ORNL Building Envelope Program and Roofing Systems Research

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Presentation summary

- Energy and environmental impacts of buildings
- Energy efficiency: where have we been and where are we going
- Does thermal mass have an energy benefit?
  - Ballasted systems research
  - BUR and modified bitumen systems
- Condensation risk in mechanically-attached roofs
- Crazy ideas

Buildings use a lot of energy

40% of all energy and 75% of all electricity used in the US

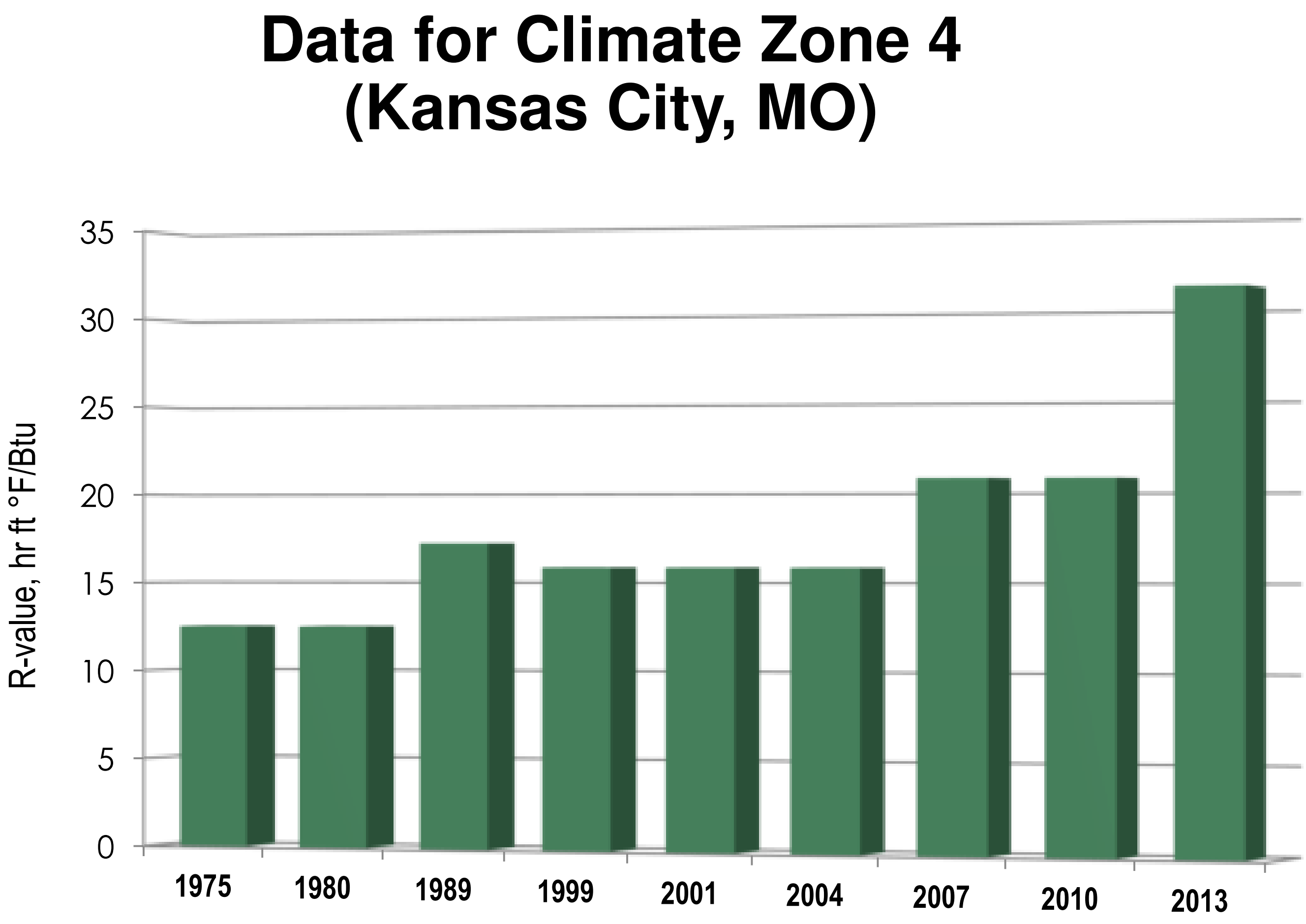
Source: US Department of Energy

Buildings pollute

Buildings account for 50% of SOX emissions, 25% of NOX emissions, and 35% of CO_2 Emissions

Source: US Department of Energy

Progress has been made (ASHRAE Standard 90.1)



DOE Climate Zone	2013 Non-Res Roof R-value
1	20
2	25
3	25
4	30
5	30
6	30
7	35
8	35

Cool roofing proof of concept

Cool roofing changes low slope market

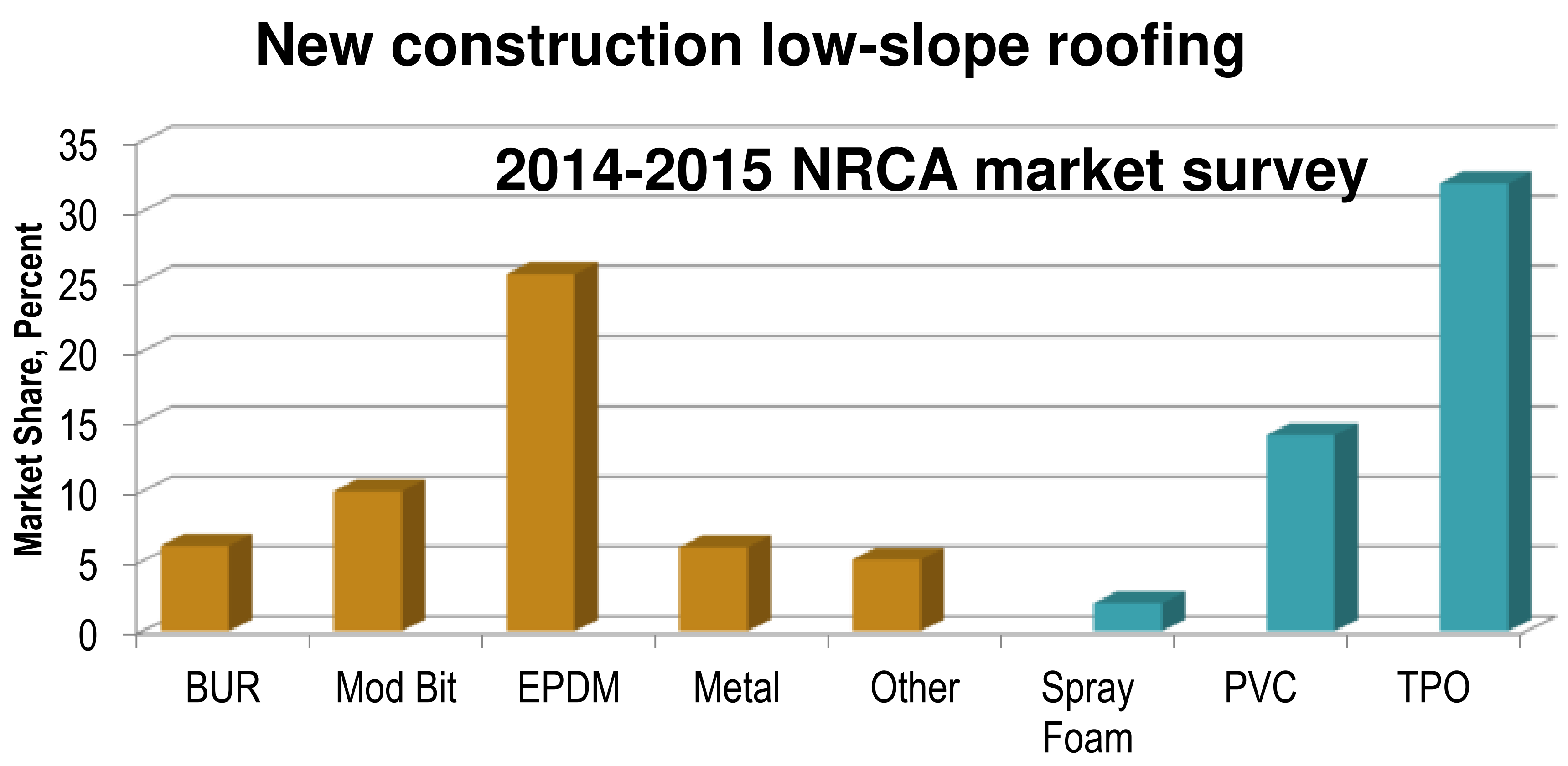
COOL ROOF CALCULATOR

Estimates Cooling and Heating Savings for Flat Roofs with Non-Black Surfaces

- Developed by the U.S. Department of Energy's Oak Ridge National Laboratory (Version 1.2)
- This version of the calculator is for small and medium-sized facilities that purchase electricity without a demand charge based on peak monthly load. If you have a large facility that purchases electricity with a demand charge, run the Peak version of the calculator in order to include the savings in peak demand charges from using solar radiation control.
- What you get out of this calculator is only as good as what you put in. If you click here , you'll find help in figuring out the best input values. Some things, such as the weathering of the solar radiation control properties and the effects of a plenum, are especially important. You'll also find help in figuring out your heating and cooling system efficiencies and proper fuel prices.
- To compare two non-black roofs, print out results of separate estimates for each vs. a black roof. Manually compute the difference in savings to compare the two non-black roofs.
- If your energy costs are determined by on-peak and off-peak rates, print out results of separate estimates with on-peak and off-peak rates for the same roof. Judge what fraction of the savings with on-peak rates is appropriate.

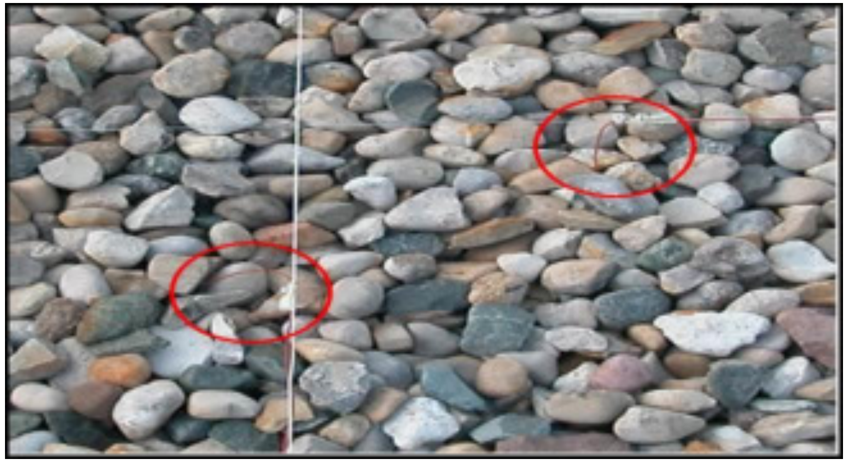
My State	Select a state ▾
My City	Select a city ▾

Low slope waterproofing market



- Cool roofs (PVC, TPO, and spray foam) represent 48% of market.
- BUR, Mod Bit, and Metal (22%) can be any color based on aggregate/paint.

Ballasted roof systems available since 1970's

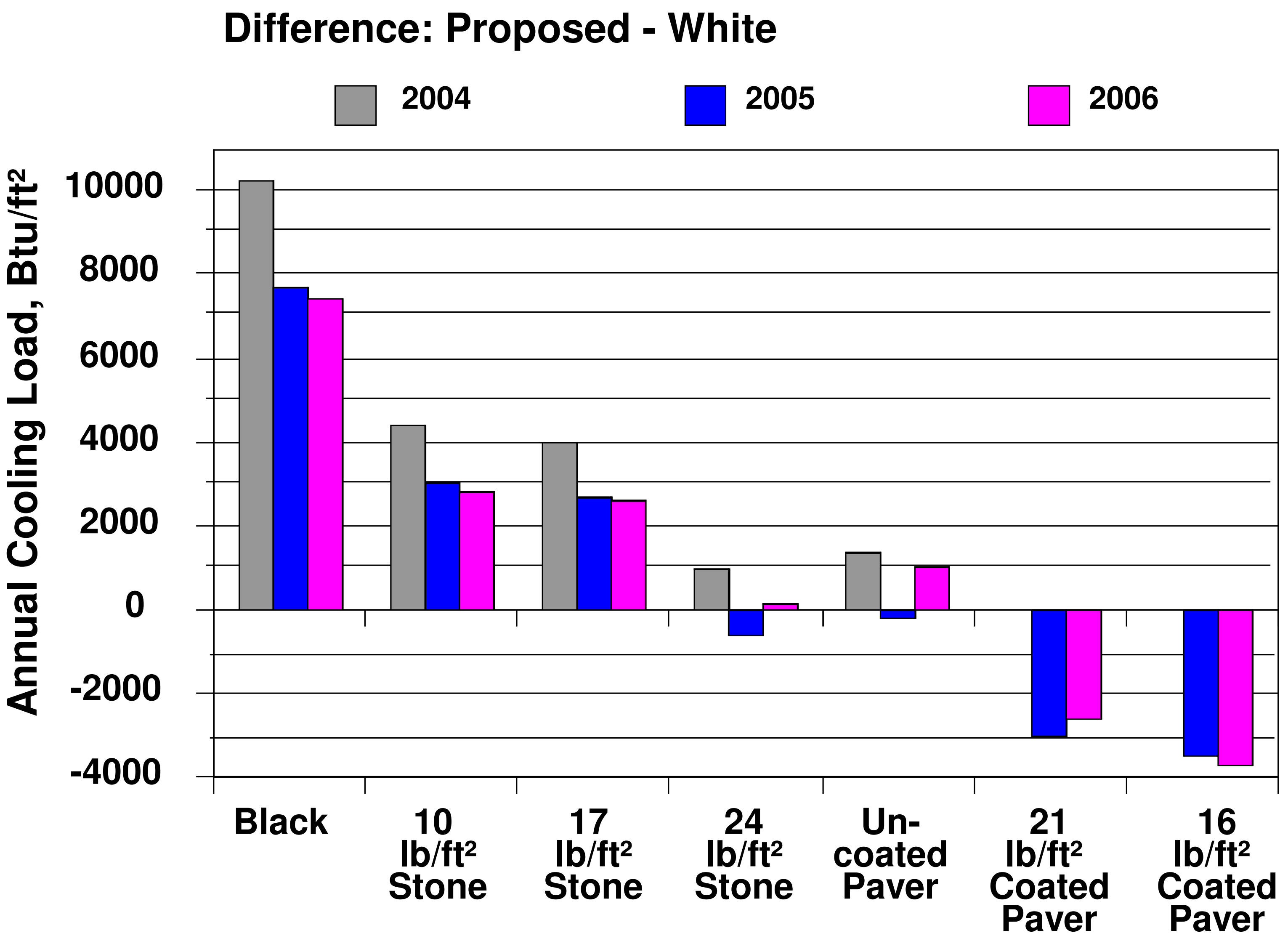


Roof Thermal Research Apparatus (RTRA)

Compare ballasted and cool roof systems

Test roof	Covering or loading	Thickness	Solar reflectance
Black control	EPDM	0.06 in.	0.06
White control	TPO	0.06 in.	0.78
10# stone	10 lb/ft² on EPDM	1.3 in.	0.22
17# stone	17 lb/ft² on EPDM	2.2 in.	0.22
24# stone	24 lb/ft² on EPDM	3.1 in.	0.22
Paver	24 lb/ft² on EPDM	2.0 in.	0.41
Coated paver	21 lb/ft² on EPDM	2.0 in.	0.70

Differences in cooling loads (Knoxville TN)



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Present study

- How about BUR and modified bitumen roofs?
  - Systems have thermal mass (not a much as ballasted systems).
  - Systems typically covered with aggregate for UV protection.
  - Aggregate can be any color.

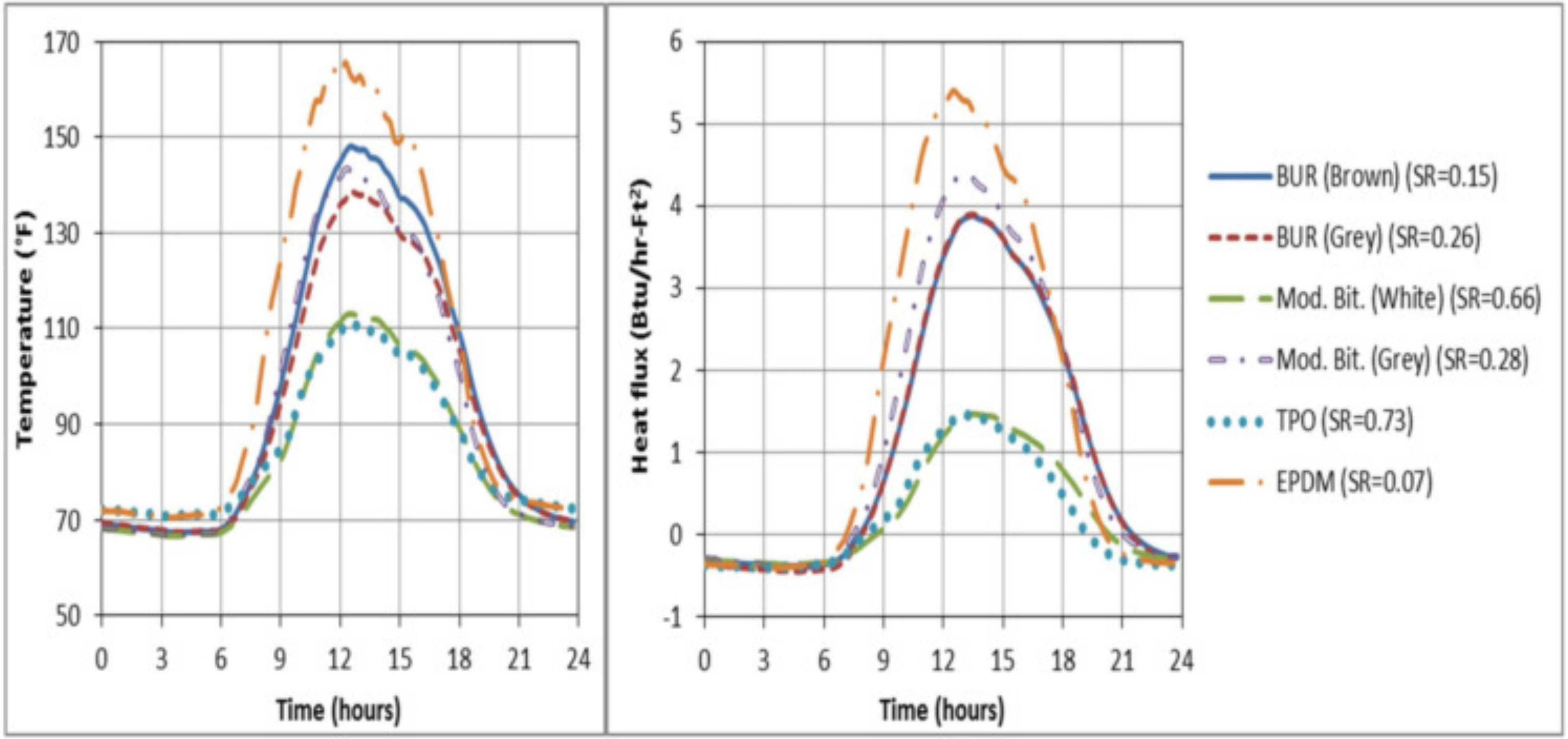
Roof Thermal Research Apparatus (RTRA) revisited

BUR and mod-bit roof sections installed on the RTRA

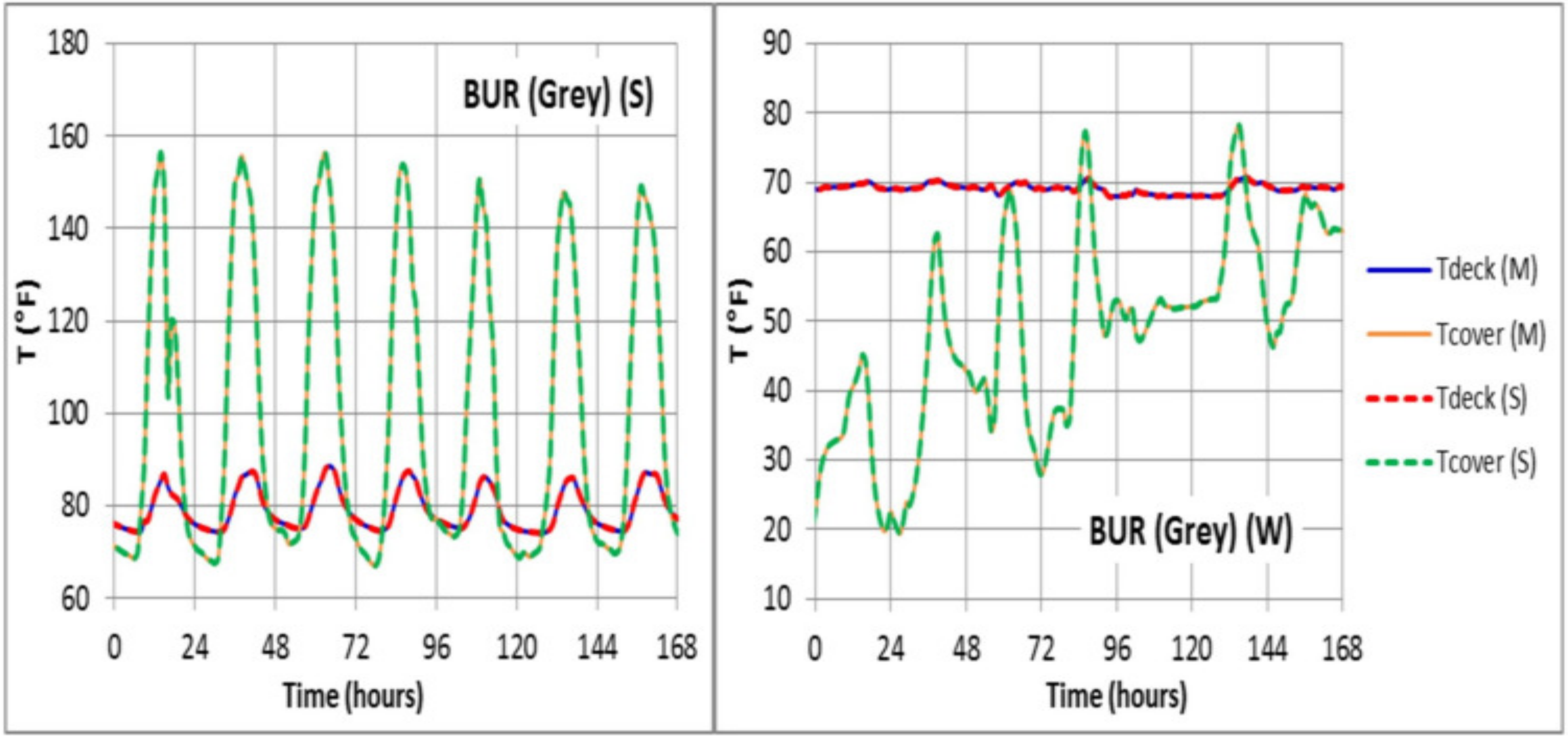
Compare BUR, Mod-Bit, and cool roof systems

Test roof	Covering or loading	Thickness	Solar reflectance
Black control	EPDM	0.06 in.	0.07
White control	TPO	0.06 in.	0.73
Grey aggregate	5 lb/ft² on BUR	0.9 in.	0.34
Brown aggregate	5 lb/ft² on BUR	0.9 in.	0.17
Grey aggregate	5 lb/ft² on Mod-Bit	1.3 in.	0.28
White aggregate	5 lb/ft² on Mod-Bit	1.3 in.	0.65

Average hourly summer temperatures and heat fluxes



Measured (M) and simulated (S) boundary temperatures



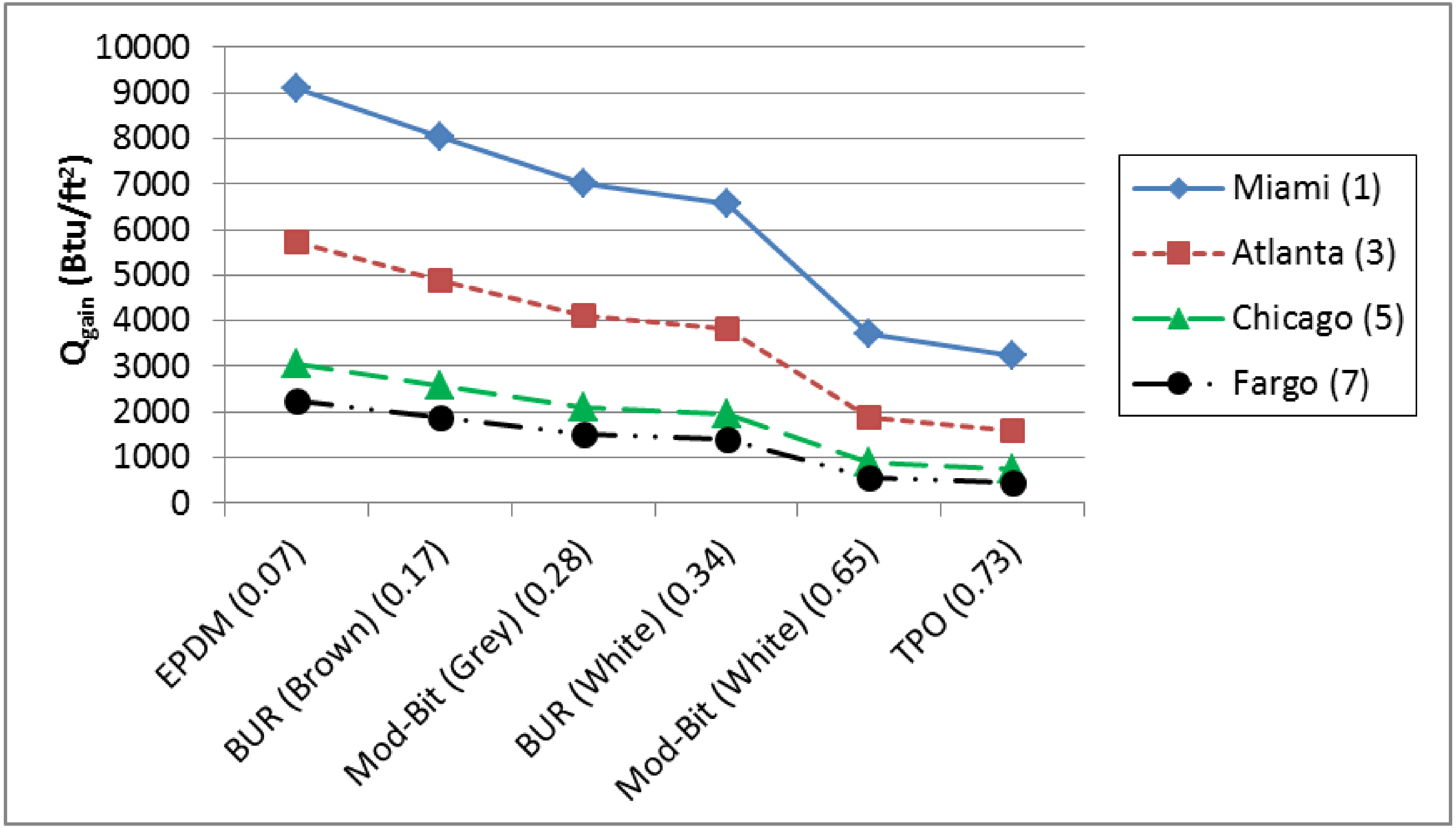
BUR roof in summer (S) and winter (W)

Solar reflectance = 0.34

Modeled cities and corresponding insulation details

ASHRAE Climate zone	City	Thickness	R-value
		Inches	hr-ft^2-°F/Btu
1	Miami FL	3.6	20
2	Houston TX	4.5	25
3	Atlanta GA	4.5	25
4	Baltimore MD	5.4	30
5	Chicago IL	5.4	30
6	Minneapolis MN	5.4	30
7	Fargo ND	6.3	35
8	Fairbanks AK	6.3	35

Comparison of calculated annual heat gains



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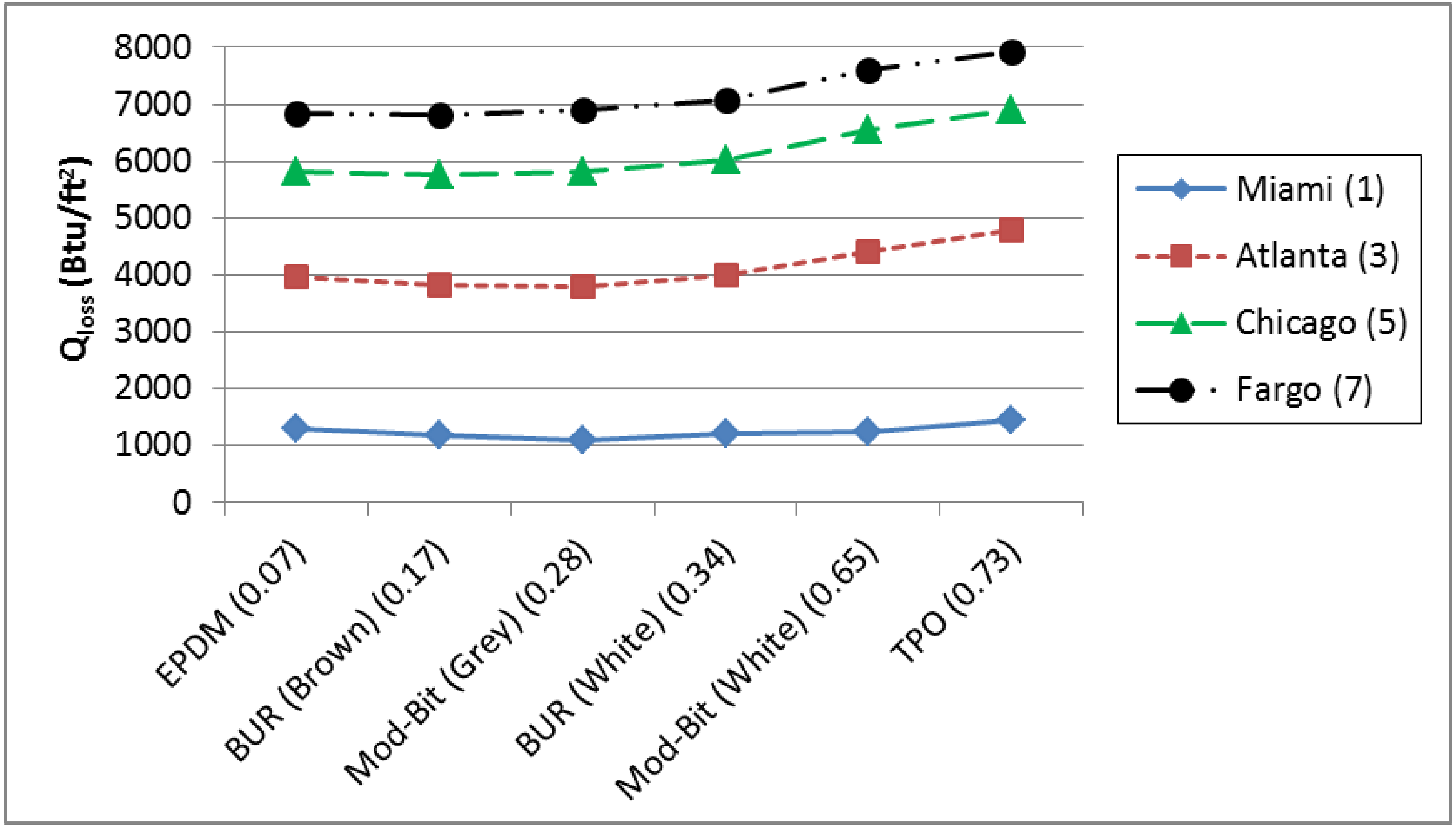
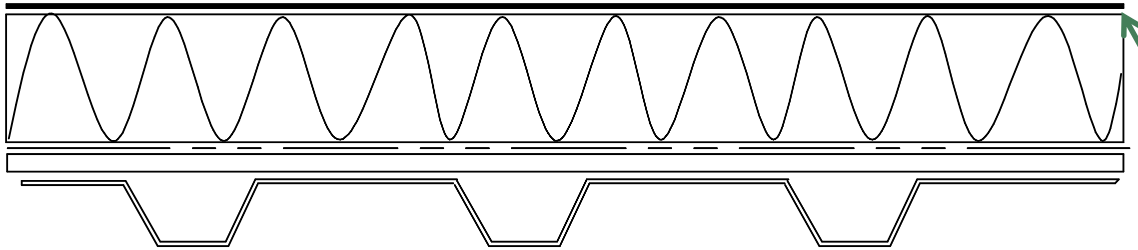
Comparison of calculated annual heat losses



Conclusions

- Energy impact of cool surfaces has been reduced due to significant increases in code-required R-values.
- BUR and Mod-Bit roofs have thermal inertia and can be constructed to have to have cool surfaces.
- BUR and Mod-Bit roofs can perform at nearly they same level of energy efficiency as traditional “cool roofs.”

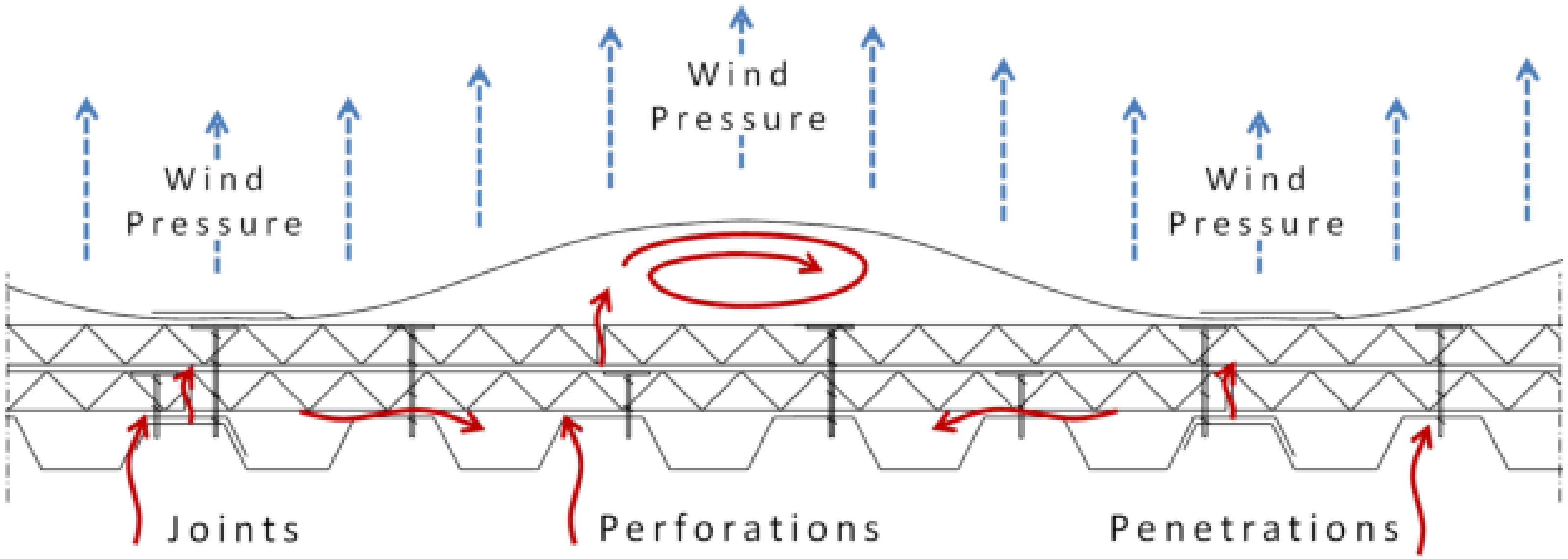
Condensation risk in mechanically-attached roofs



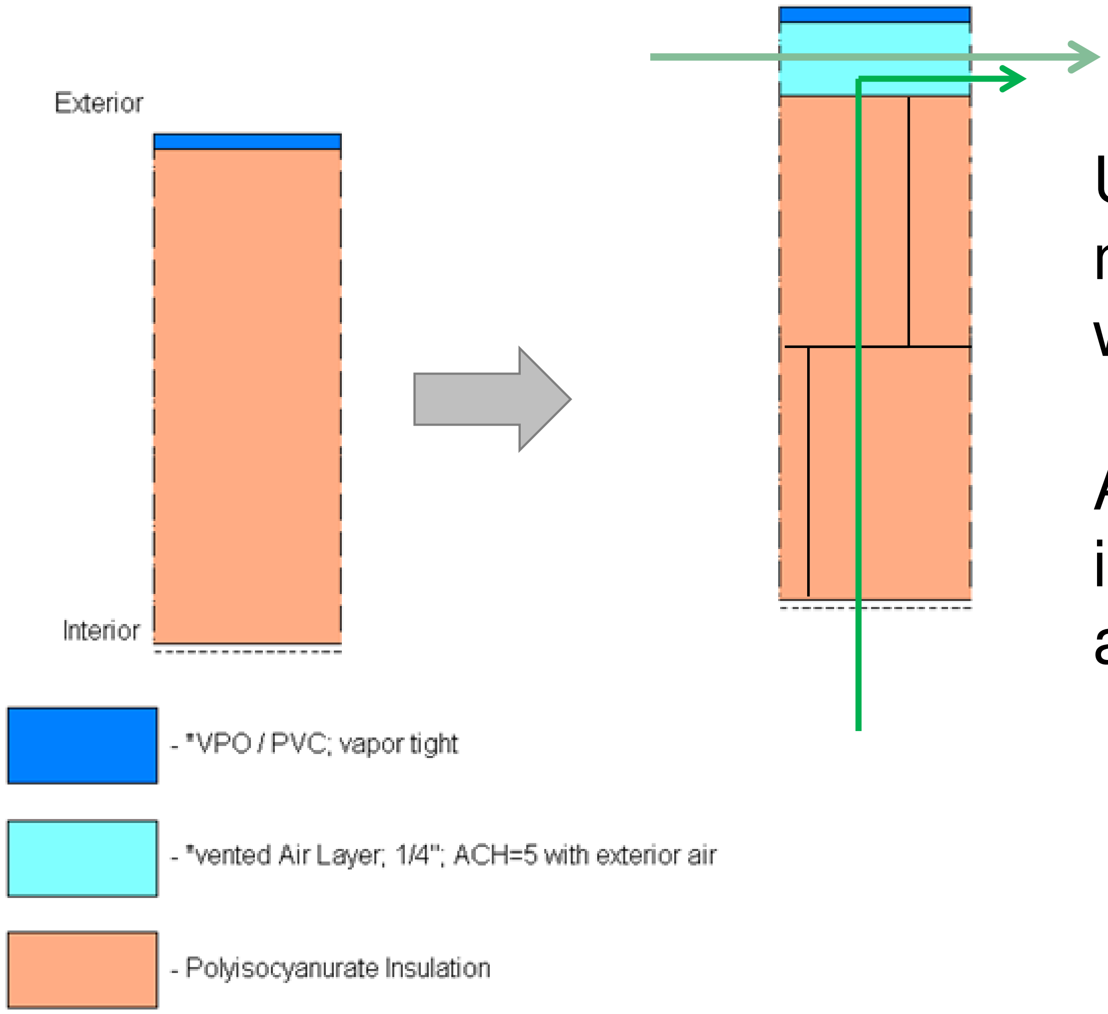
Does moisture condense here and freeze during winter?

- White membranes to reduce the solar heat load
- Black membranes are typically 50°F warmer than white membranes on a sunny day
- Theorized impact
  - Location/occurrence of dew point
  - Impact ability of system to dry out

The physics of air intrusion



Hygrothermal modeling



Uplift of the exterior membrane, due to wind pressure.

Air infiltration from indoors through joints and fastener holes.

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Model inputs

Climate

Zone 4 – Baltimore, MD
Zone 5 – Chicago, IL
Zone 6 – Minneapolis, MN
Zone 7 – Fargo, ND

Solar Reflectance

0.70 (White Surface)
0.15 (Dark Surface)

Indoor Moisture Supply

ASHRAE 160, Low
EN-15026, Normal
EN-15026, High
ASHRAE 160, High

Air Tightness

Q_{50}=0.27 [l/s m^2] – no perforations

Q_{50}=0.56 [l/s m^2] – slight leak

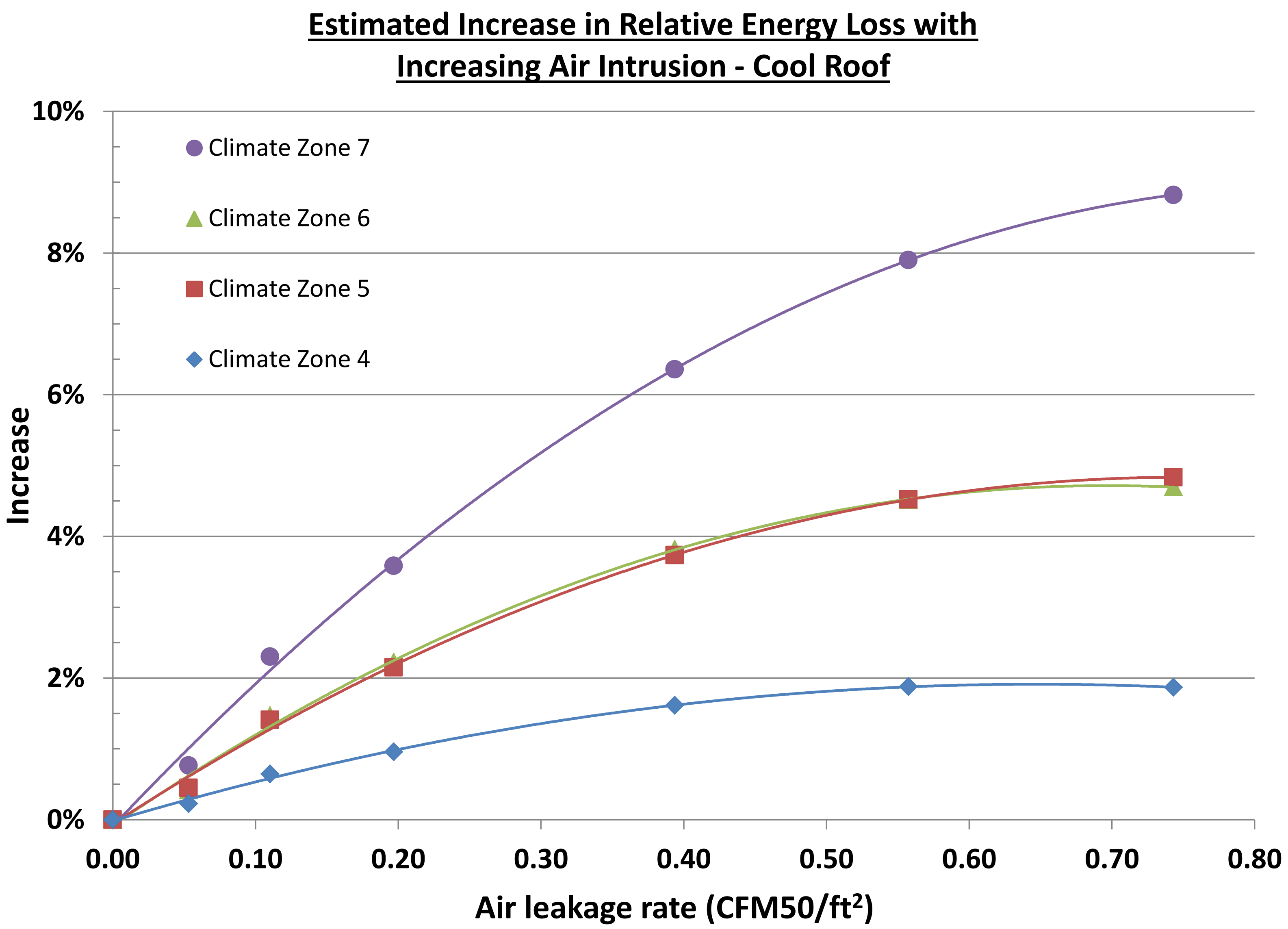
Q_{50}=1.0 [l/s m^2] – average leak

Q_{50}=2.0 [l/s m^2] – real leaky

Results

Climate Zone - 4								
Indoor moisture supply	Q_{50} = 0.27		Q_{50} = 0.56		Q_{50} = 1.0		Q_{50} = 2.0	
ASHRAE - Low	B	W	B	W	B	W	B	W
EN - Normal	B	W	B	W	B	W	B	W
EN - High	B	W	B	W	B	W	B	W
ASHRAE - High	B	W	B	W	B	W	B	W
Climate Zone - 5								
Indoor moisture supply	Q_{50} = 0.27		Q_{50} = 0.56		Q_{50} = 1.0		Q_{50} = 2.0	
ASHRAE - Low	B	W	B	W	B	W	B	W
EN - Normal	B	W	B	W	B	W	B	W
EN - High	B	W	B	W	B	W	B	W
ASHRAE - High	B	W	B	W	B	W	B	W
Climate Zone - 6								
Indoor moisture supply	Q_{50} = 0.27		Q_{50} = 0.56		Q_{50} = 1.0		Q_{50} = 2.0	
ASHRAE - Low	B	W	B	W	B	W	B	W
EN - Normal	B	W	B	W	B	W	B	W
EN - High	B	W	B	W	B	W	B	W
ASHRAE - High	B	W	B	W	B	W	B	W
Climate Zone - 7								
Indoor moisture supply	Q_{50} = 0.27		Q_{50} = 0.56		Q_{50} = 1.0		Q_{50} = 2.0	
ASHRAE - Low	B	W	B	W	B	W	B	W
EN - Normal	B	W	B	W	B	W	B	W
EN - High	B	W	B	W	B	W	B	W
ASHRAE - High	B	W	B	W	B	W	B	W

Energy loss due to air intrusion in a cool roof



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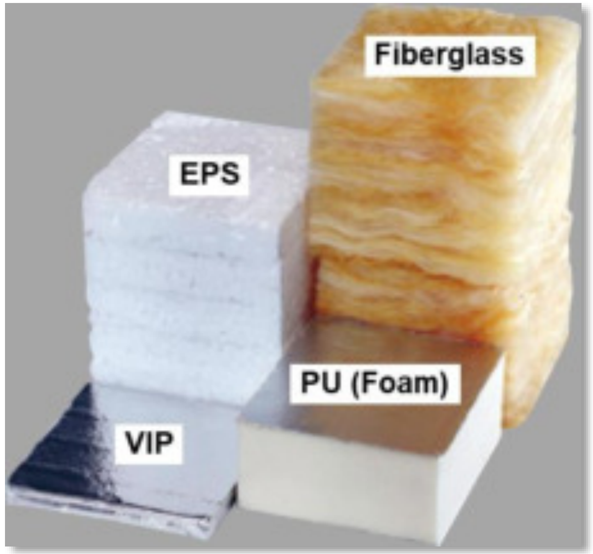
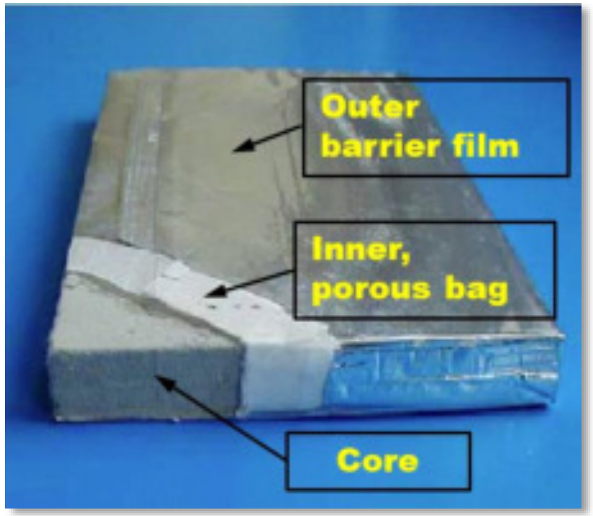
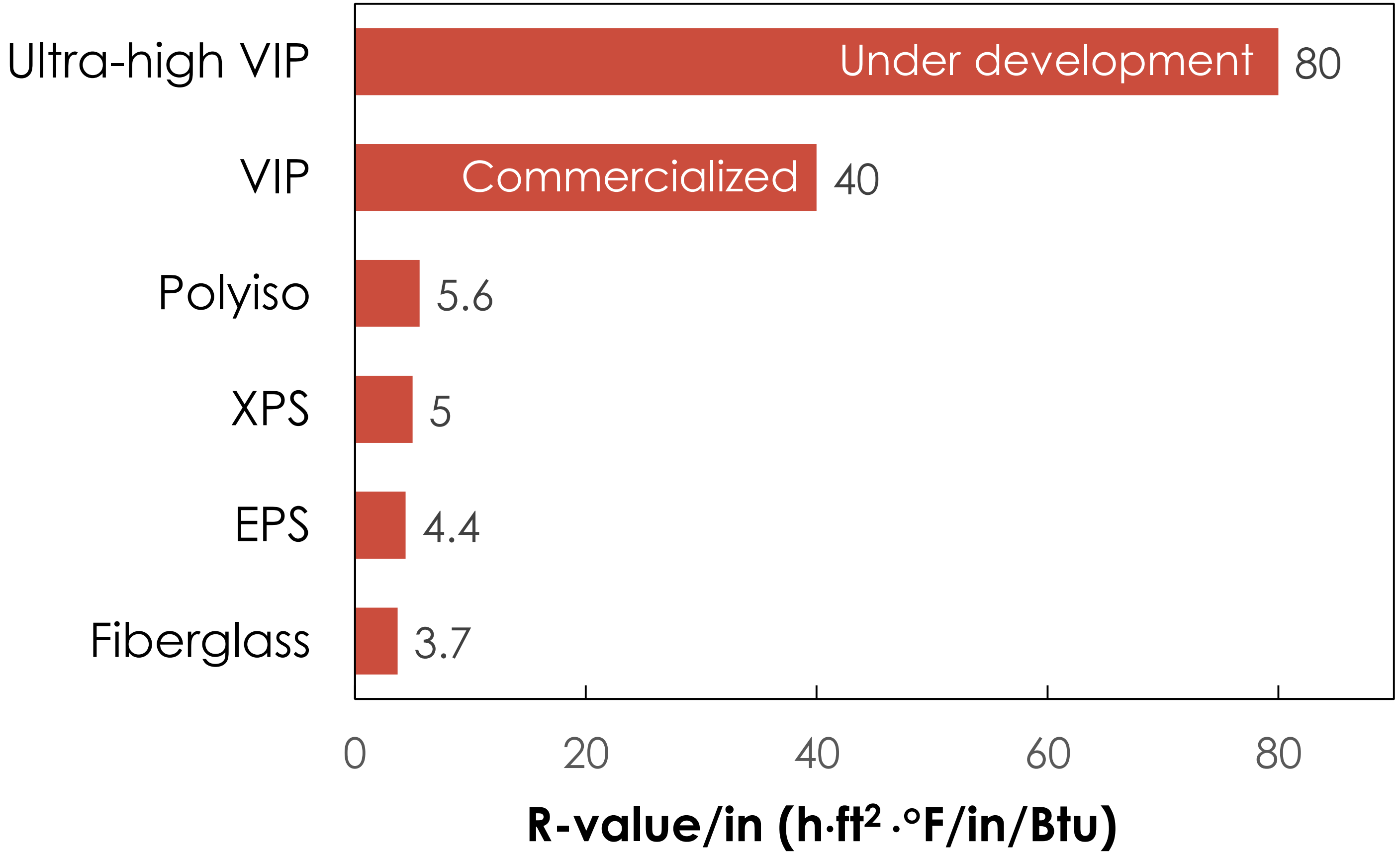
Vacuum Insulation Panels (VIPs)



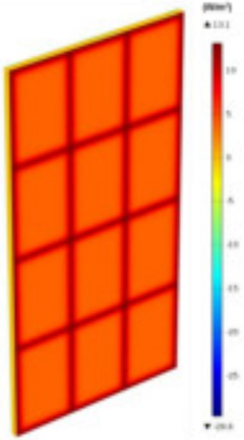




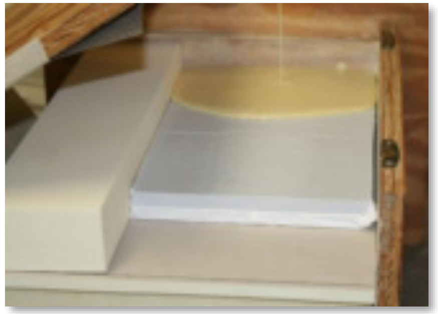
Source: ECBCS 2005, ECBCS/IEA Annex 39, Vacuum Insulation Panels (Subtask A)

R13/in. foam-VIP composites

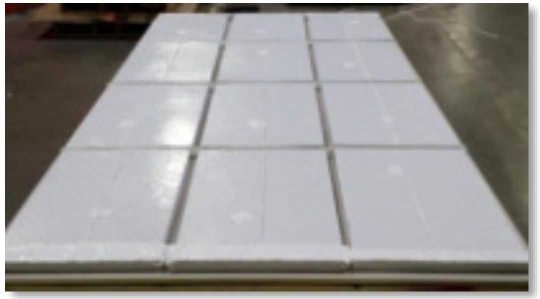
Thermal testing of VIPs and preliminary modeling

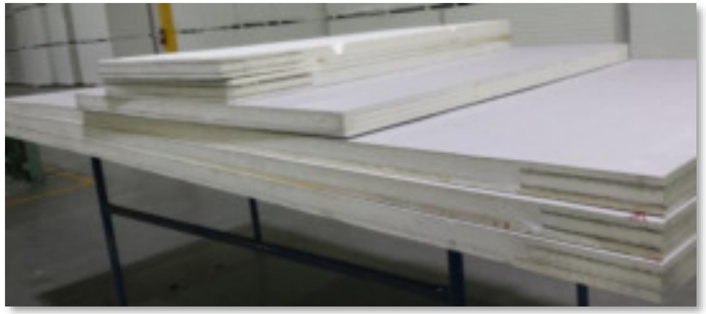


Lab foaming tests



Prototype development using existing factory infrastructure & practices





Full-scale performance verification and field-testing

Large-scale chamber

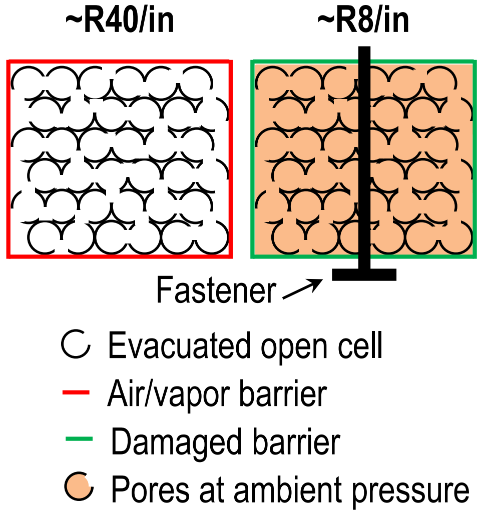
Natural exposure test facility

Roof of existing building

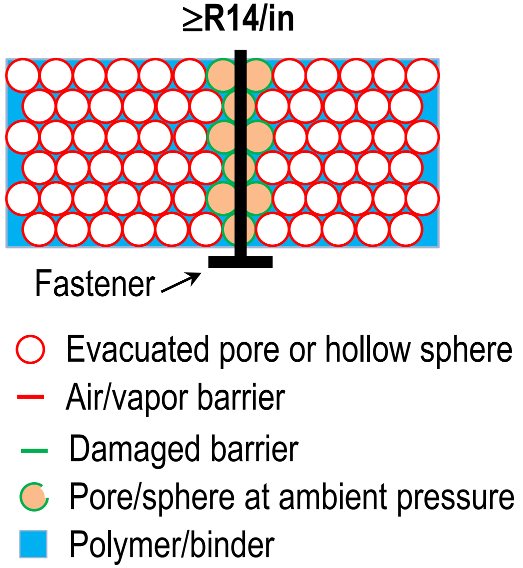
Closed-cell VIPs

- Current VIPs are open-celled, so damages to the barrier film degrades the R-value to ≤ 8/in
- Closed-cell VIPs localize damages
- Two approaches:
  - Polymer-based foam with evacuated pores
  - Start with hollow particles, evacuate the interior and coat the surfaces to create an impermeable shell

Vacuum insulation panels

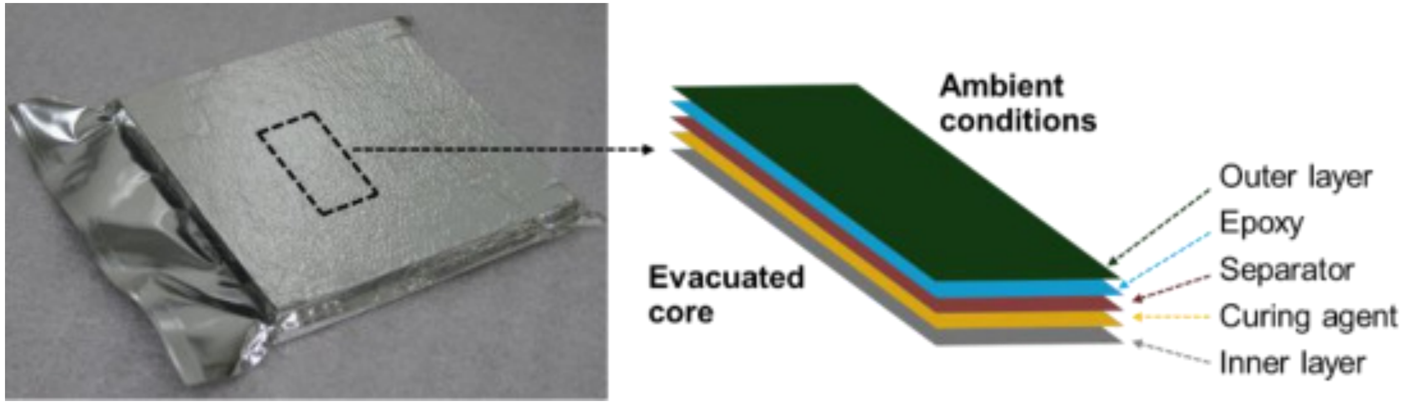


Evacuated pores or spheres

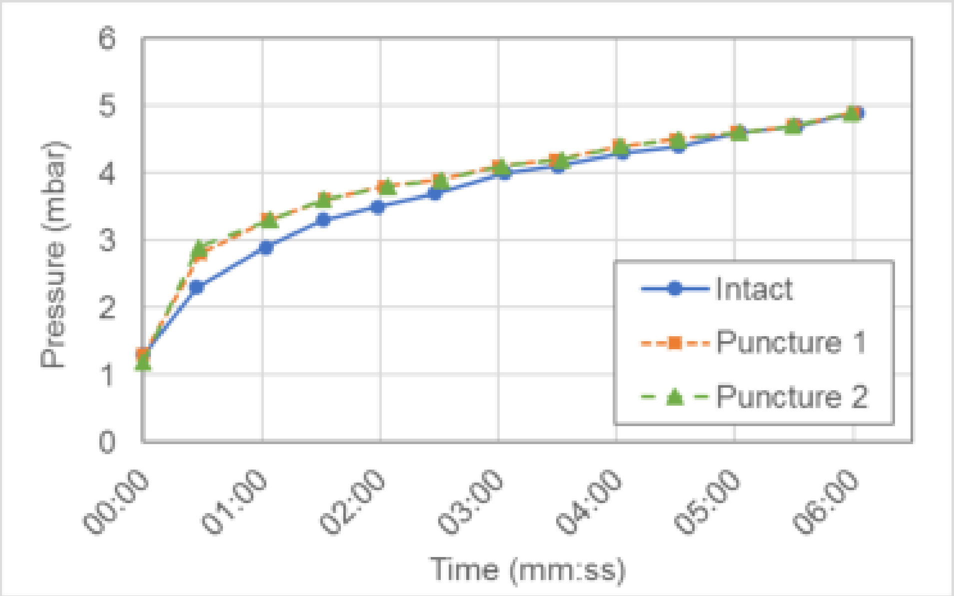


Self-healing barrier for VIPs

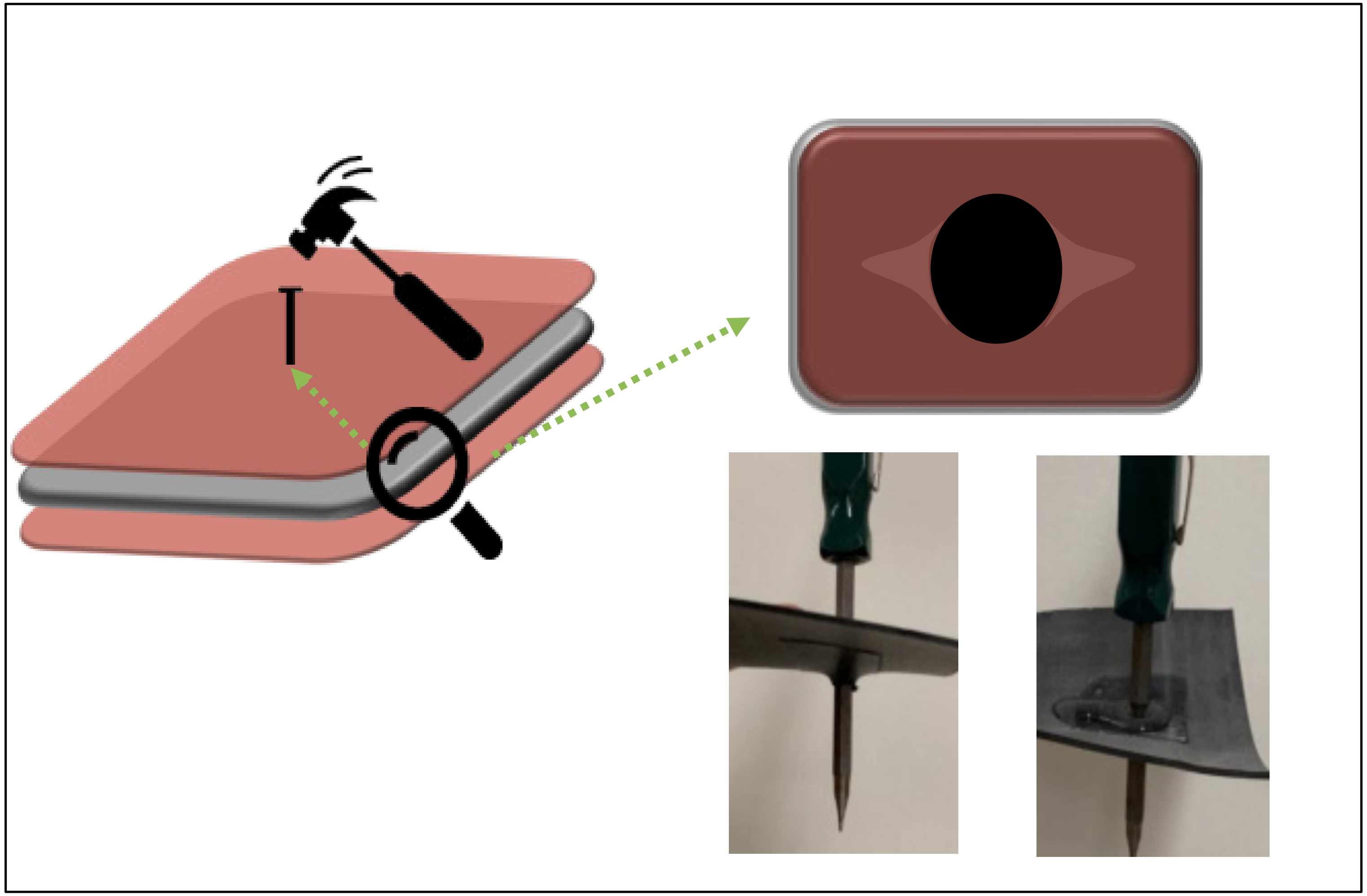
Two-component sealant



Immediate self-healing prevents vacuum loss



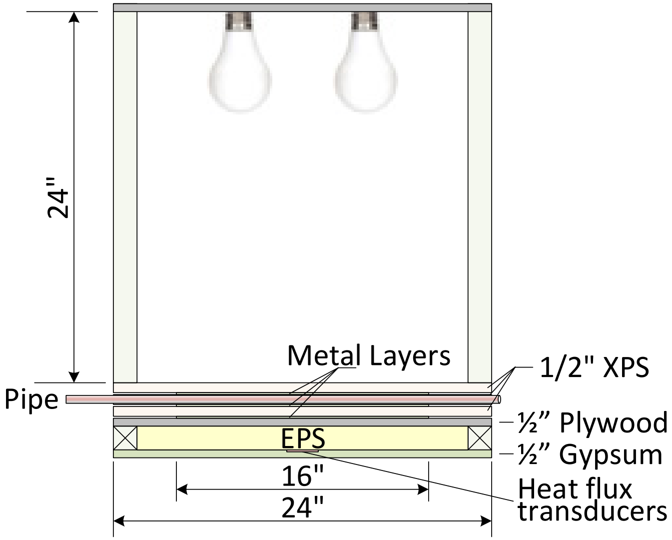
Self-healing roofs?

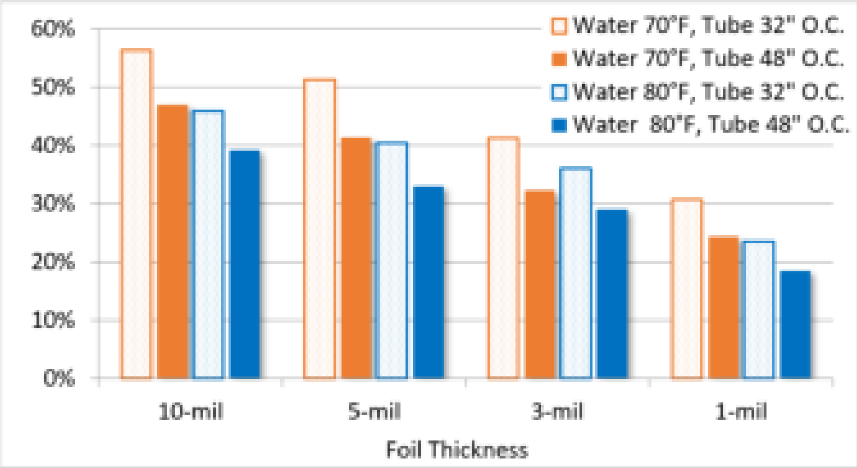


Applying the coating of self-healing polymers might mitigate roof leaks.

Space age technology (50 years later)

Use anisotropy to redirect solar load on roof.





Reduction in heat flux
3 alternating layers of aluminum foil and XPS
Indoor T 72°F, irradiance 80%

Discussion

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