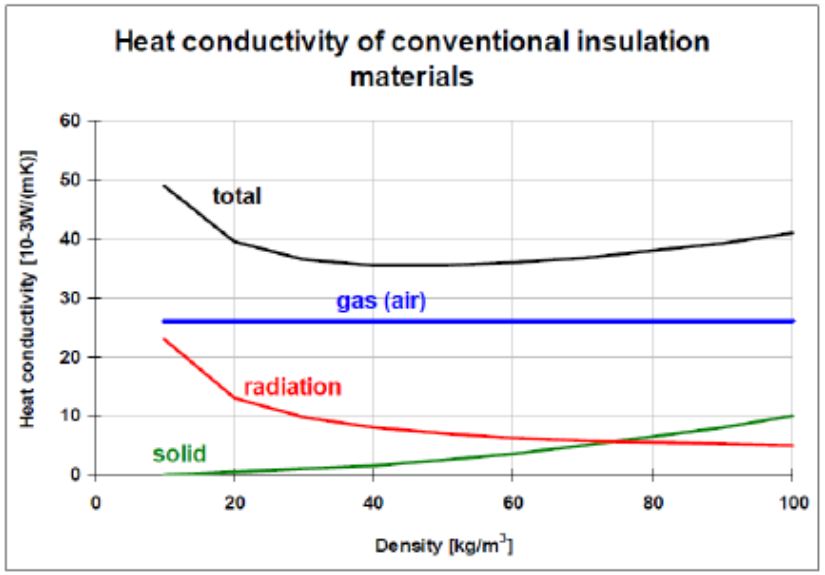
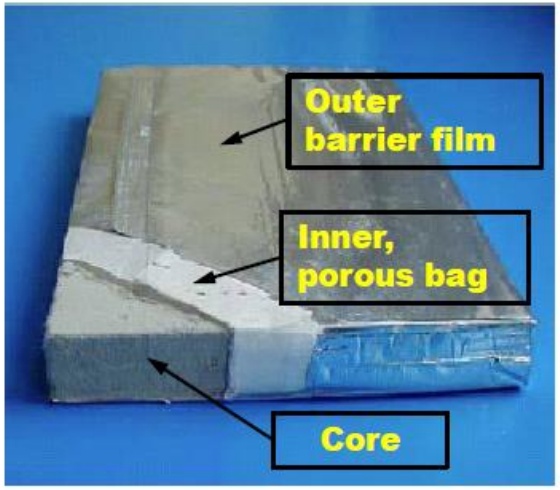
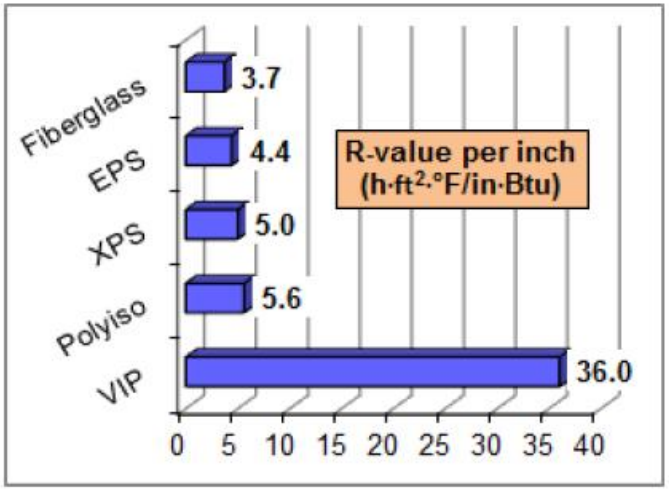
Thermal conductivity in insulation material



- Heat transfer through material by Conduction + Convection + Radiation

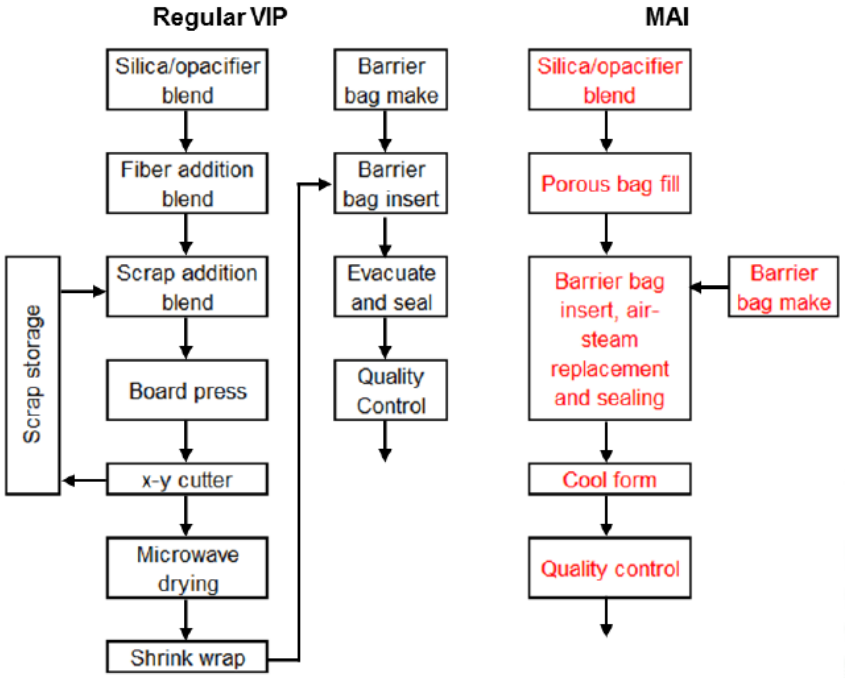
Vacuum Insulated Panels

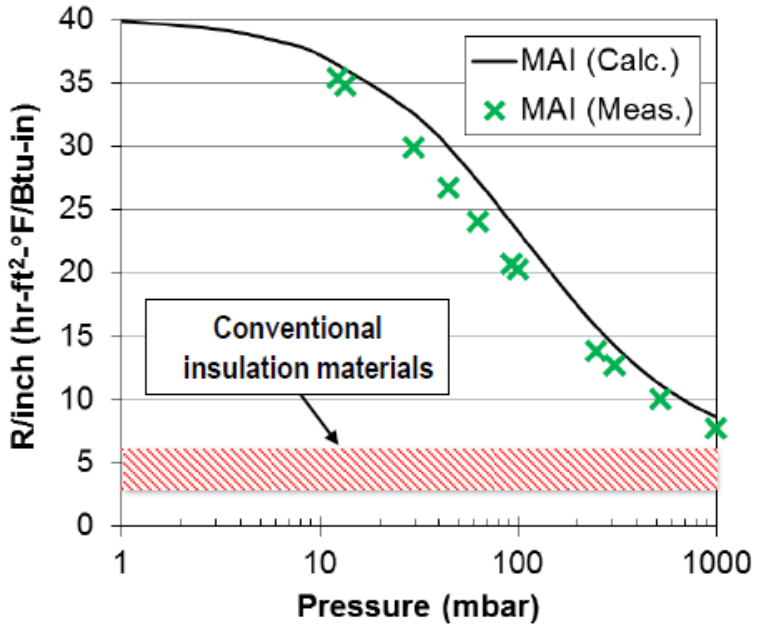




- Vacuum insulation provides significant higher R-Value
- VIPs usually comprise of a nano/micro-porous core encapsulated in impermeable barrier and evacuate to low pressure (~ 5 mbar)
- Two major issues : cost and integration into the building

Modified Atmosphere Insulation (MAI) panels





- MAI manufacture process steps have reduced about 50%
- MAI achieves R-Values similar to regular VIP

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New Approach

- Use of MAI panels (40% lower cost than regular 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.

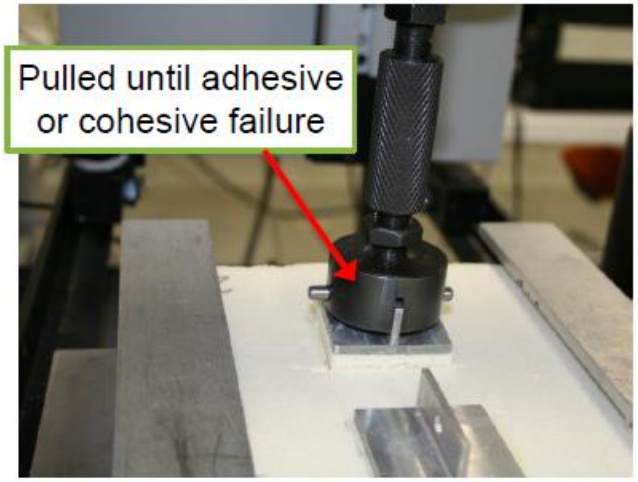
Lab scale evaluation

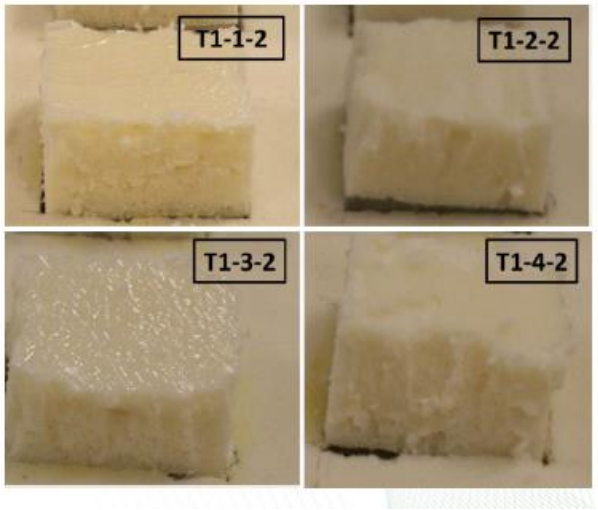
- Foam flow around MAI
- Adhesion between MAI and foam
- MAI dimensional stability and pressure during foaming process
- Temperature effect on MAI barrier from foaming process
- Several barrier films (3 metallized/polymeric and 1 polymeric) were evaluated

Foam flow

- Foam flow well for area with liquids present
- Liquid foam need to be placed strategically to avoid voids
- No problem is expected with commercial process

Adhesion between MAI and foam





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

- MAI with different barrier material were tested for adhesion with foam
- All MAI panels have acceptable adhesion with foam

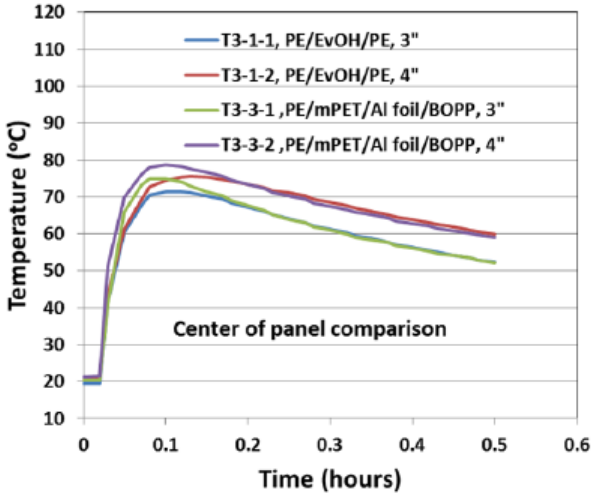
Dimensional stability and internal pressure change on MAI from foaming process

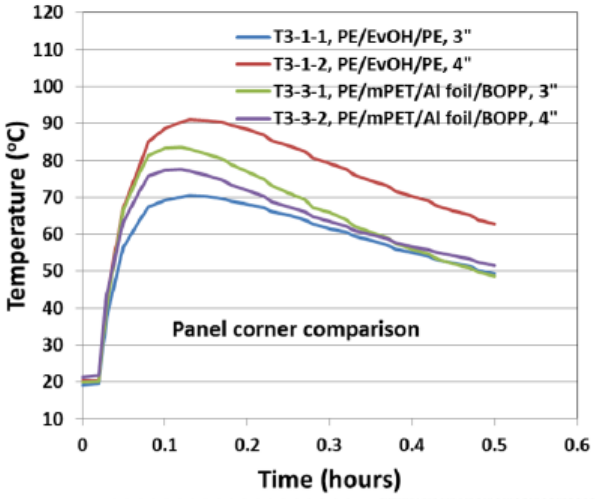
- MAI panels with polymeric and metalized barriers were tested in foaming process
- No dimensional change was observed
- No pressure was lost during foaming process

		Before Foam			
Panel		Length (inch)	Width (inch)	Thickness (inch)	Pressure @~20 °C (mbar)
T2-1-1		12 1/16	7 15/16	1	5.3
T2-1-2		11 7/8	7 15/16	1 1/32	5.2
T2-2-1		12 1/32	7 7/8	1 1/16	3.5
		After Foam			
Panel		Length (inch)	Width (inch)	Thickness (inch)	Pressure @~20 °C (mbar)
T2-1-1		12 3/32	7 15/16	1	5.3
T2-1-2		11 13/16	7 7/8	1	5.3
T2-2-1		11 15/16	7 7/8	1	3.8

Temperature effects on MAI from foaming process

- Thermocouple were attached to the barrier surface of MAI and monitored during the foaming process
- The maximum temperature were well below the 110-120°C threshold that could damage the barriers





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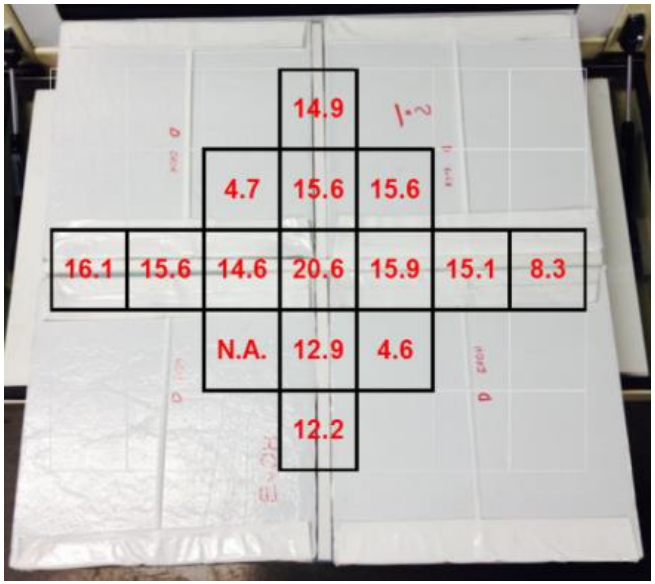
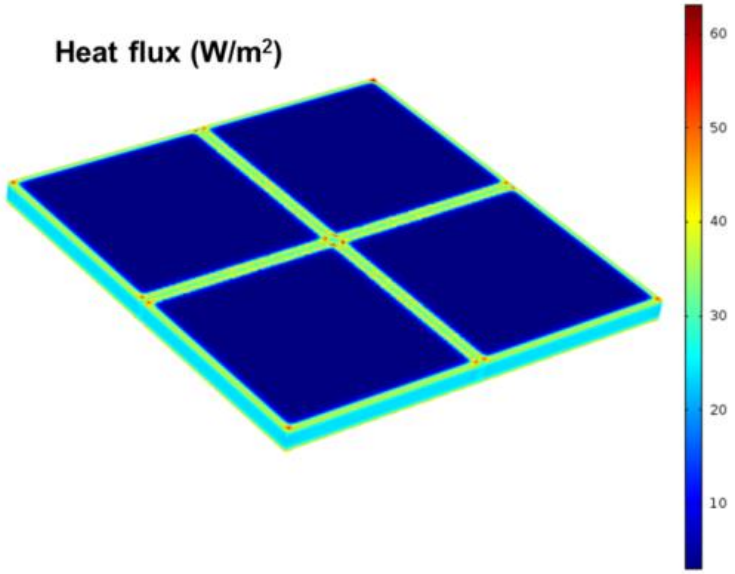
Manufacture scale evaluation

- Different MAI configuration designs
  - MAI panels with a polymeric barrier film were used
  - All-polymer barrier films significantly reduce thermal bridging around the edges compared to metallized films
- Foam flow in manufacture scale
- Thermal insulation performance (R-Value) evaluation

Testing and Modeling of Foam-MAI Composite





- Small scale models were created to match the tested composites.
- Data from the tests were used for further modeling
- 4'*8' full scale model were created by varying MAI area coverage
  - Preliminary models indicated that ≥R12/in is achievable with 84-89% coverage of 1" MAI panels

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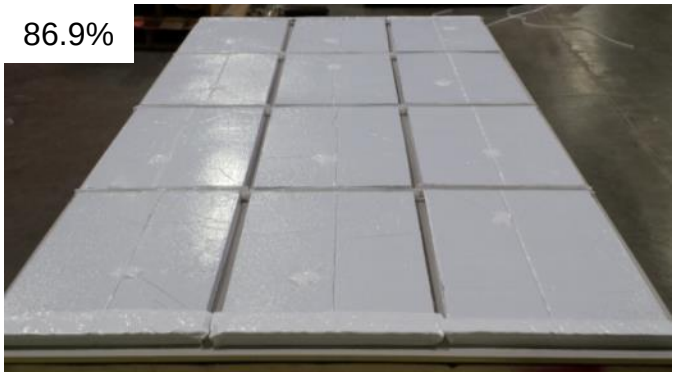
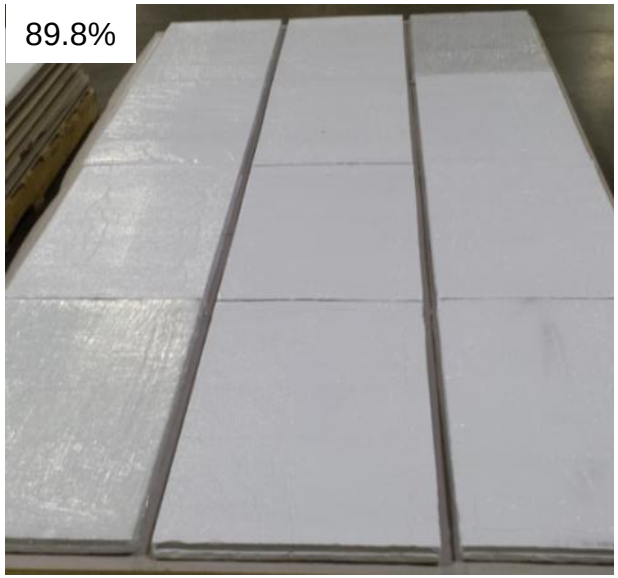
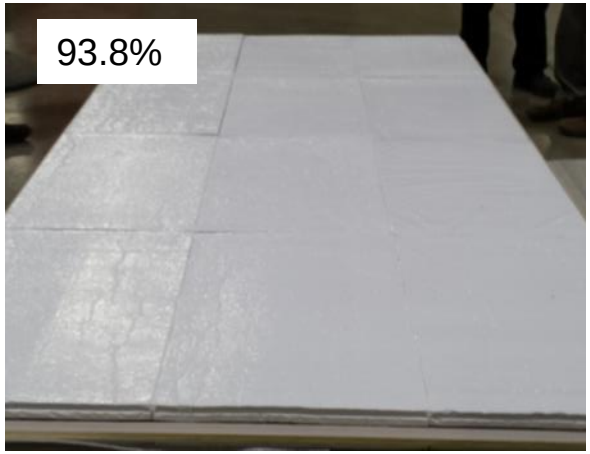
MAI configurations



- Different MAI area coverage were designed
- MAI panels were fixed on HD board
- Polyiso foam was introduced to cover the gaps and top of MAI in Polyiso Manufacturing plant





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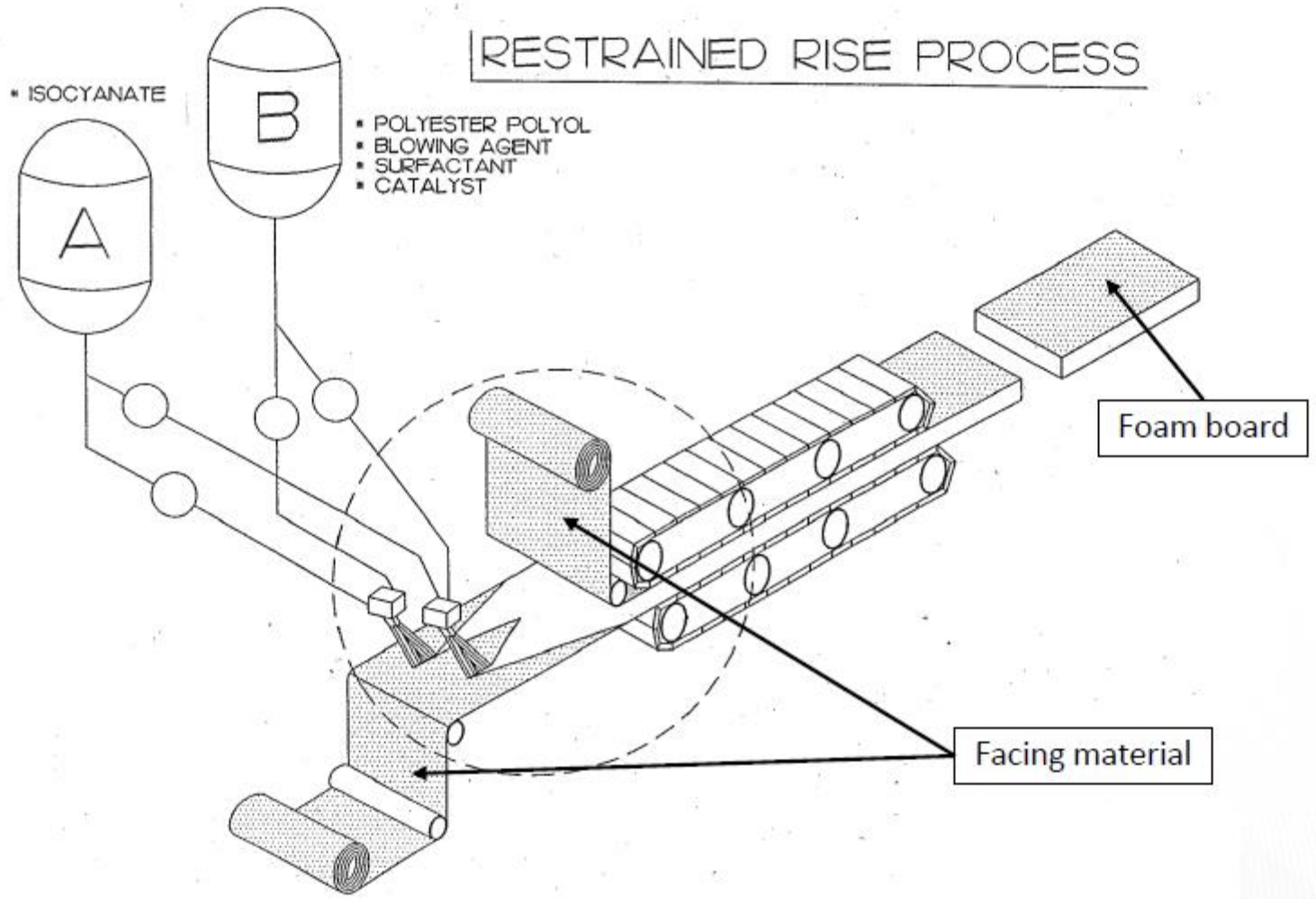
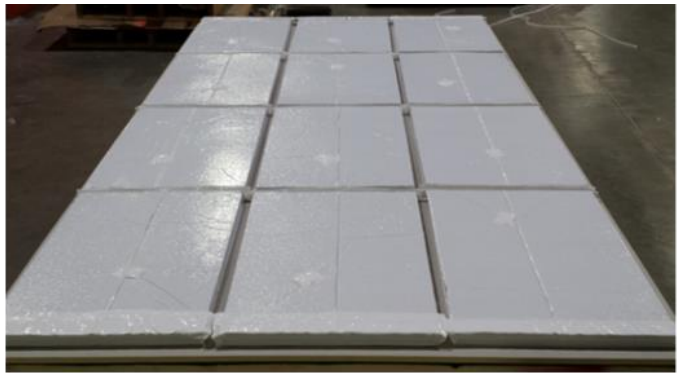
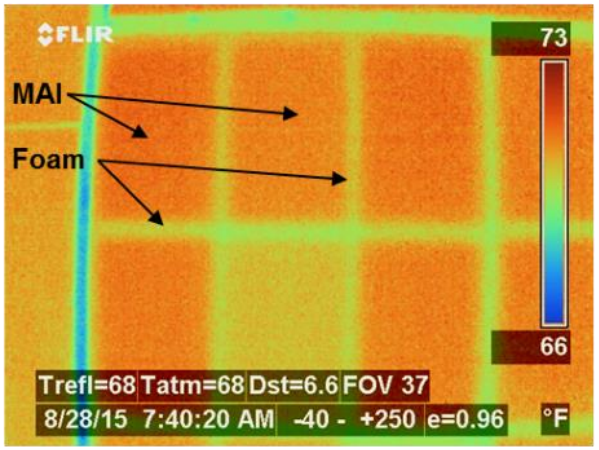
Polyiso process

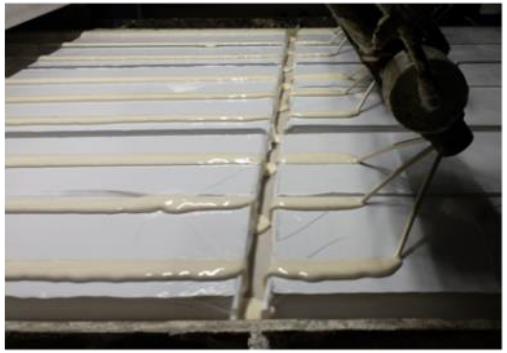


MAI-foam manufacture scale trial

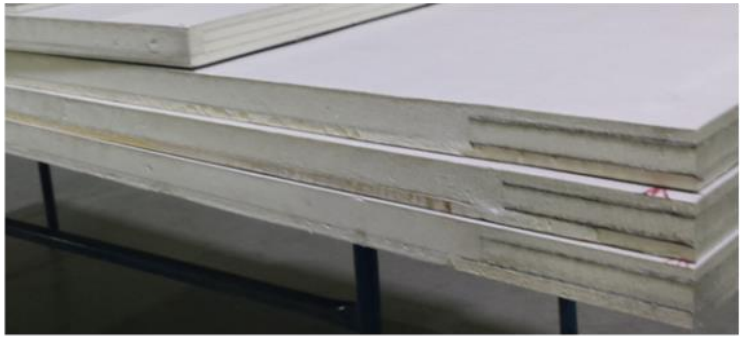


Modified Atmosphere Insulation (MAI) panels on high-density (HD) foam substrate





Foam application on manufacturing line



Finished composite insulation boards

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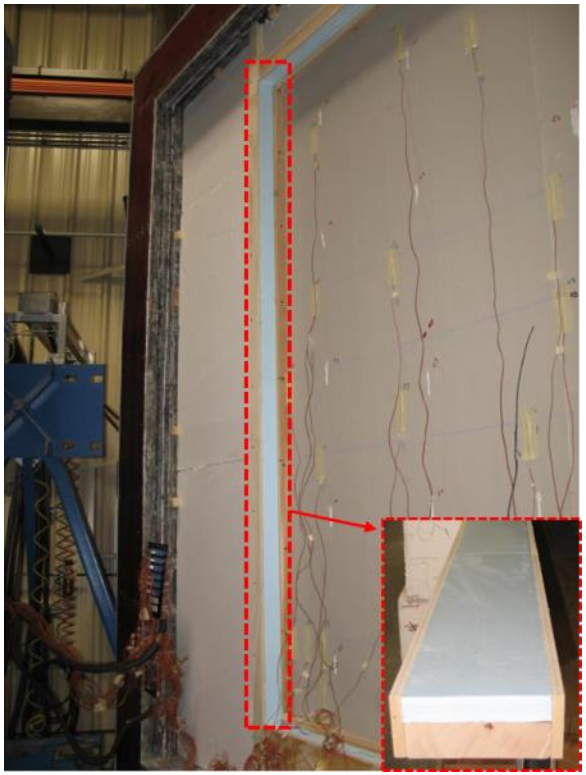
Foam flow in manufacture trial

- Foam filled the gaps and encapsulated MAI panels successfully

Hot box test



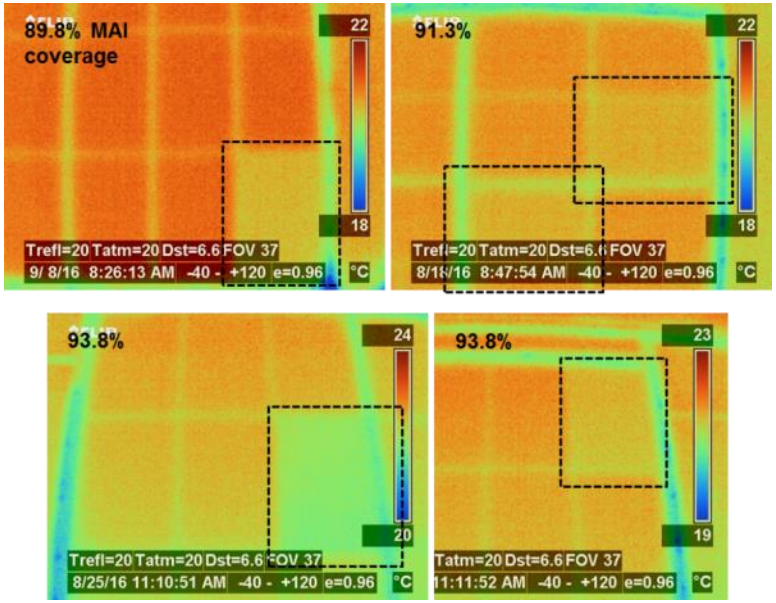
- Method ASTM C1363
- Test area 8'*8'
- Temperature for hot(meter) chamber and cold (climate) chamber is100°F and 50°F

Results

Table 1. Details of one Guarded Hot Box Test

Meter Side Surface Temperature (°F)	Climate Side Surface Temperature (°F)	Area-weighted Δ T (°F)	Heat input (q_{meter}, Btu/hr)	Test Wall Area (ft^2)	R-value ($hr\text{-}ft^2\text{-}°F/Btu$)
98.1	50.9	47.6	141.4	64	21.6

MAI coverage (%)	R/inch ($hr \cdot ft^2 \cdot °F/Btu \cdot in$)
86.9	10.8
89.8	11.6*
91.3	11.4*
93.8	11.9*



* Tested composite boards contained 1-2 damaged MAI panels (out of 24)

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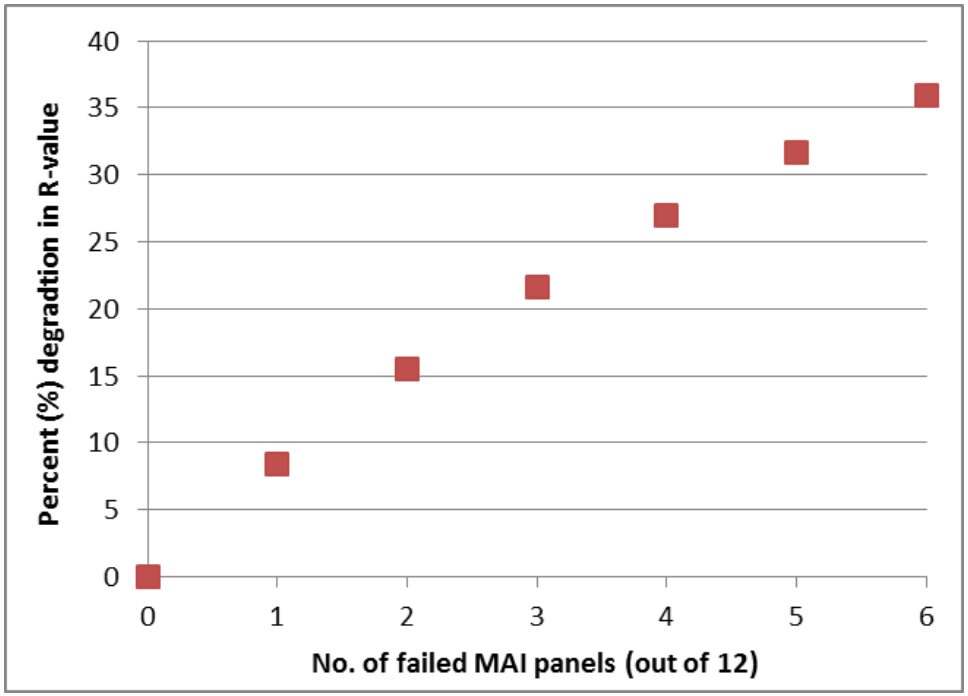
Results (contd.)

Simulated impact of damaged MAI panels on R-value



- Assuming 5% R-value degradation in the tested MAI-foam boards, ***R-values of 12-12.5/inch can be expected***, if all MAI panels were intact.

Summary

- Both lab and manufacture evaluations indicated the viability of the concept
- A composite system with MAI and polyiso foam was developed
- The system demonstrated R12/inch was achievable
- Next step: further optimize the system and start long term field testing

Thank you!

Questions?