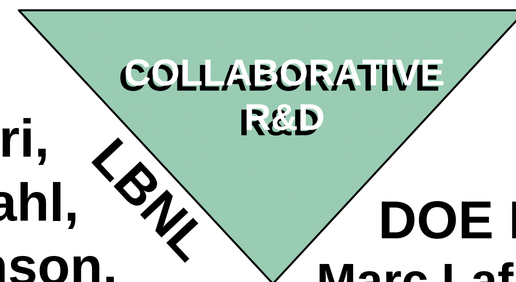
High Performance Roofs
How to Beat the Heat

INDUSTRY



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OBJECTIVES

1. Merge strategies into Next Generation Attics
    - Cool color roofs
    - Ventilation
    - Radiant barrier
    - Thermal mass

ESRA

2. Energy impact of alternative attic ventilation schemes
3. Energy benefit of thermal mass (PCM)
4. Consensus based calculator

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WHAT ARE COOL COLOR ROOFS ?

- **Cool color, sub-tile venting and thermal mass concrete and clay tile**
  - **Key Find: Cool color and sub-tile venting eliminated 70% of peak heat transfer penetrating roof deck (asphalt shingle control)**

- **Demonstration homes showcasing cool color medium profile concrete tile (Hanson Roof Products) and painted metal shakes (Custom-Bilt Metals)**
  - **Key Find: Cool color roofs reduced summer electricity ≈ 3 to 5%**

- **Demonstration homes with cool color asphalt shingles (GAF/ELK Group)**
  - **Key Find: Peak shingle temperature drops 3°C (5.4°F)**

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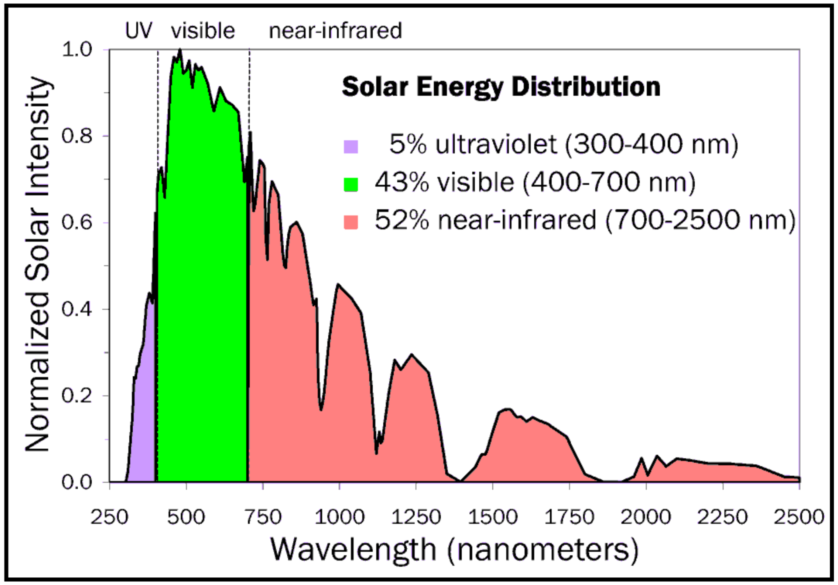
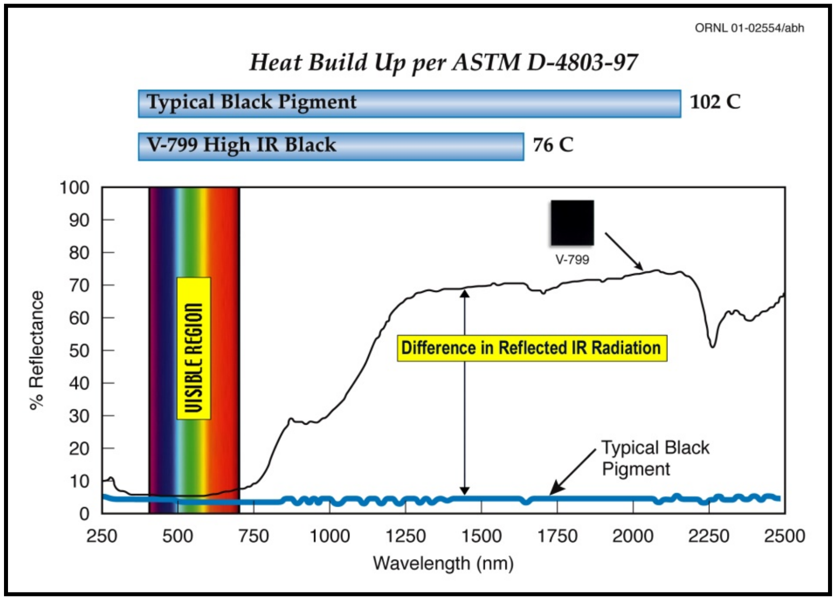
COOL COLOR PAINTS ARE HIGHLY REFLECTIVE IN INFRARED SPECTRUM





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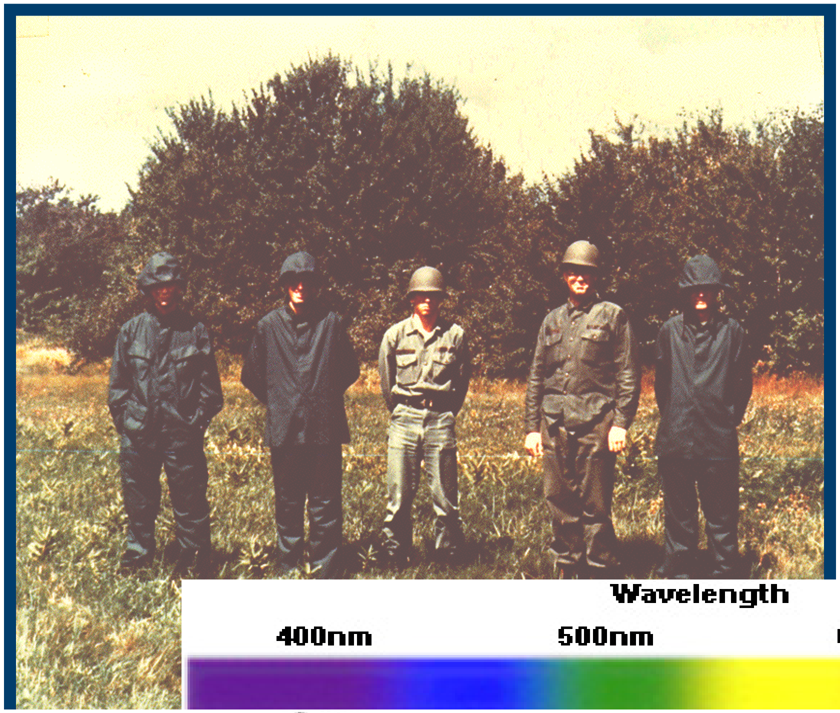
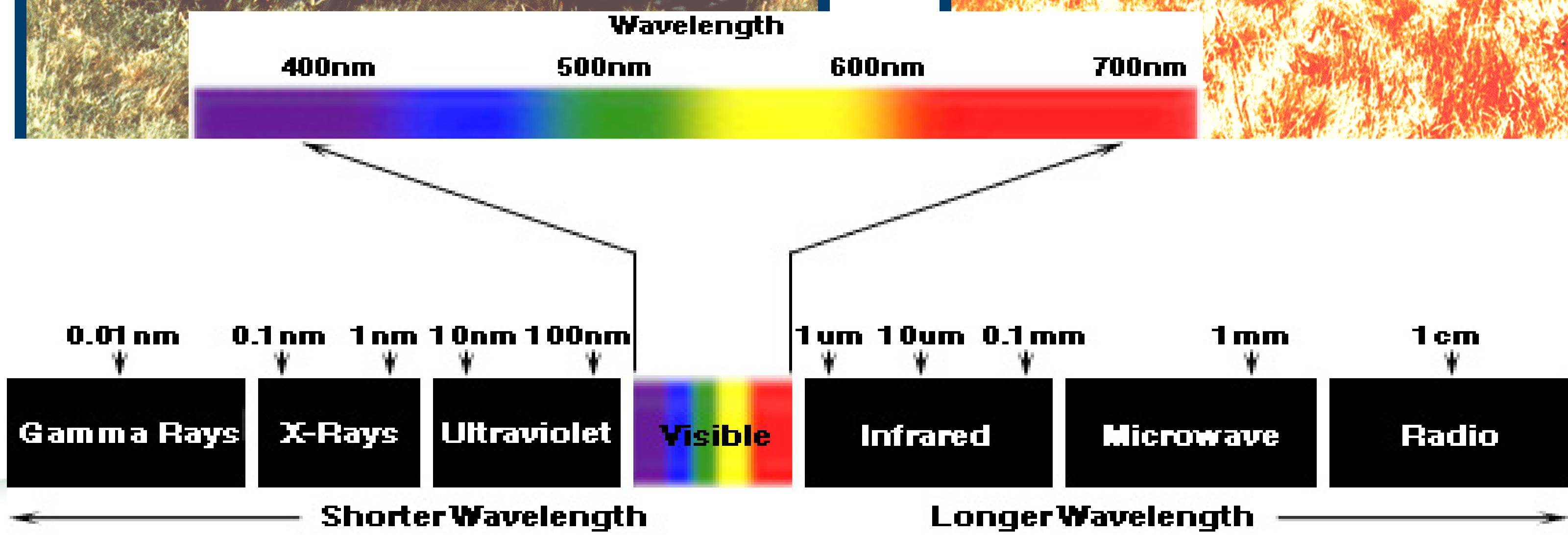
CAMOUFLAGE INVISIBLE TO IR NIGHT VISION

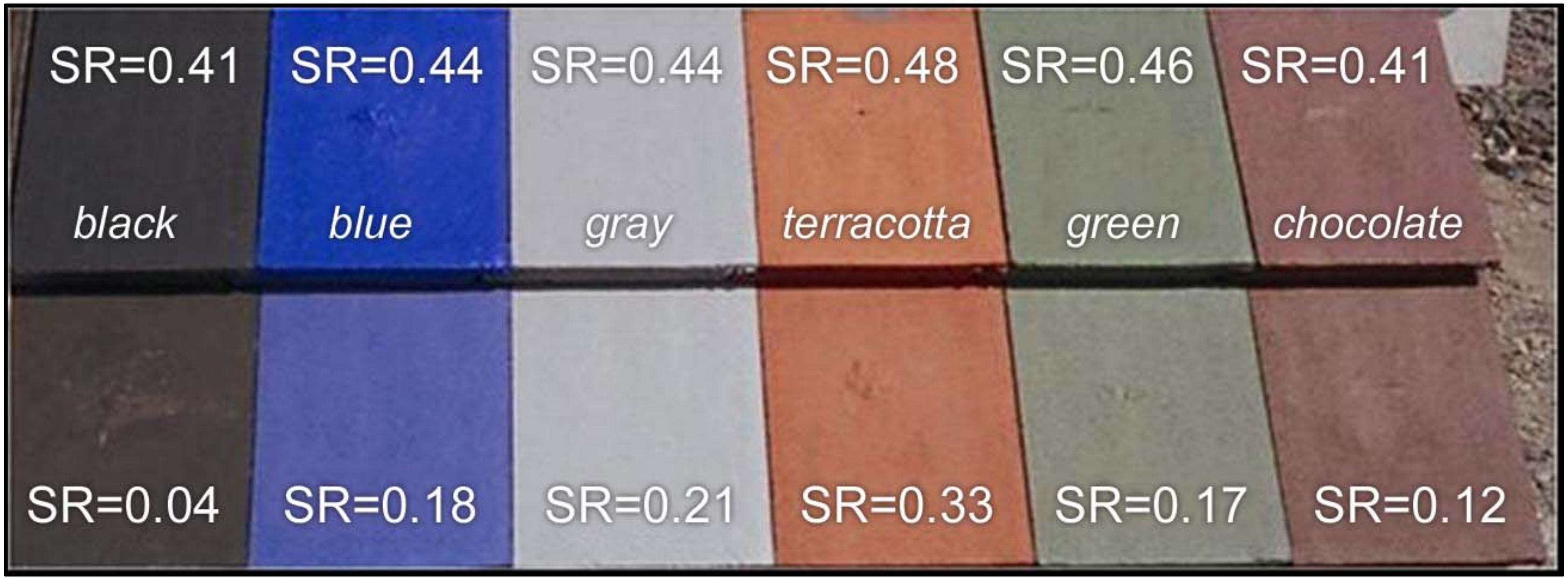
Conventional Film



Near Infrared Film

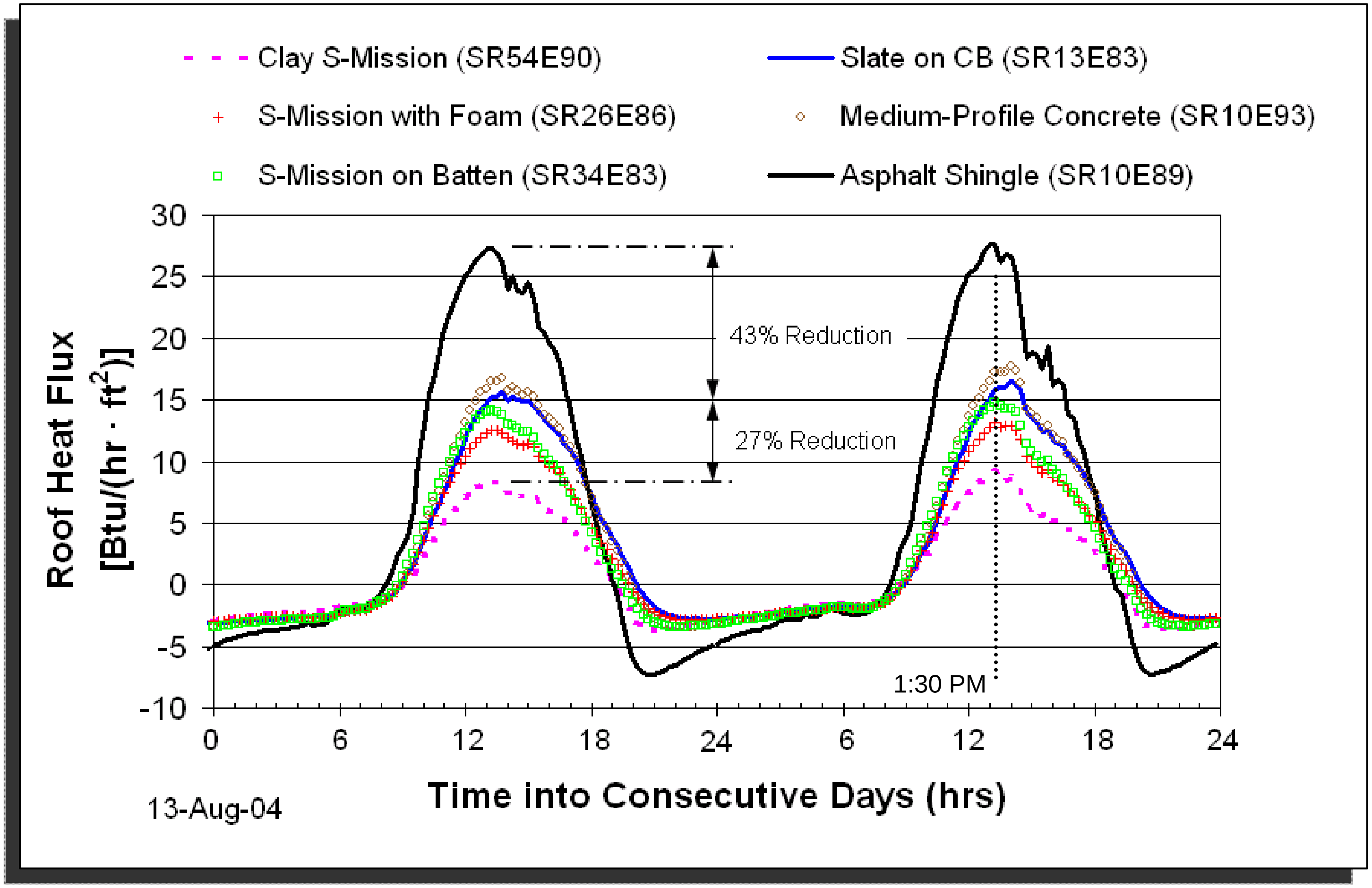


Cool Tile IR Coating™ Applied to Concrete Tile



- COOL TILE IR COATING™ technology was developed by Joe Reilly of American Rooftile Coatings

S-Mission Tile Have Lowest Heat Transfer Penetrating the Roof Deck



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Demonstration Showcasing Painted Metal Shakes at Fair Oaks, CA

- **Custom-Bilt Painted Metal Shakes and Stucco**

House-2 4983 Mariah Place

House-4 4991 Mariah Place

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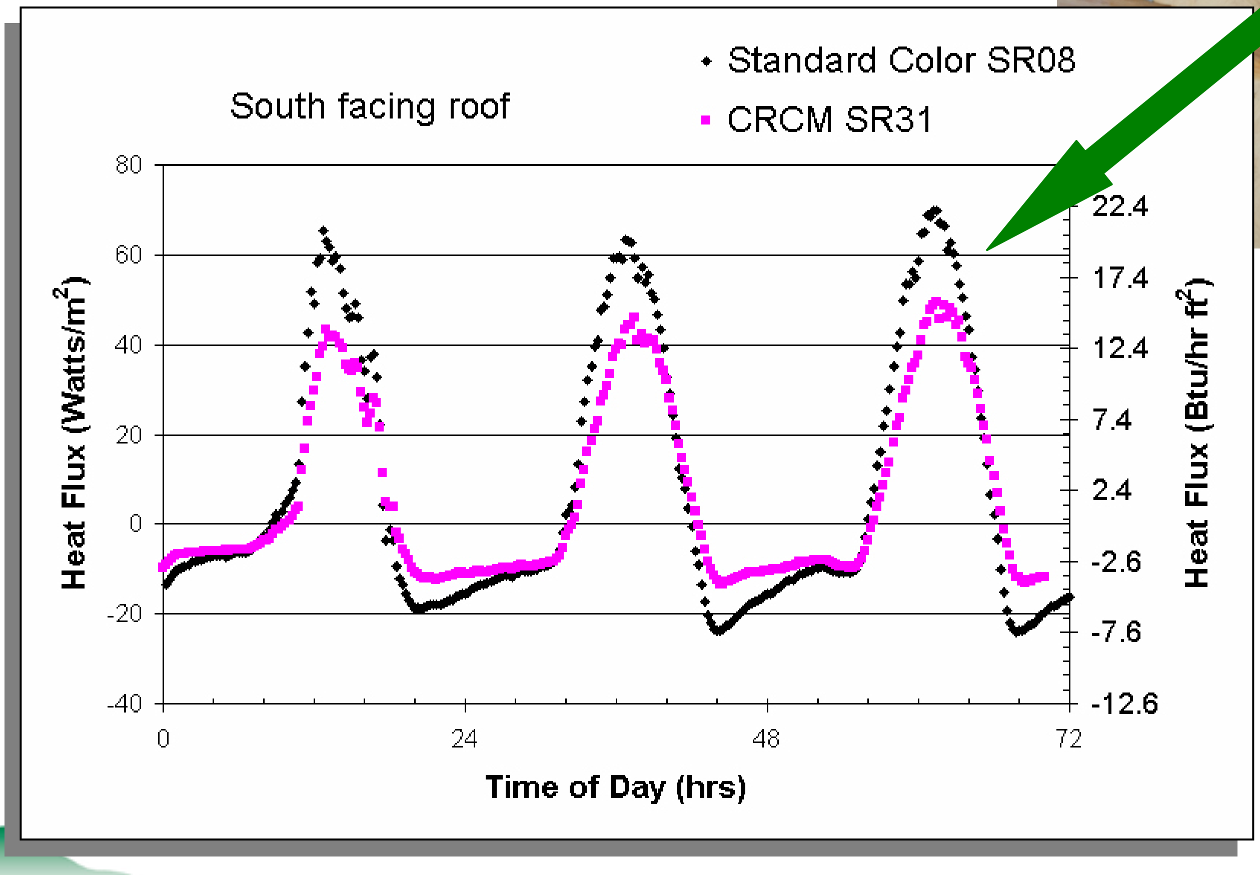
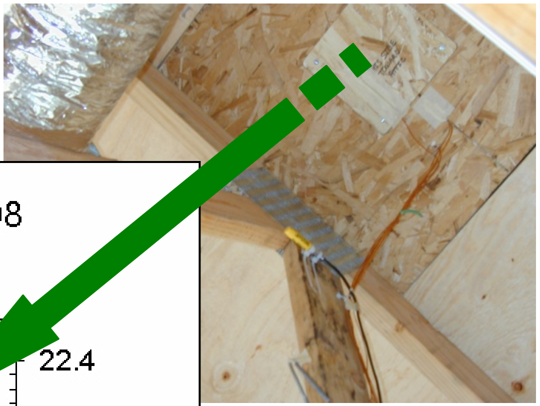
Cool Coating Reduces Heat Flux Through South Facing Roof Deck

Painted Metal Roofs





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Demonstration Showcasing Hanson Concrete Tile at Fair Oaks, CA

- **Finished with Medium-profile Concrete Tile and Stucco**

House-1 4979 Mariah Place

House-3 4987 Mariah Place

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Medium-profile concrete tile

Same setup used at Fair Oaks Demonstration

(ESRA) Envelope Systems Research Apparatus

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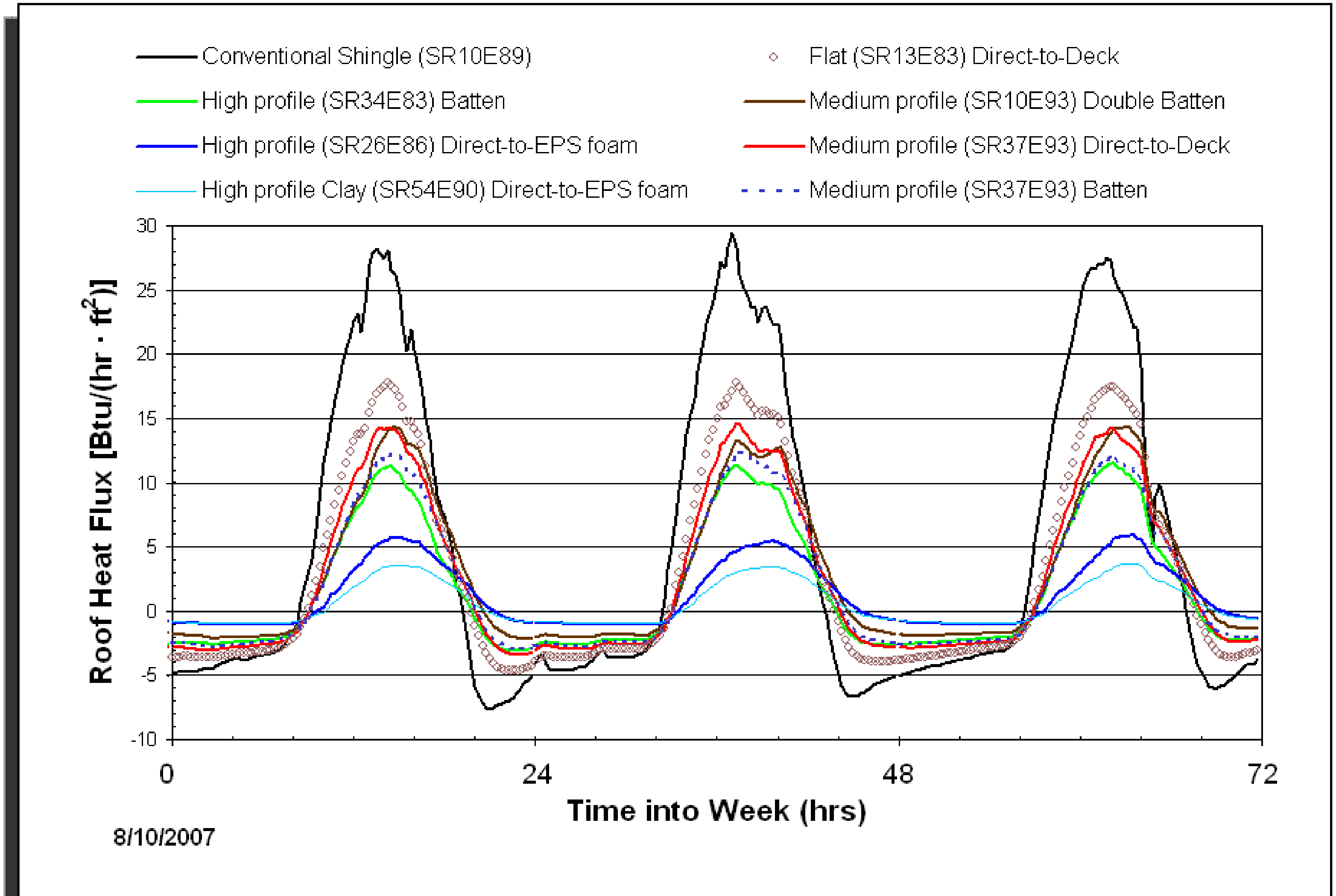
Medium-profile conventional concrete tile on double batten performs as well as cool-color tile direct-to-deck



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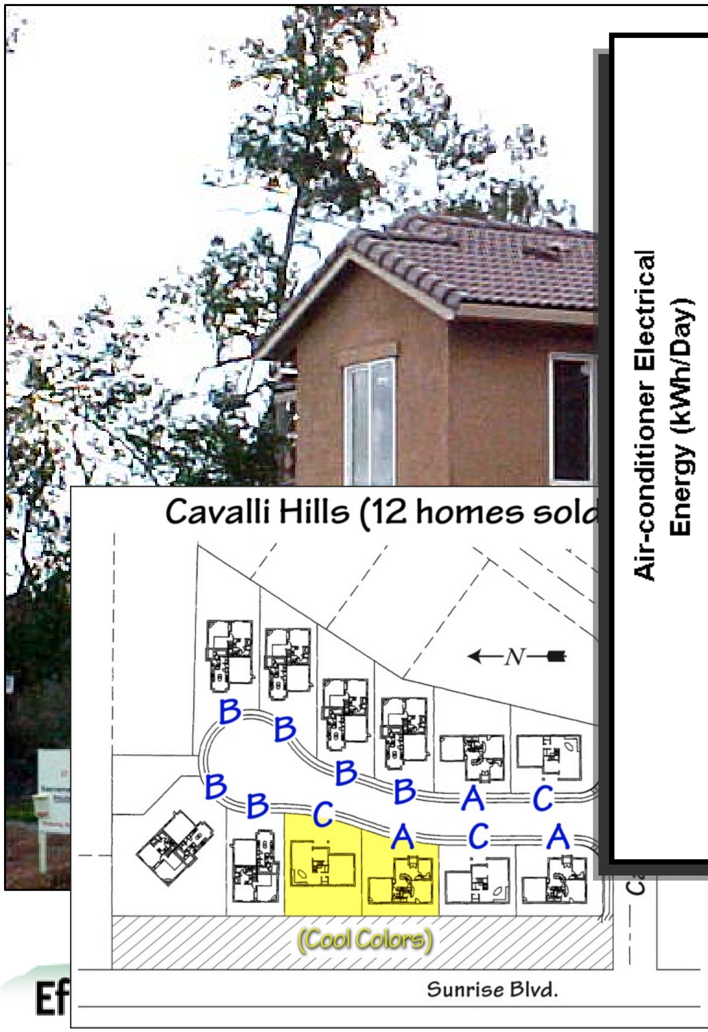
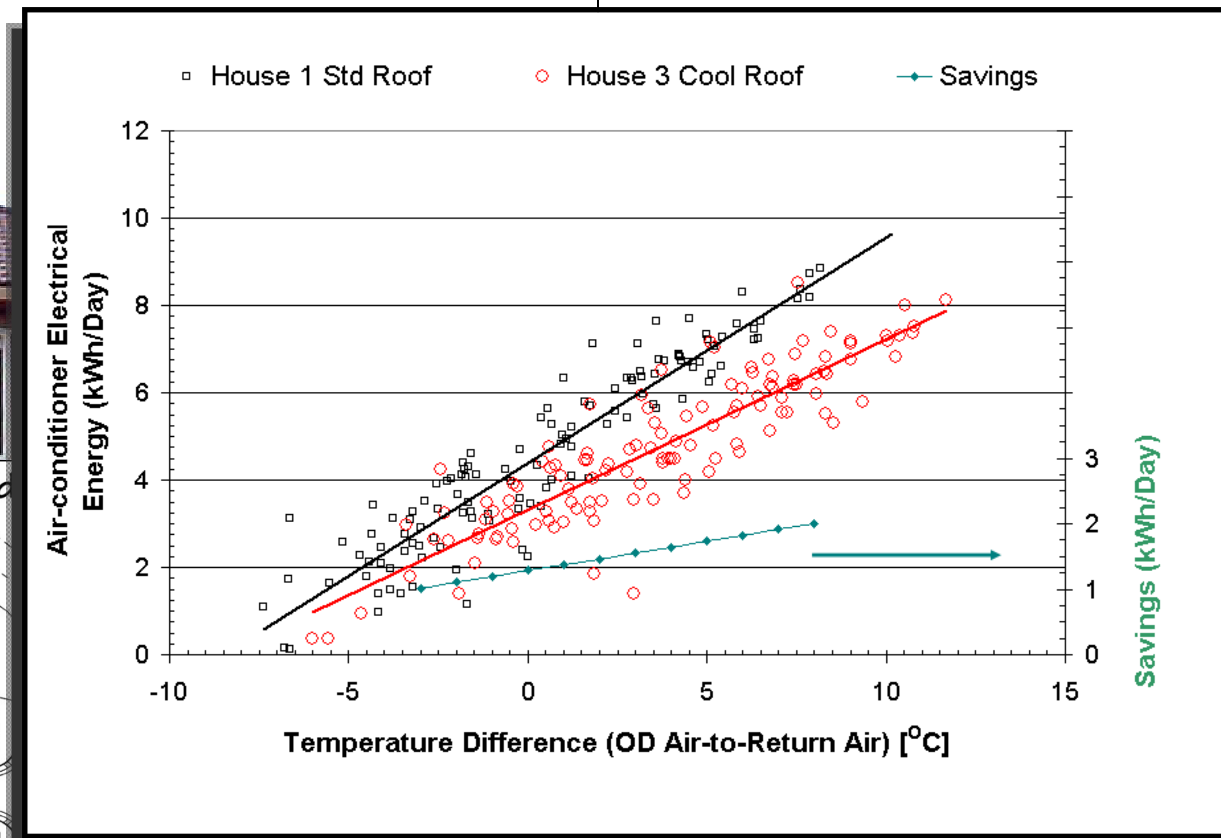
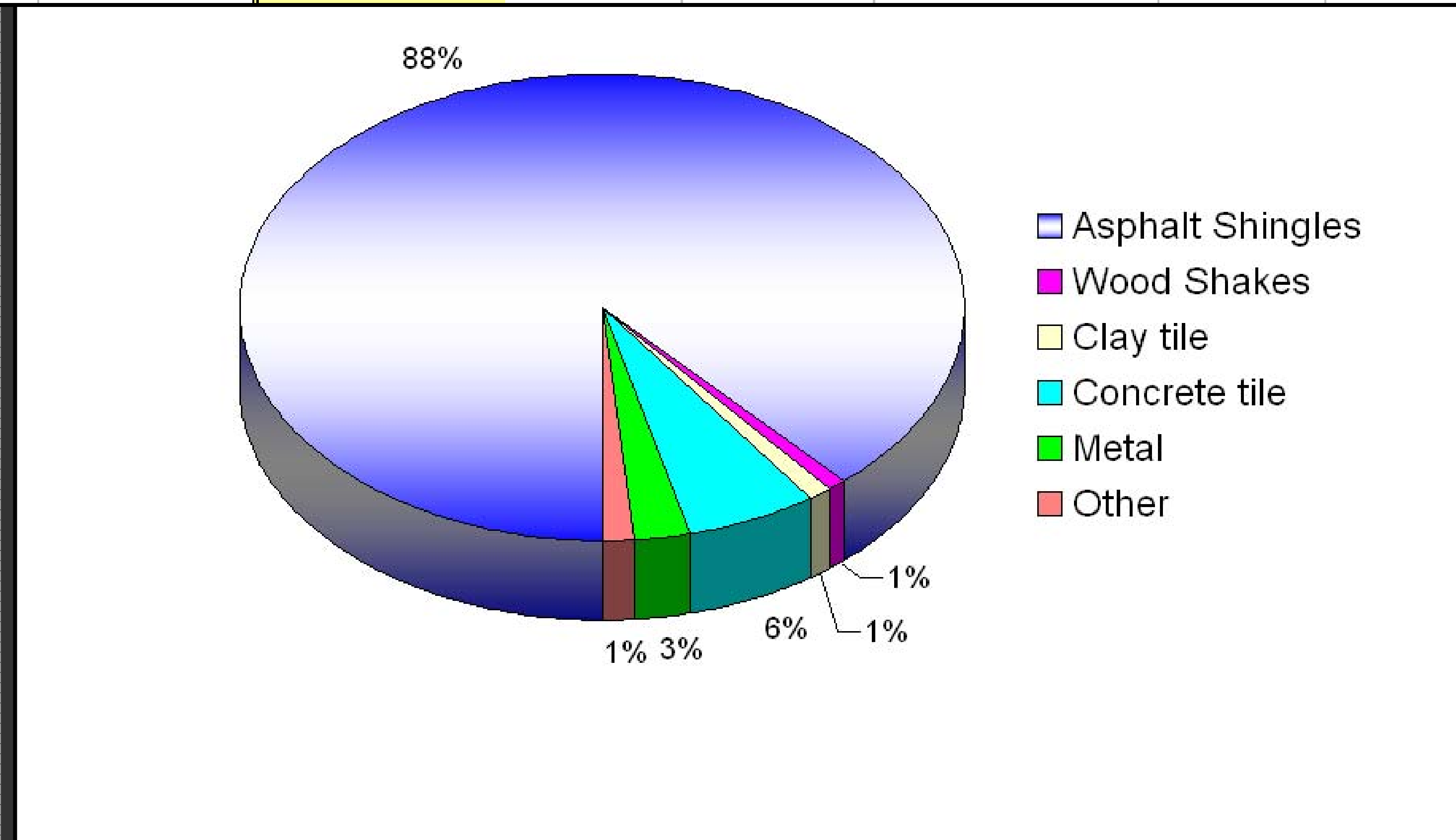
Fair Oaks Demonstrations Show Positive Benefits of Cool Colors





Squares of Roof Products F.W. Dodge Report 2003

United States	Asphalt Shingles	Wood Shakes	Clay tile	Concrete tile	Metal	Other
New Construction	29,955,734	280,821	323,763	1,965,500	889,134	461,263
Reroof	115,054,533	6,445,277	892,926	1,657,307	466,234	4,400,195
Total	145,010,267	6,726,098	1,216,689	3,622,807	1,355,368	4,861,457



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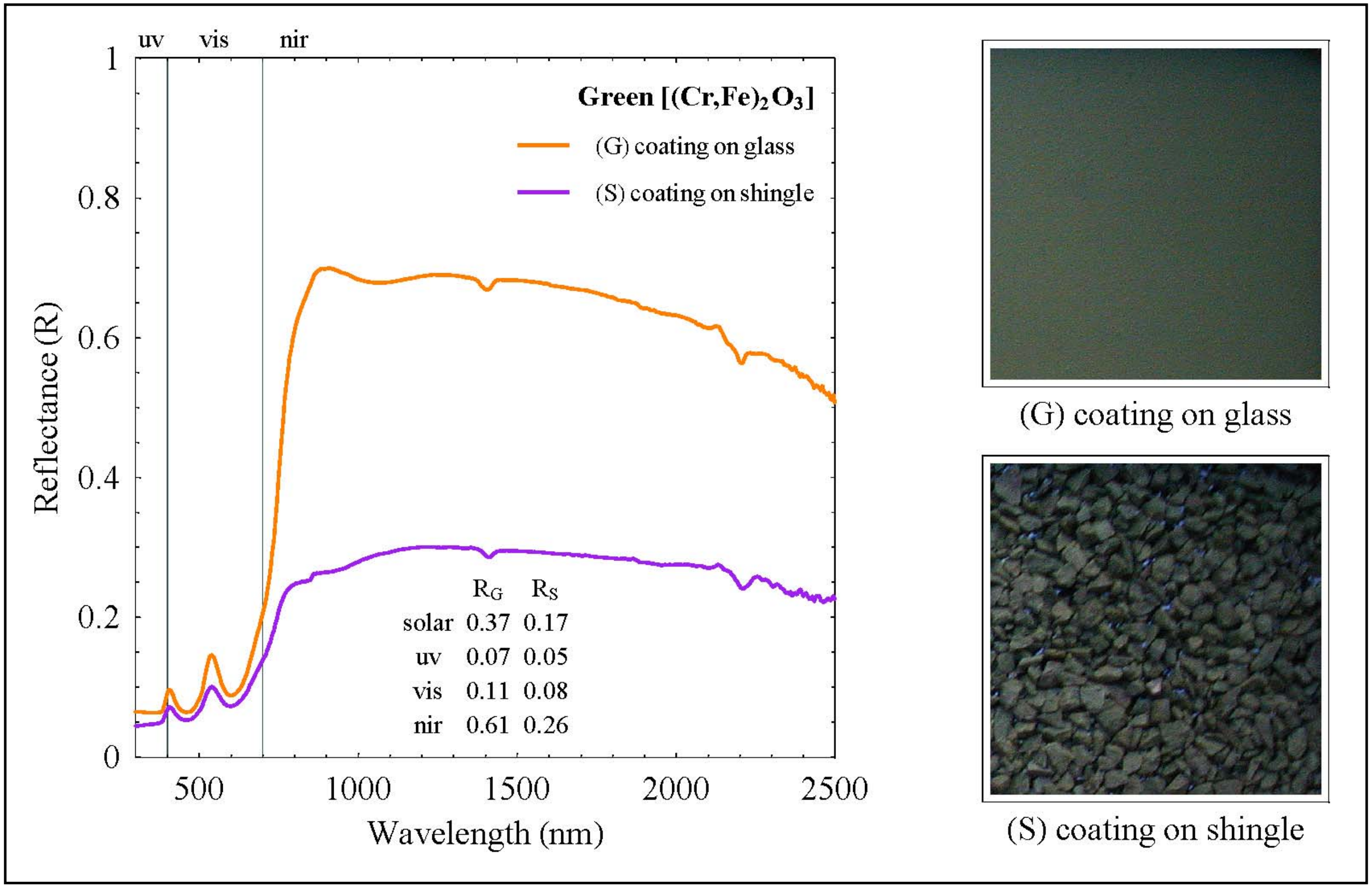
Hurdle: optimize reflectance of Cool Shingles and Stone Coated Metals



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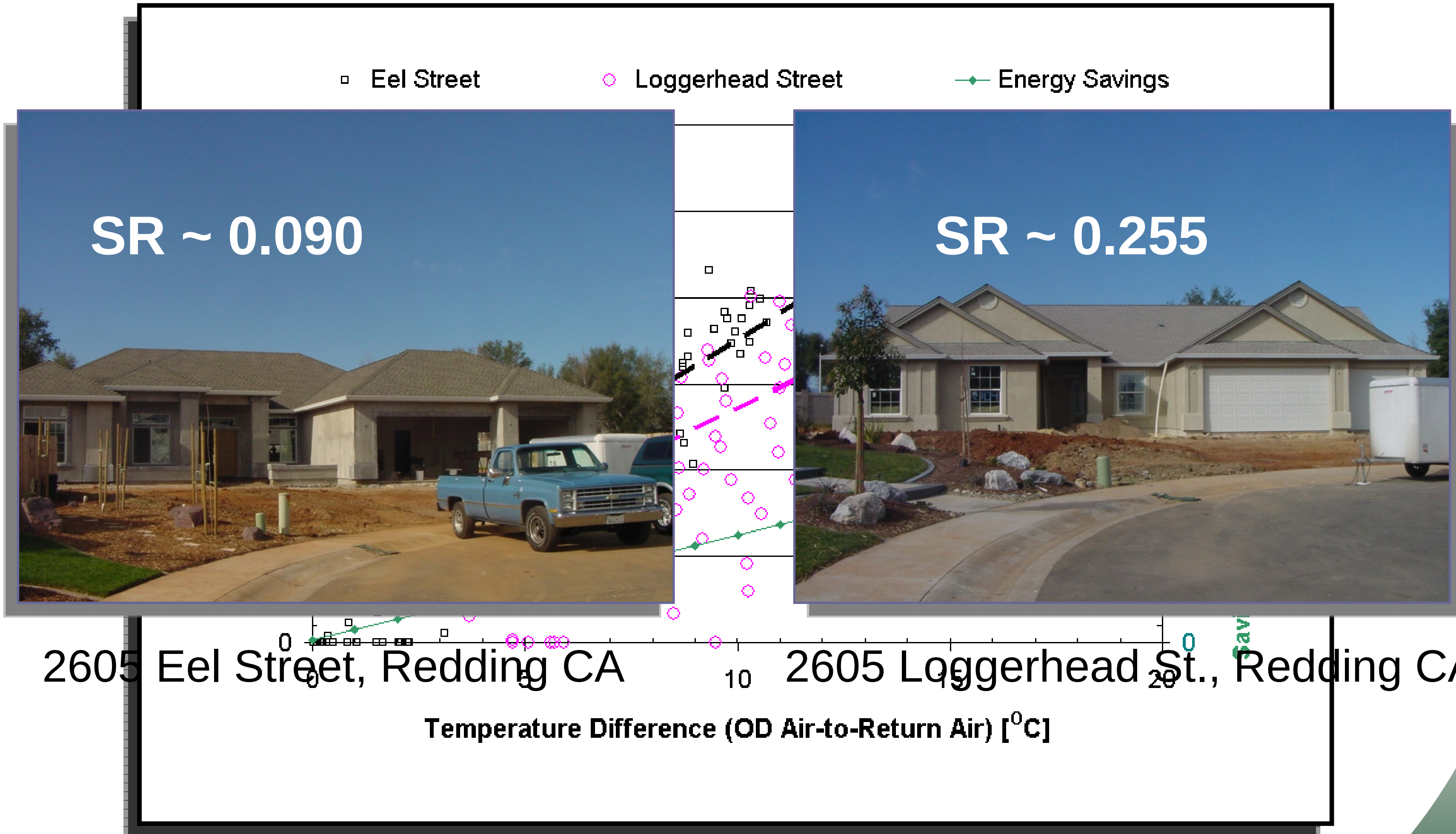
Berkeley Lab

Demonstration Homes Provided by Elk Corp and Ochoa & Shehan Custom Homes



2605 Eel Street, Redding CA

2605 Loggerhead St., Redding CA

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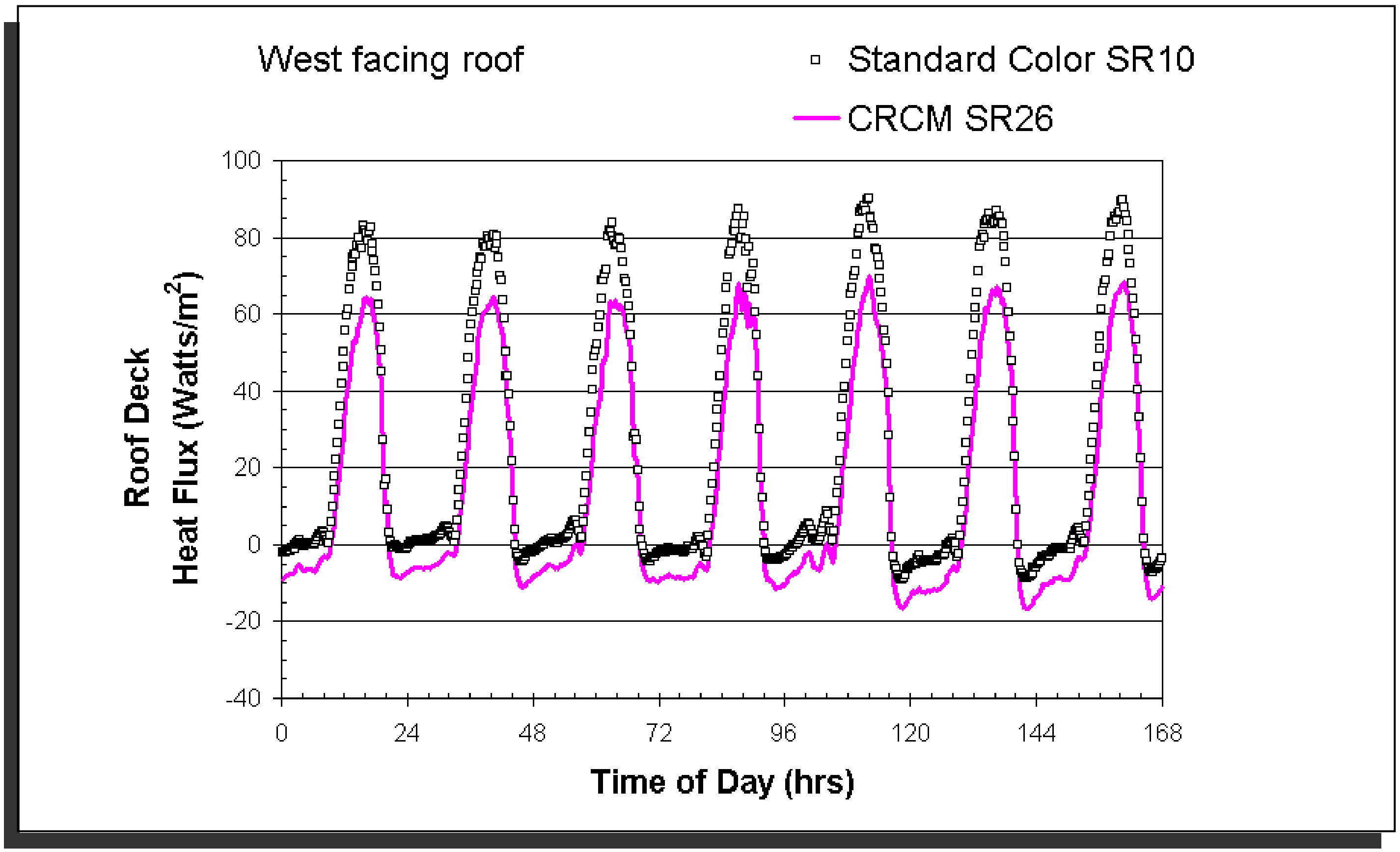
Heat Flux Penetrating West Roof Reduced 25% of Conventional Shingle



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110 Million Existing Homes in U.S. that Require Improvements in Building Envelope

WHAT ABOUT ROOF/ATTIC VENTILATION ?

- **Develop empirical algorithms to capture energy benefits of above-sheathing ventilation**
  - **Status: heat transfer correlations checked against field data, tracer gas used for airflow measures, algorithm formulated & validated**

MCA installing stone-coated metal roofs on ESRA

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Clay tile, concrete tile, painted metal shake, asphalt shingle, and stone-coated metal roofs field tests

Formulate and Validate AtticSim for Cool Color and Above-Sheathing Ventilation

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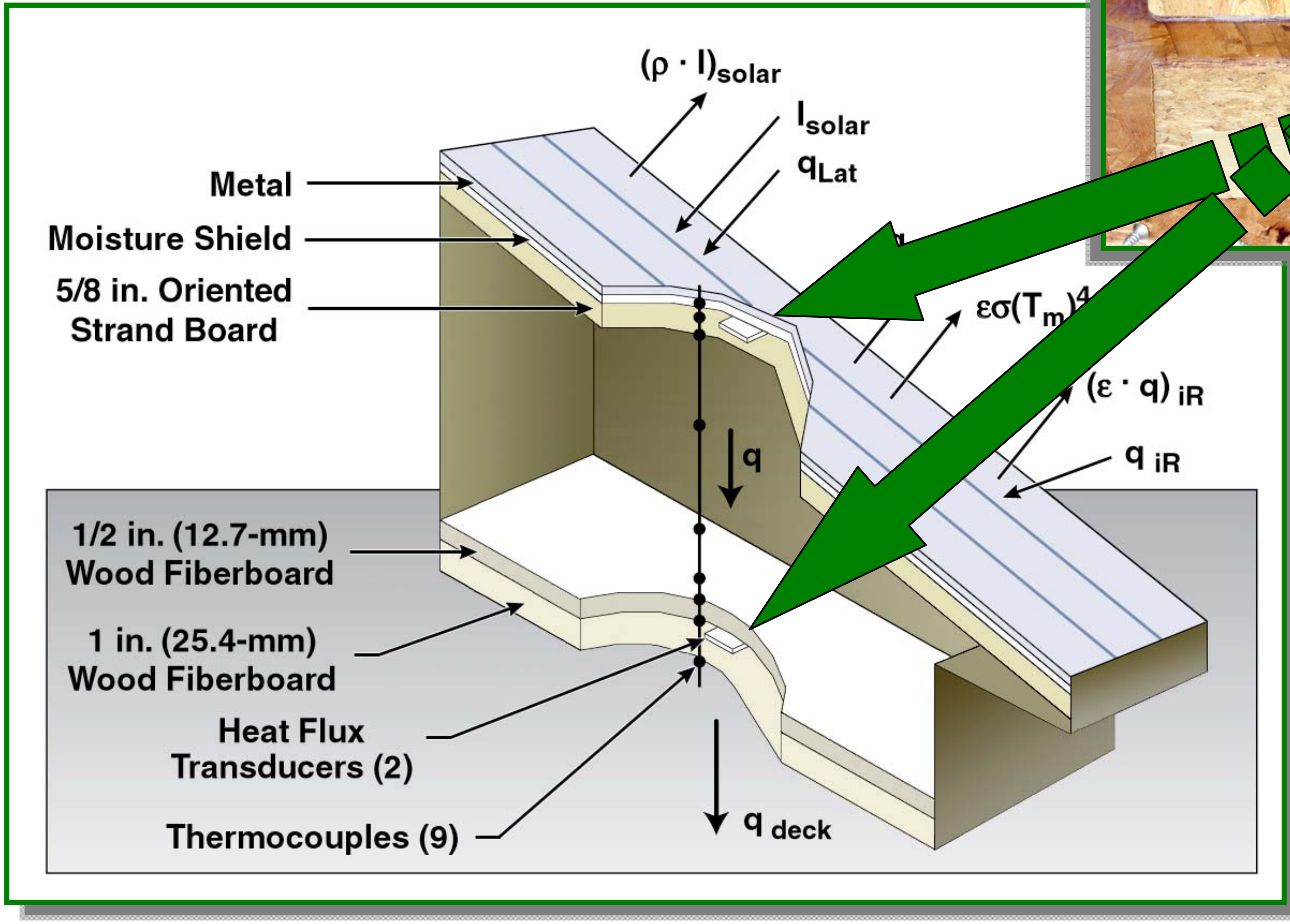
Attic Assembly Construction and Instrument Setup



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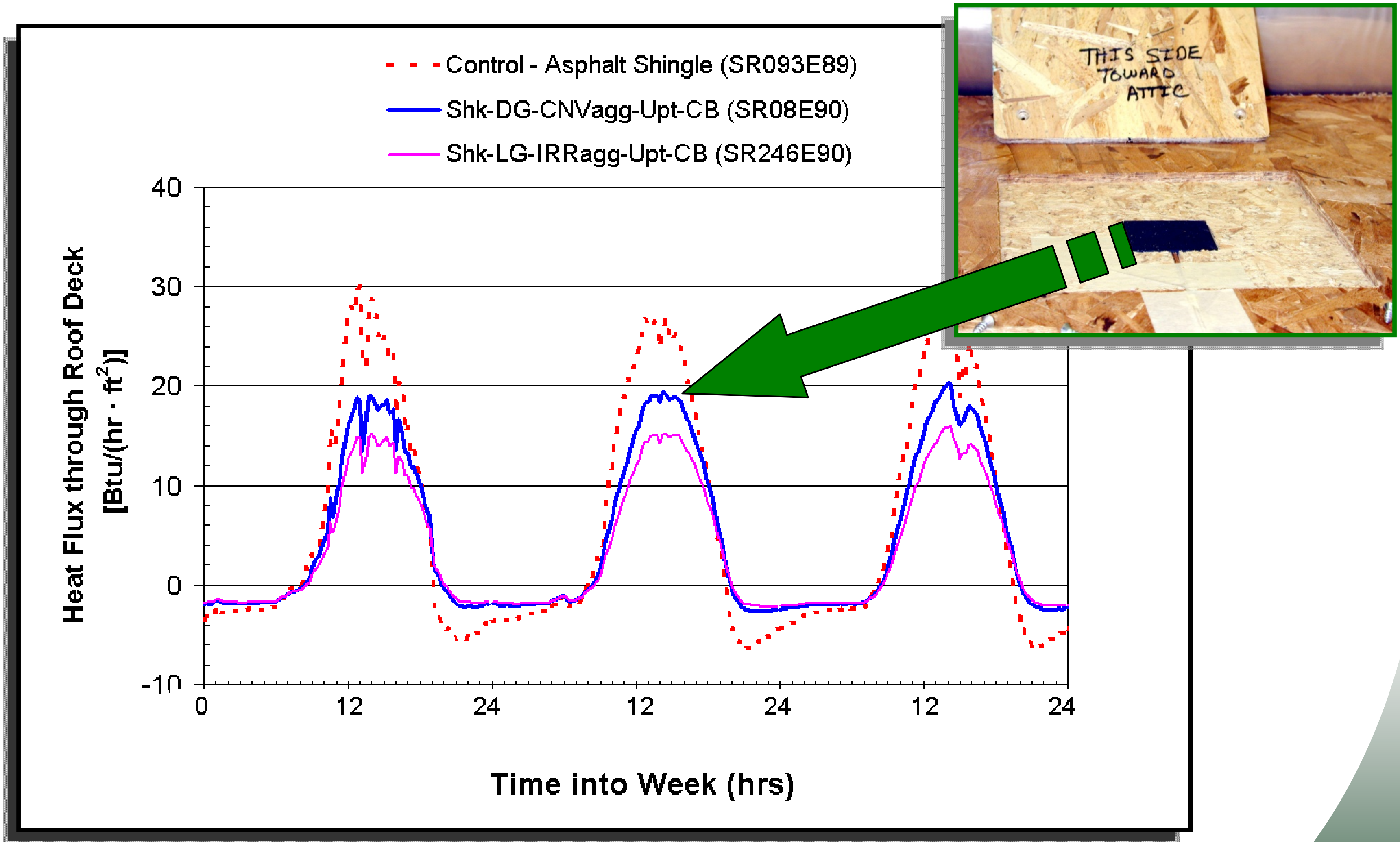
ASV Reduced Heat Flow Crossing Deck by 30% of Asphalt Shingle



August 2005

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Deck Heat Flow Reduced 45% by IRR pigments and ASV

- Above Sheathing Ventilation ~ 30% of control
- SR increase of 0.17 ~ 15% of control

Roof Deck and Attic Floor Heat Flows (Btu/ft²) summed over the daylight hours for a July week

During Daylight Hours[1]	Shingle (SR093E89)	Shk-LG-IRRagg-Upt-CB (SR246E90)	Shk-DG-CNVagg-Upt-CB (SR08E90)
Solar Abs (Btu/ft²)	3723.2	2095.2	3714.5
Roof Deck (Btu/ft²)	1216.4	670.3	853.9
Attic Floor (Btu/ft²)	326.6	95.5	112.2
$Q_{Attic\ Vent}$ (Btu/ft²)	889.7	574.8	741.8
$Q_{Deck\ Vent}$ (Btu/ft²)		1280.6	2703.8

[1] Daylight defined as period when solar flux normal to roof exceeds 30 Btu/hr ft²

$$Q_{Attic\ vent} = \frac{Q^{HFT}_{Roof\ Deck}}{COS(\theta)} - Q^{HFT}_{Attic\ floor} \qquad Q_{Deck\ vent} = \frac{Q_{Solar\ Abs} - Q_{Mass} - Q^{HFT}_{Roof\ Deck}}{COS(\theta)}$$

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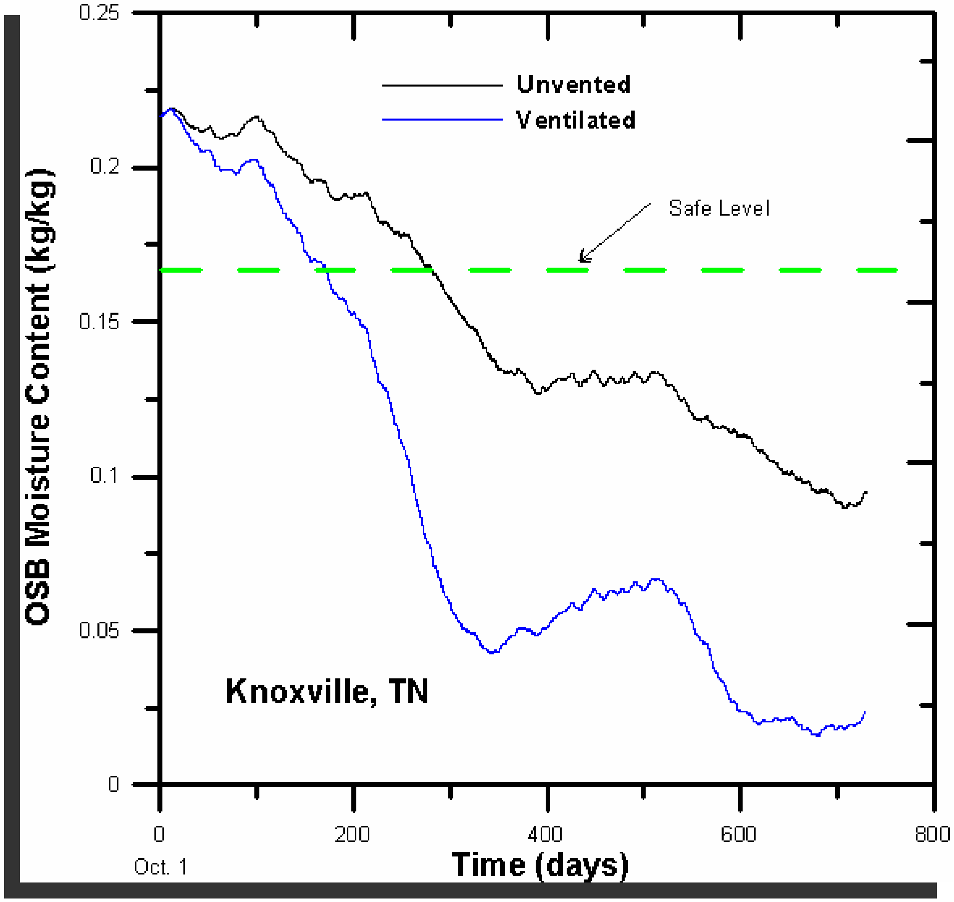
Above-sheathing ventilation accelerated the removal of unwanted moisture

- reduced moisture content in OSB well below that of OSB in a non-vented cavity



2-D MOISTURE-EXPERT model (Karagiozis)

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Next Generation Prototypes

Milestones (●)

- **Regional Criteria for Above-Sheathing Ventilation**
  - **Develop Recommendations for above-Sheathing Ventilation and submit for public review and acceptance as standards practice**
- **Maximize attic contribution to energy savings through integration of key strategies into Next Generation Attic**
  - **PCM, cool roofs (IRR), above sheathing ventilation and radiant barriers combined into Next Generation Attic**
- **Computer Tool Benchmarking**

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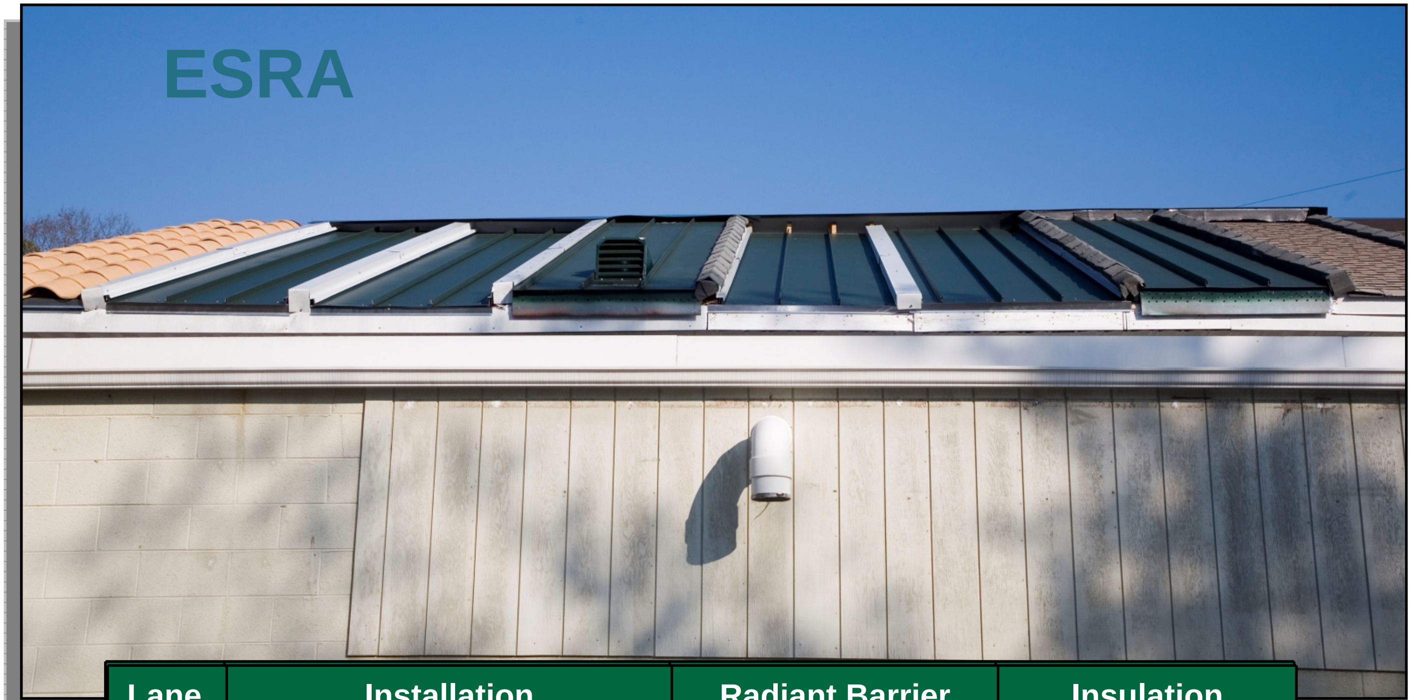
MCA Field Testing of Painted Metal



Lane	Installation	Radiant Barrier	Insulation
10[1]	Offset from deck 4.0-in, dual air channel	Low-e foil on deck facing up	Hardy Board (0.5-in)[2]
11	**Offset from deck 4-in using clips**	**Backer on metal underside**	**No insulation above deck**
12	**Offect from deck 2-in using clips**	**Low-e paint on underside**	**No insulation above deck**
13[1]	Offset from deck 4.0-in, forced ventilation	Low-e foil on deck facing up	No insulation above deck
14	Offset from deck 0.75-in using clips	Backer on metal underside	≈ R-1.0 above deck
15	Offset from deck 0.75-in using clips	Low-e paint on underside	No insulation above deck

[1]Roof and attic assemblies already under evaluation.
[2]Hardy board used to separate two air channels above roof deck.

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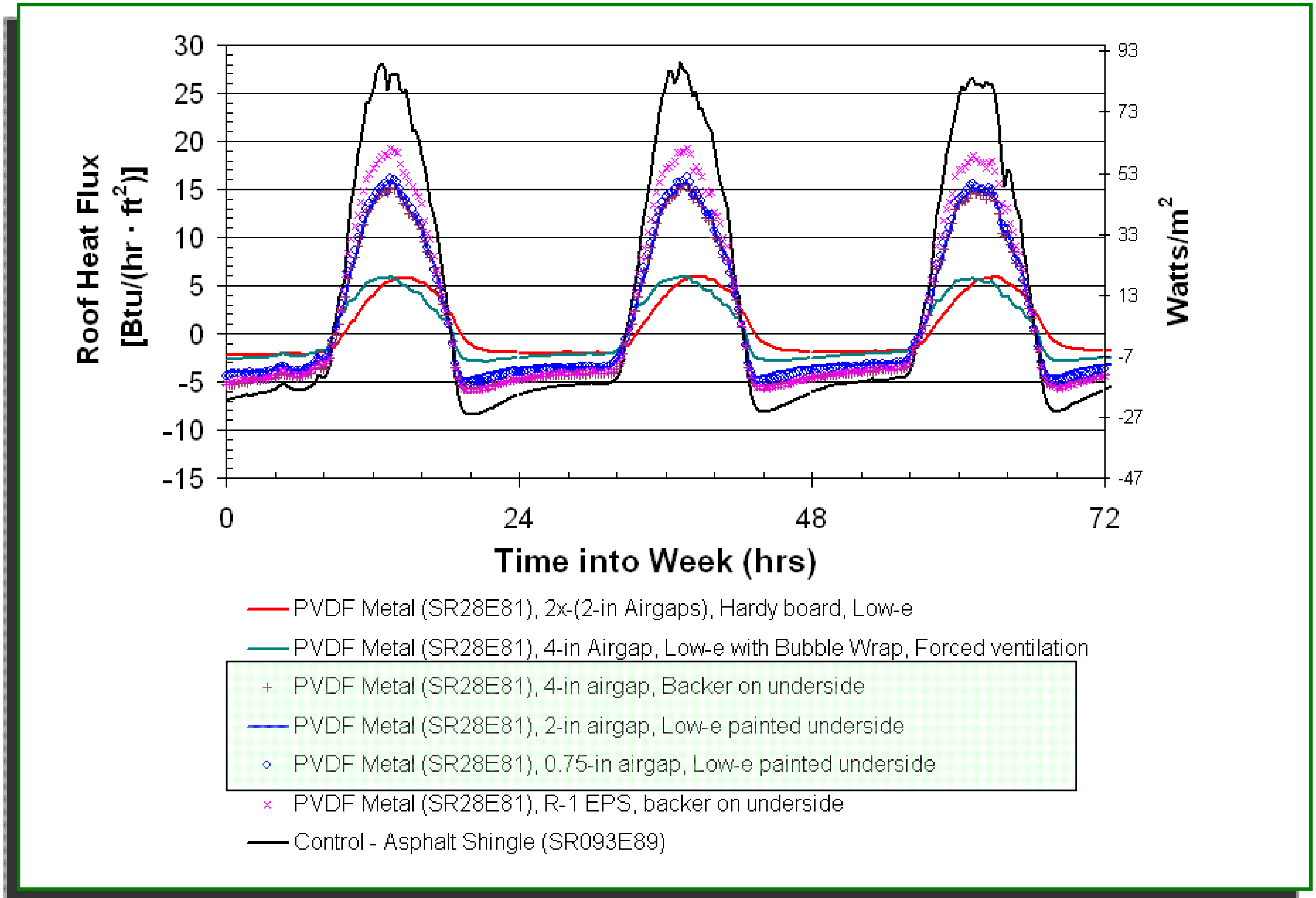
Roof with ¾- and 2-in airspace yield similar roof heat flows to roof with 4-in airspace



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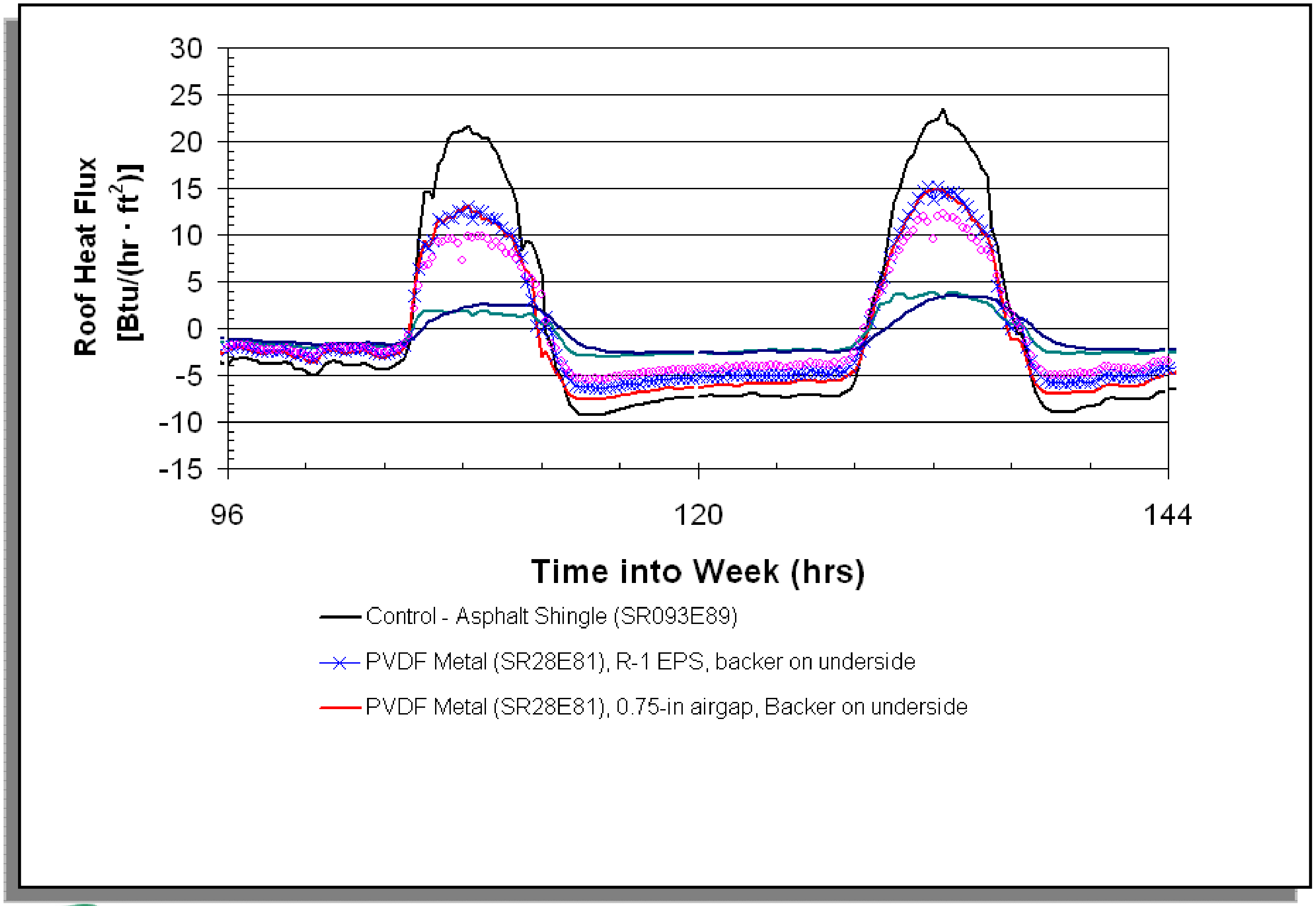
Roof with R-1 insulation placed above deck yields similar thermal performance to roof with ¾-in airspace above deck



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AtticSIM II *(Attic Simulation)* Model

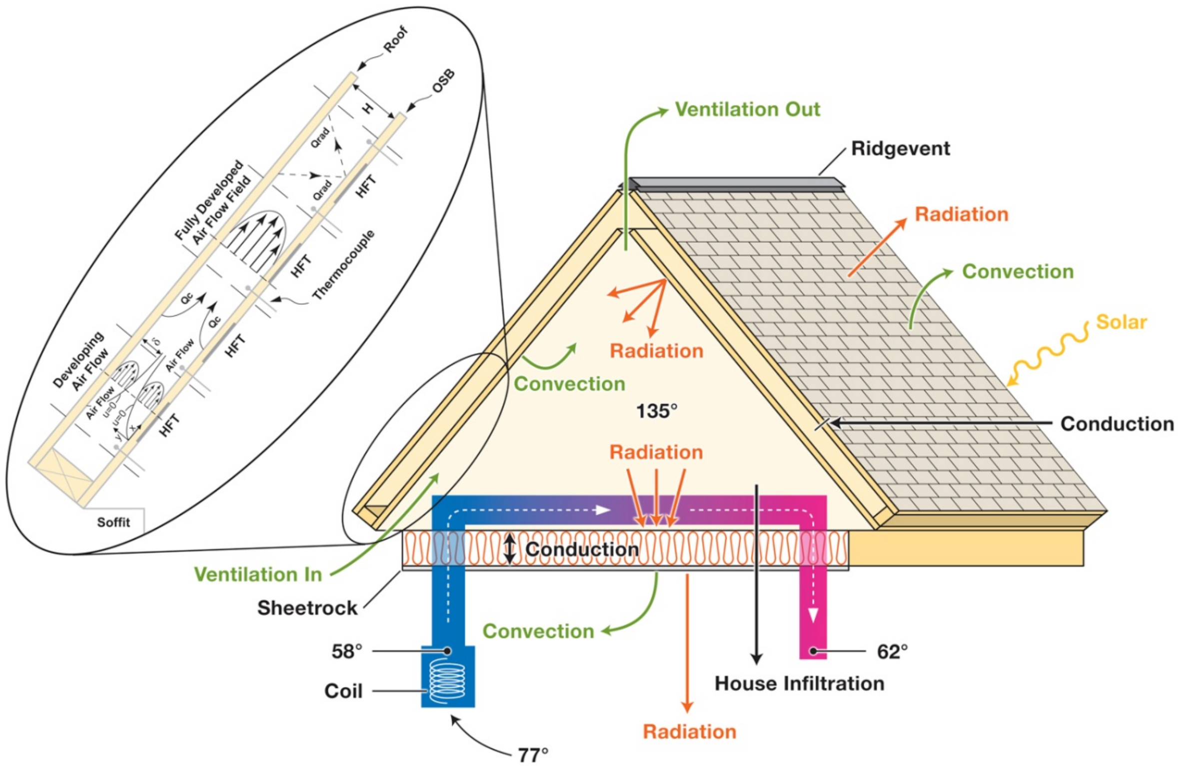

Table 1. Data for daylight hours with average outdoor air temperature of 84°F; 0.75-in air space.

System	Nu number	Temperature (°F)			Heat Flux (Btu/hr ft²) over Day light hours					
	Roof Underside	Roof Underside	Air Space	Roof deck	Roof Underside	Radiation to sheathing	Convection to air space	Convection to sheathing	ASV	Sheathing
Open Cavity	0.9	137.9	124.9	123.5	19.0	15.7	3.3	0.3	3.0	16.0
Low-e in Open Cavity	1.1	141.7	116.9	97.8	10.2	3.0	7.3	5.3	1.9	8.3

Solar reflectance 0.26, emittance 0.95; air space 4.0-in.

$$\hbar = \frac{k}{\Delta}$$

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1st Generation Roof and Attic

Painted metal roof (SR28E81, 4-in air gap, 2 Low-e, PCMs)

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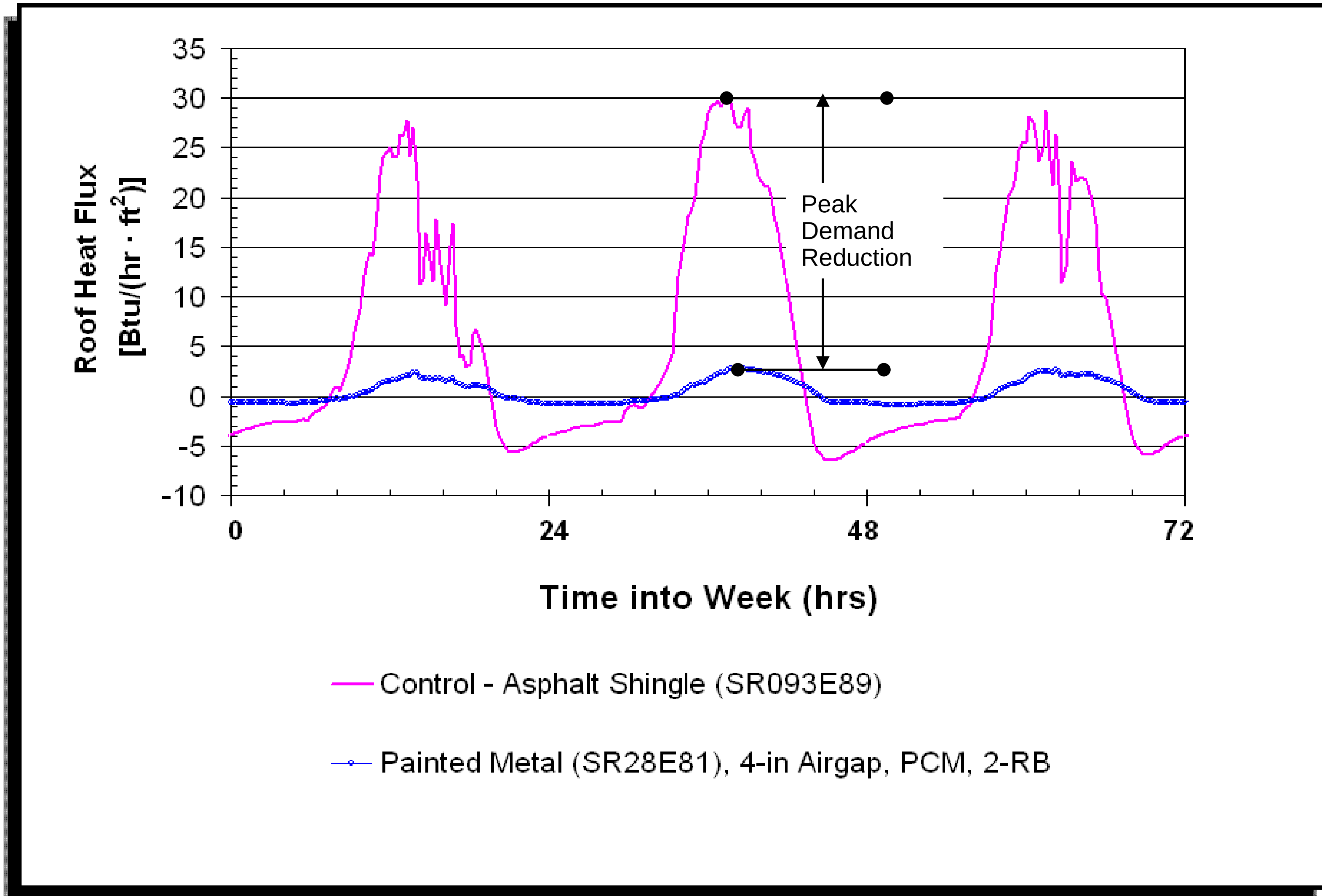
Advanced Attic with PCM Shaves Peak Demand and Reduces Night Sky Losses



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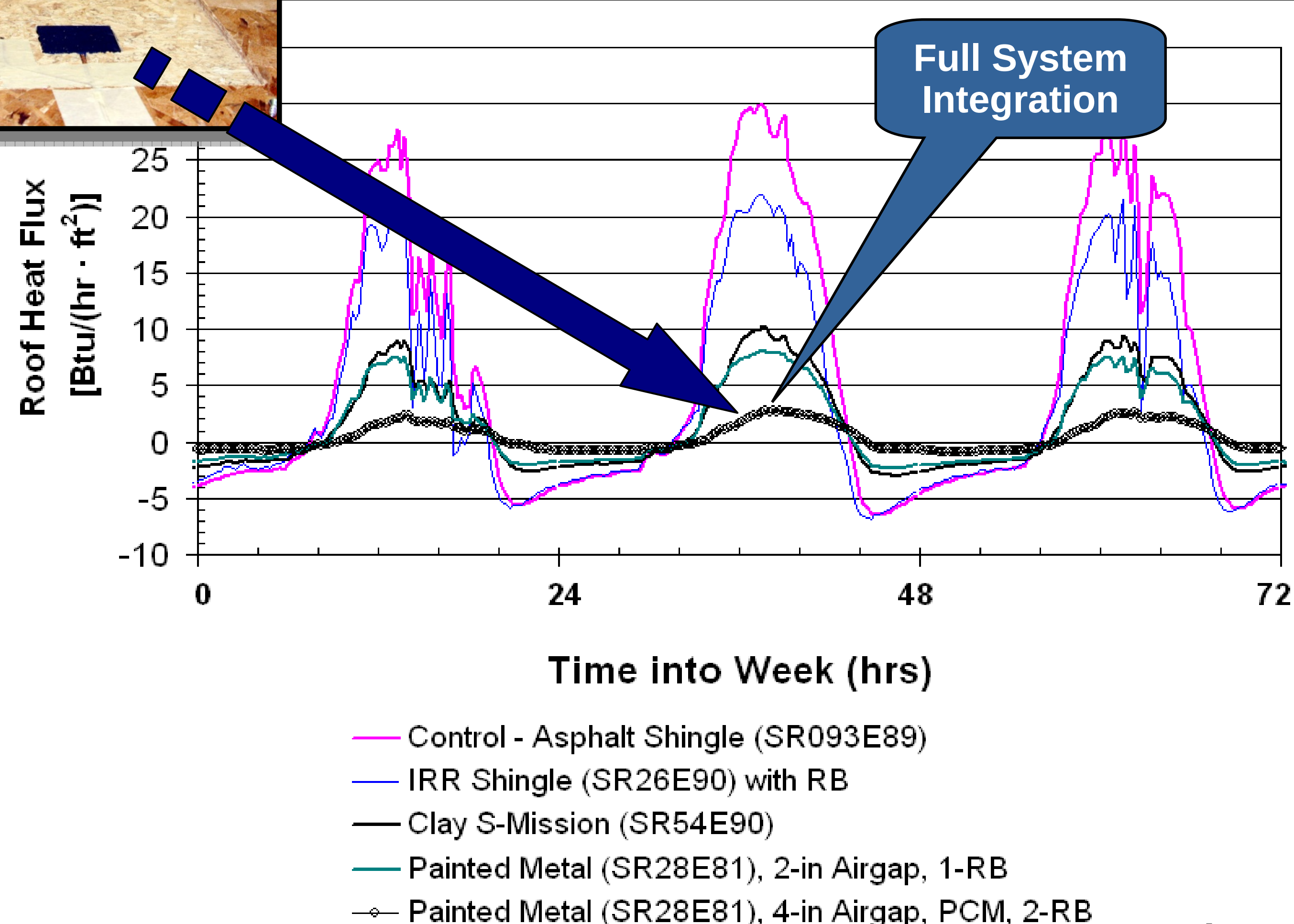
Effect of Cool Color, Above-Sheathing Ventilation, PCMs, and Low-e Reflective Insulation



July 28, 2006

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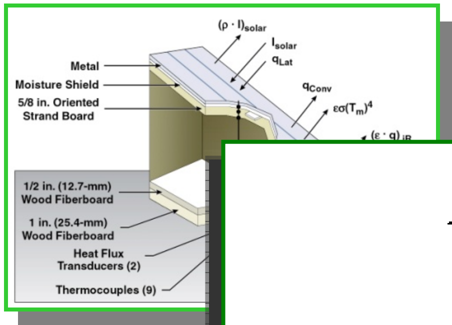
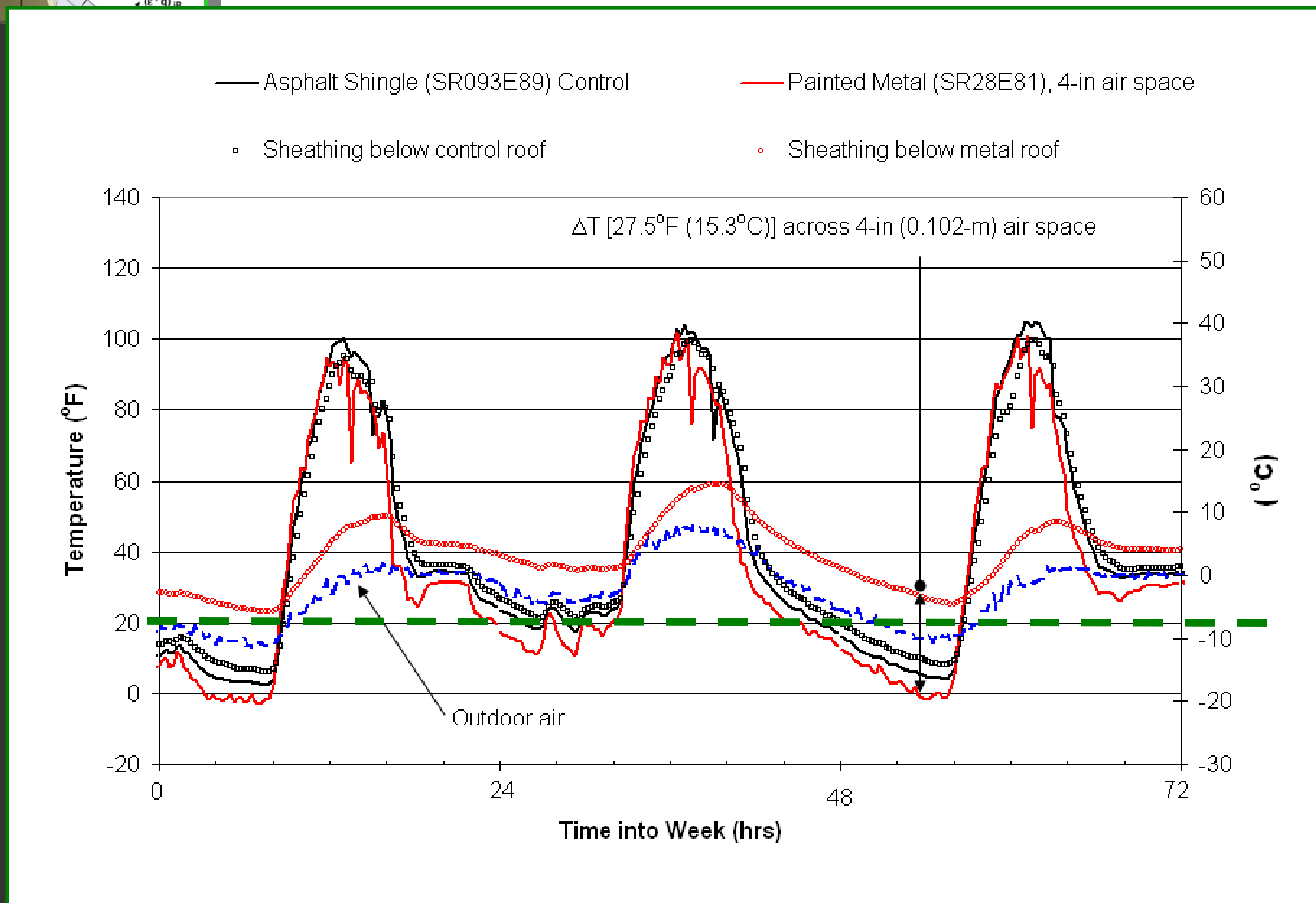
Above Sheathing Ventilation Roofs Negate Heating Penalty





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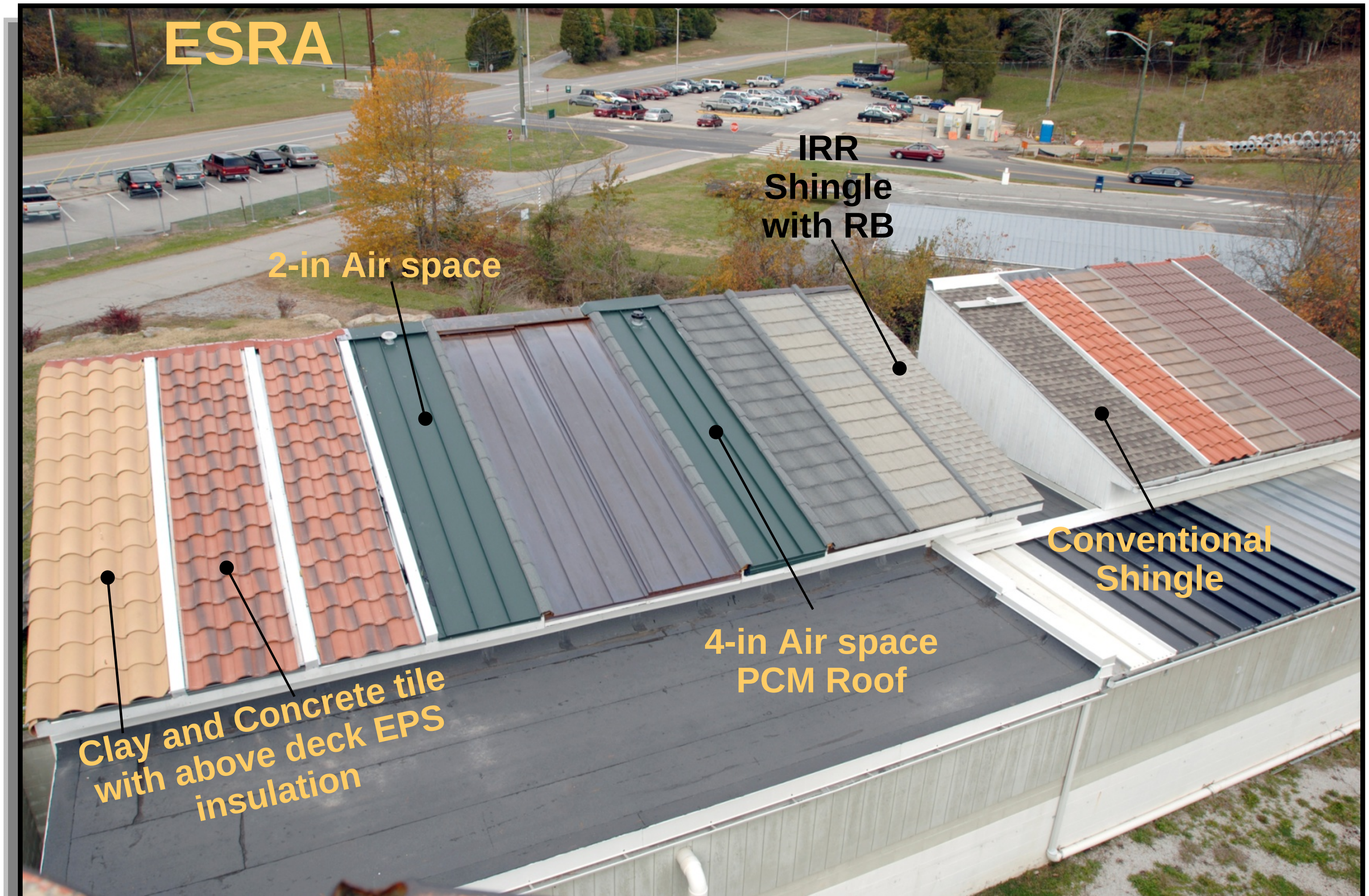
Cool Color painted metal with ASV, Low-e surface and PCM [2nd Generation prototype]



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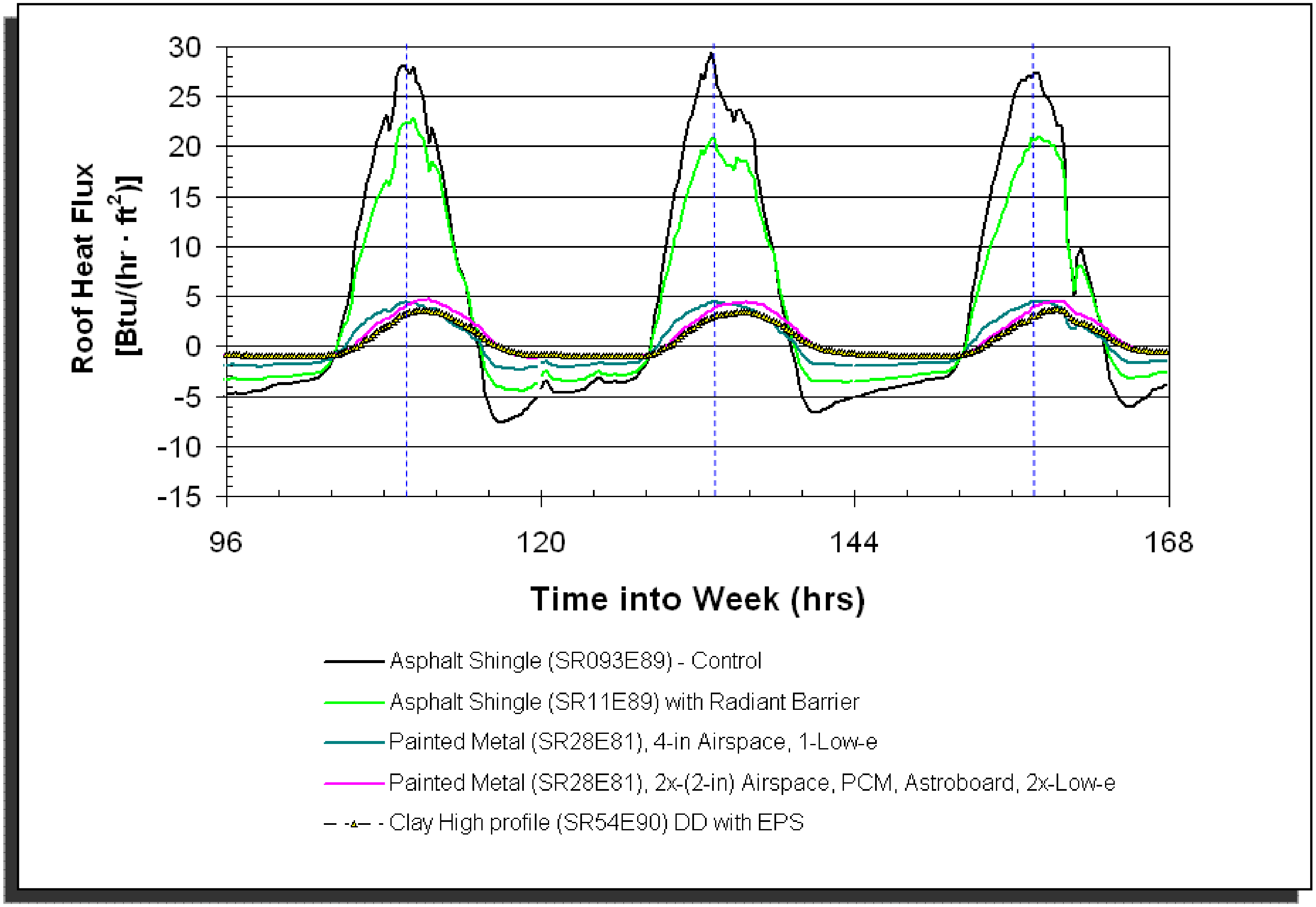
Next Generation Attics (in progress)



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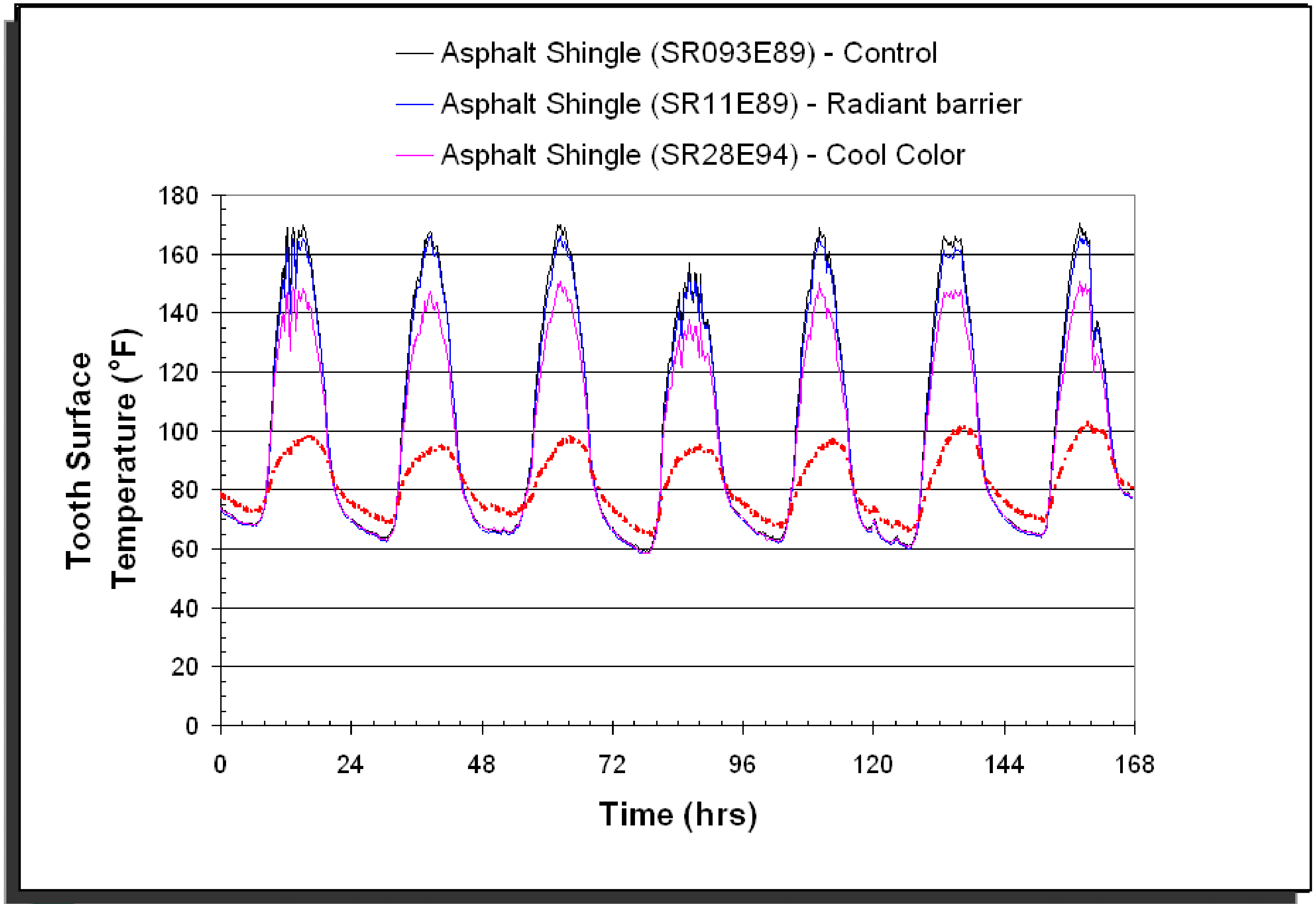
Surface and Underside Temperatures of tooth and valley not affected by RB



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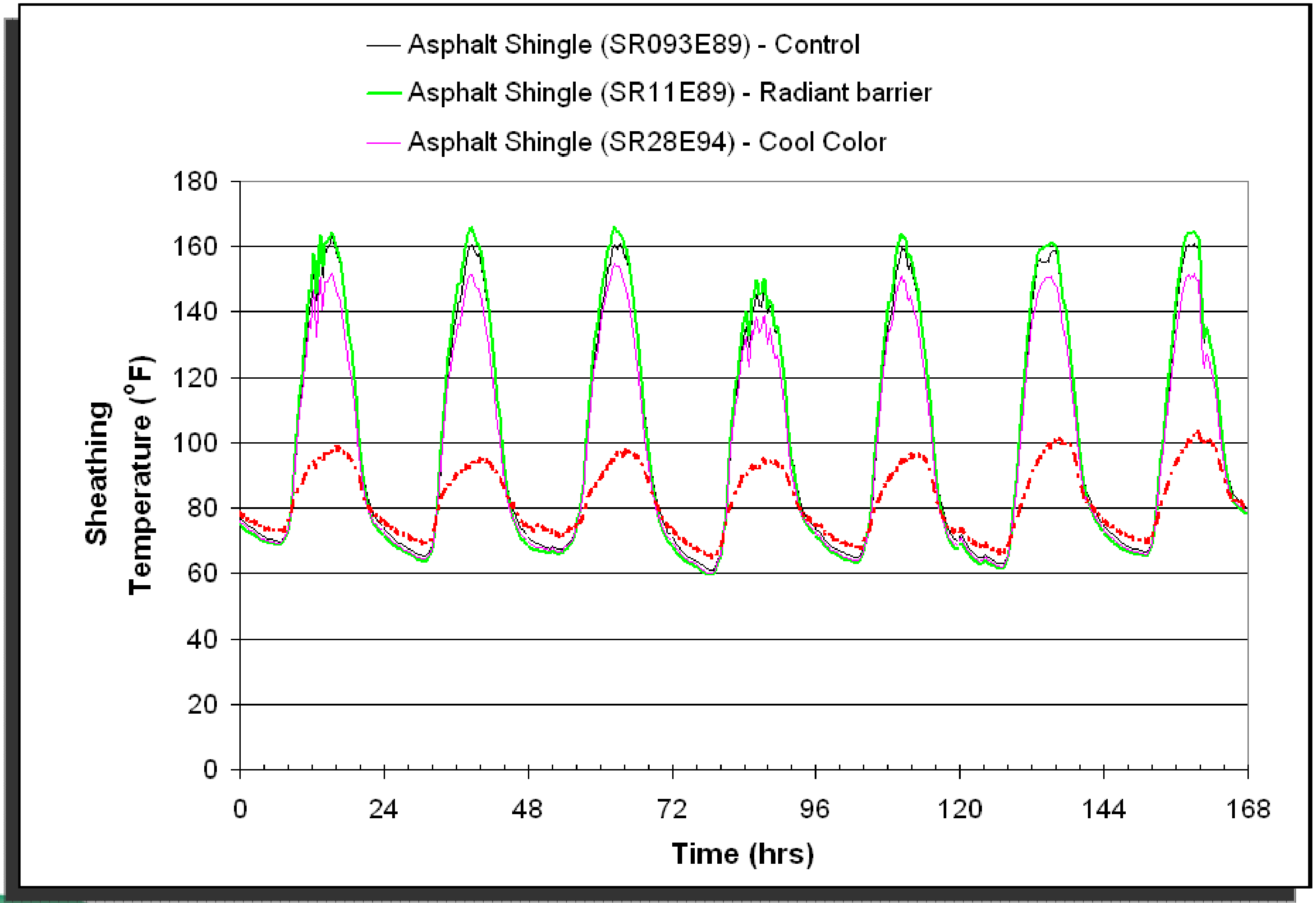
OSB Deck Temperature Increases

- **Sheathing 4ºF increase**
  OSB Underside 15ºF increase



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2nd Generation Roof and Attic

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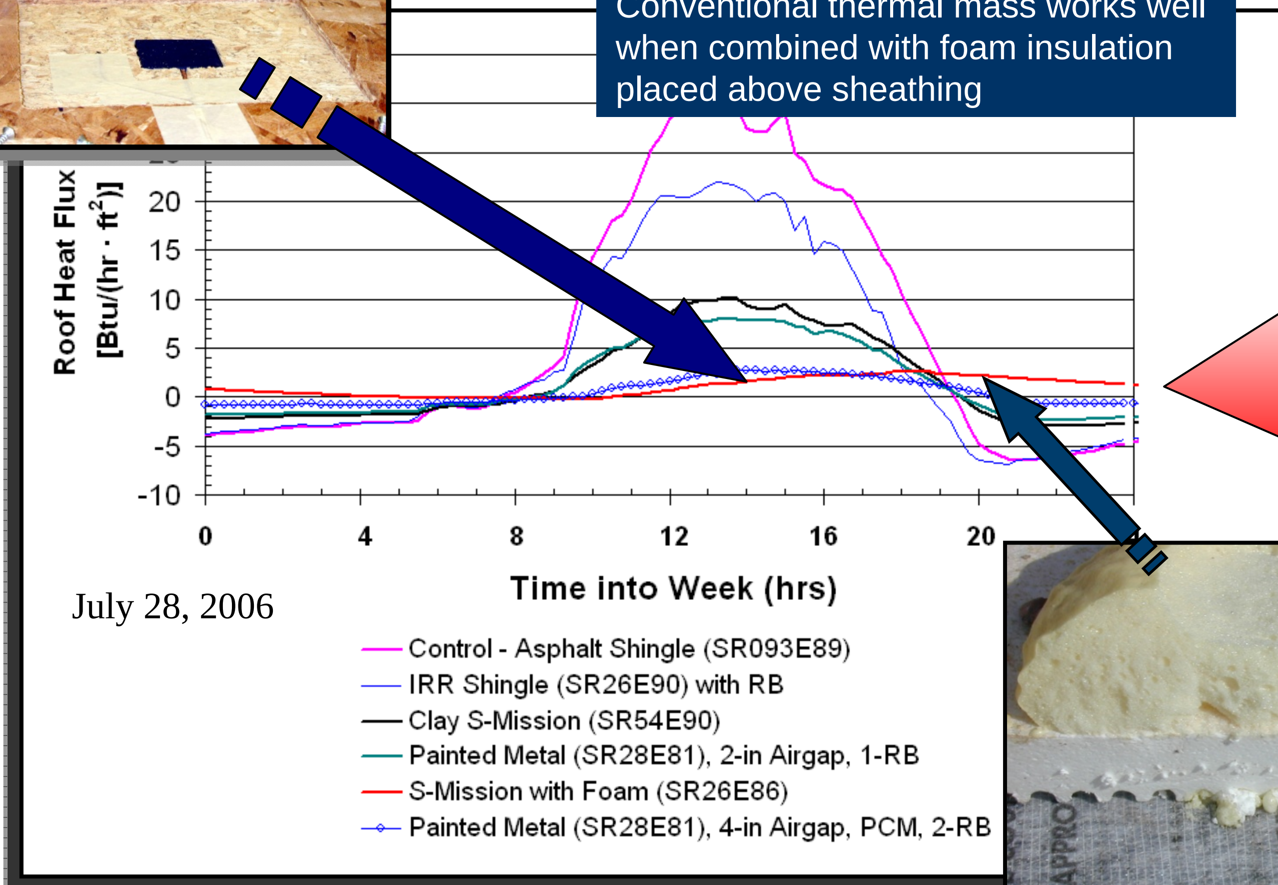
Conventional Mass, Above-Sheathing Ventilation and Above Deck Insulation

ECOSET SYSTEM

Conventional thermal mass works well when combined with foam insulation placed above sheathing



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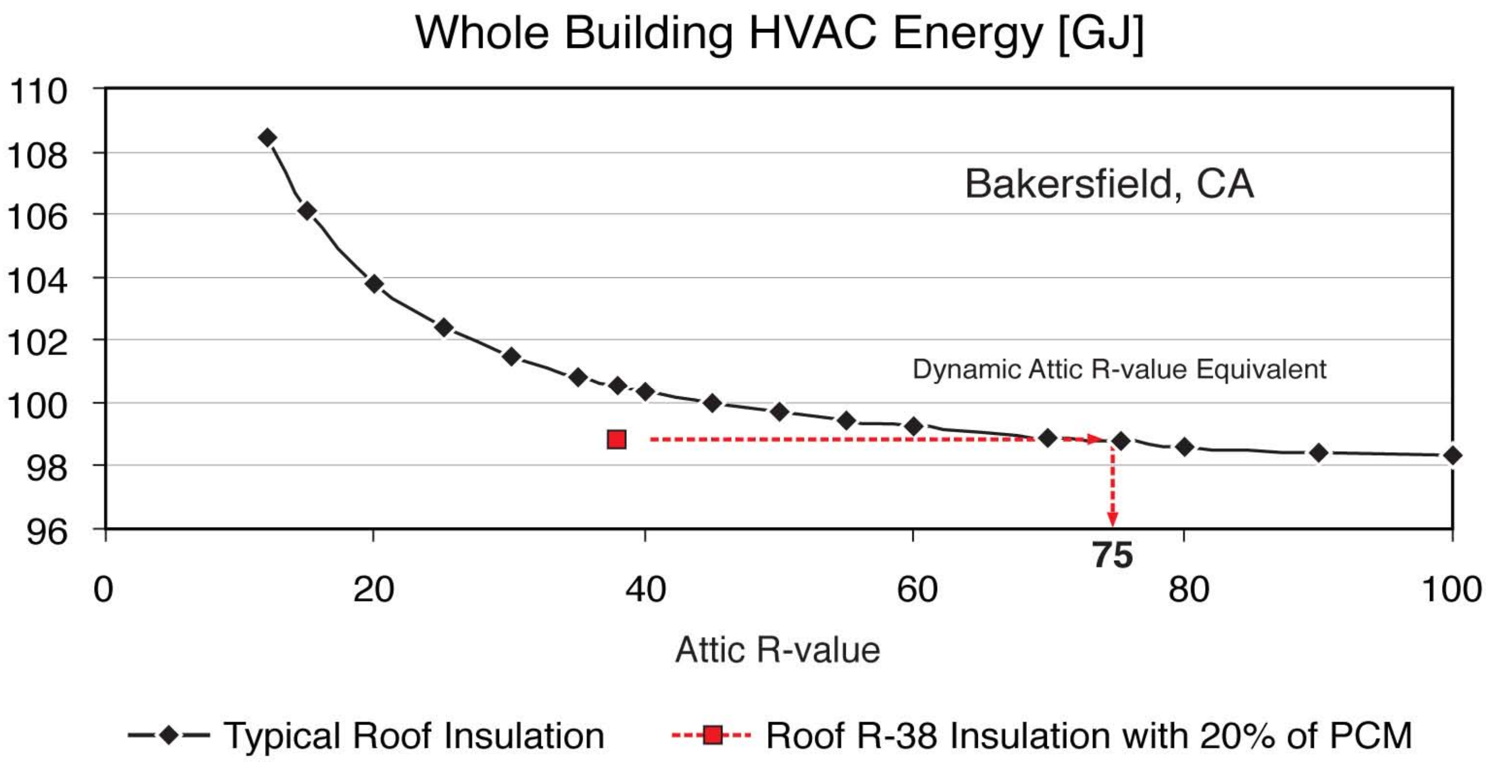
Energy Plus Simulation: PCM in Fiberglass Insulation Blown on Attic Floor

- About \$1.30 per ft^2 of attic floor would be spent to increase thermal resistance of conventional blown-in fiberglass insulation



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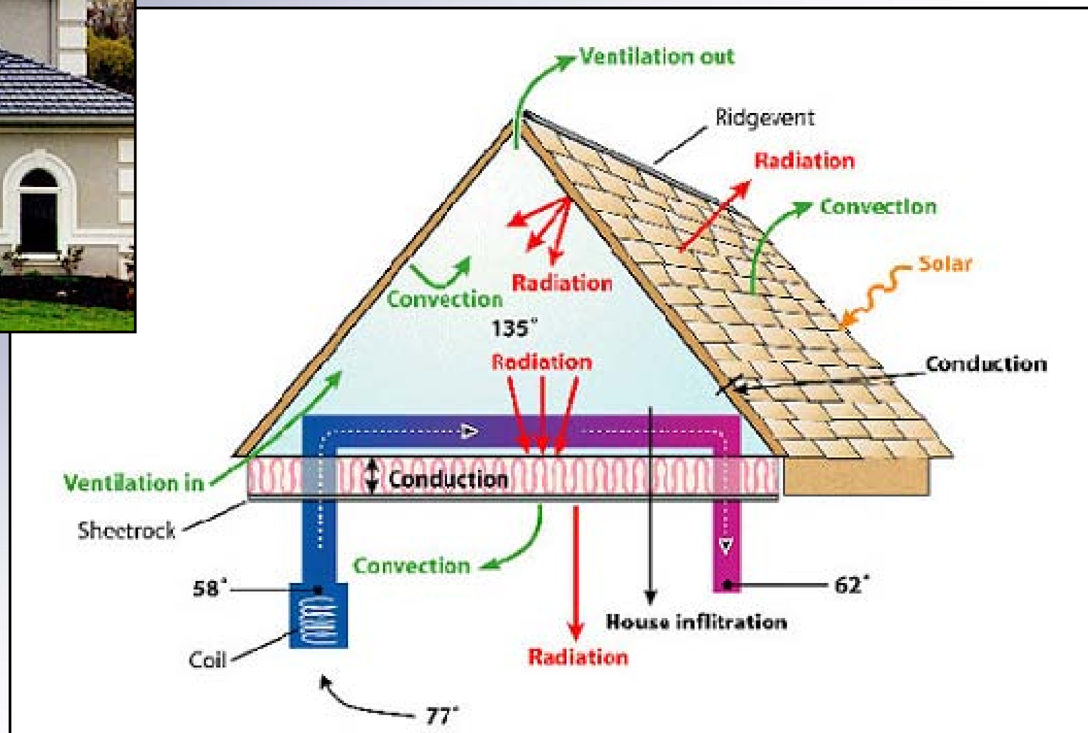
AtticSIM *(Attic Simulation)* Model

ASTM C 1340-99 Standard For Estimating Heat Gain of Loss Through Ceilings Under Attics

Roof Energy Balance



Florida Solar Energy Center

Miller et al. (2007), "*Natural Convection Heat Transfer in Roofs with Above-Sheathing Ventilation*."

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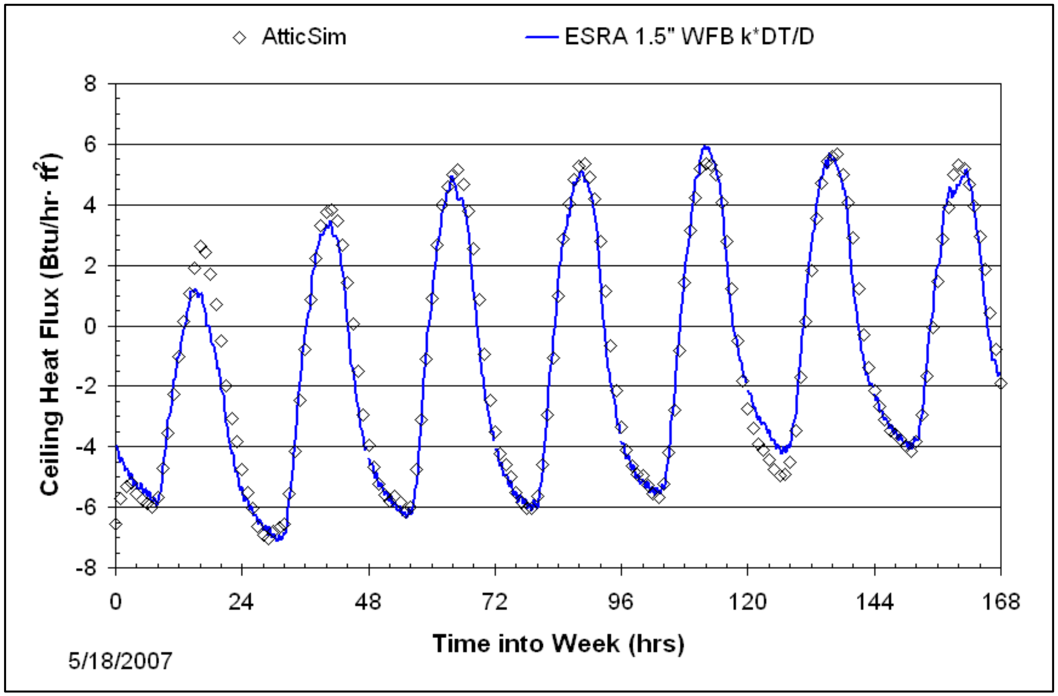
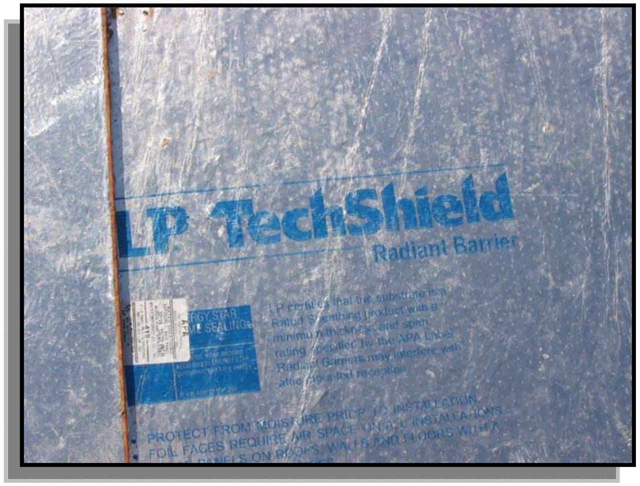
AtticSIM II Validations
Asphalt Shingle (SR093E89)

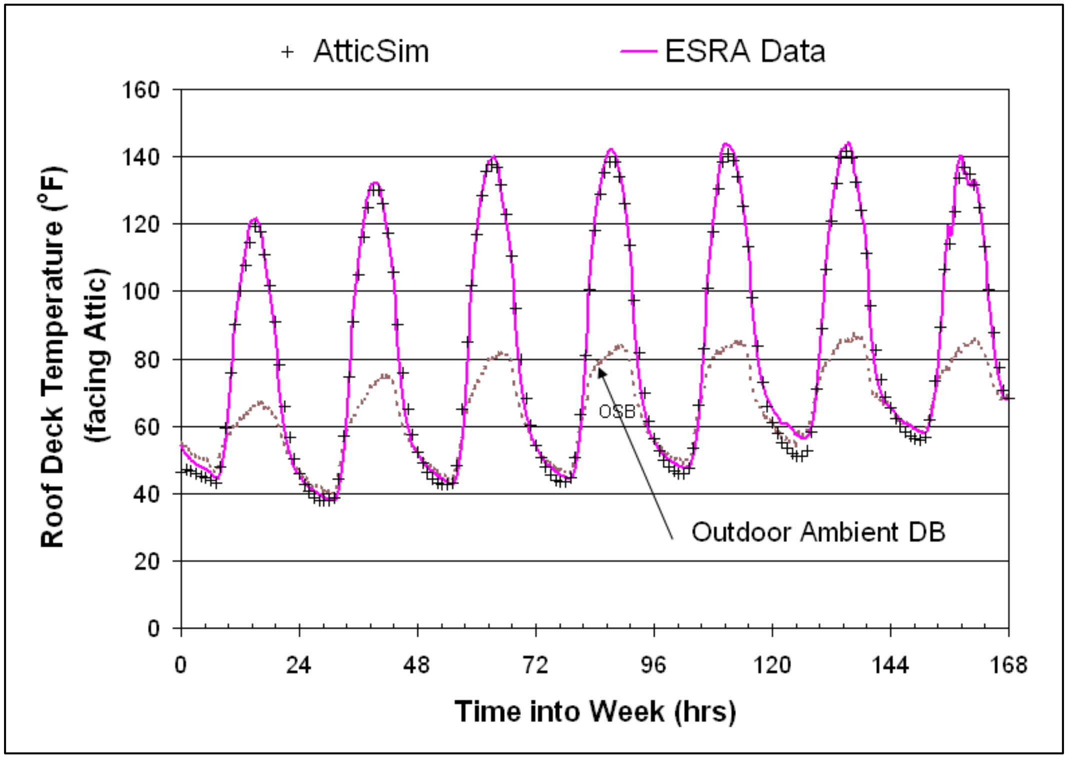
Ceiling Heat Flux



Asphalt Shingle (SR093E89) with radiant barrier facing attic space

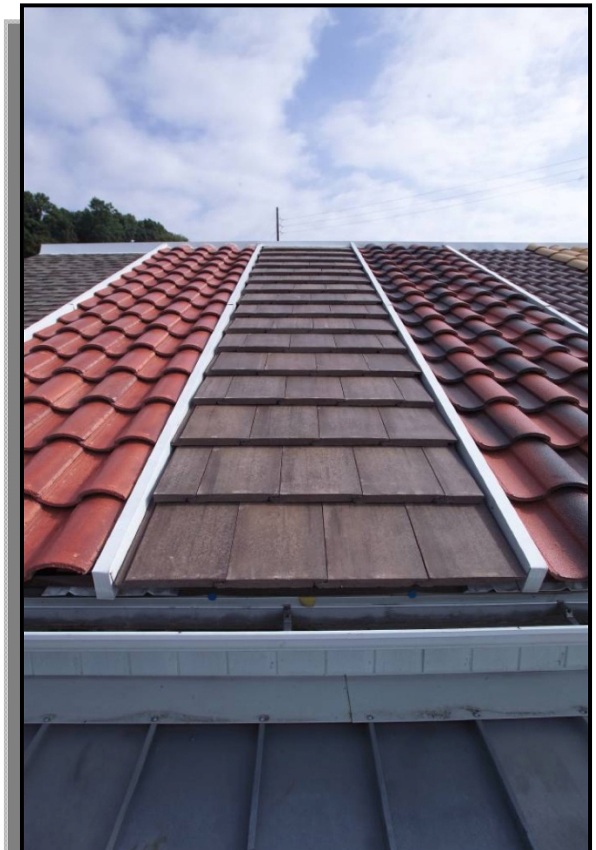
OSB with RB facing attic

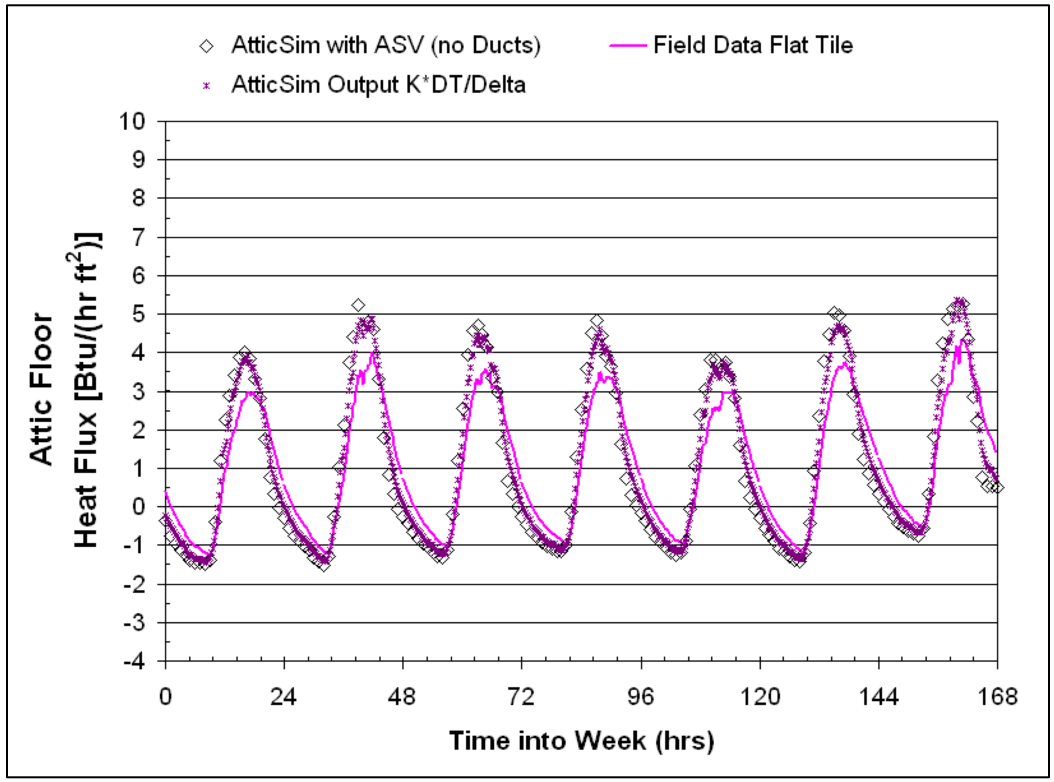




AtticSIM II Validations
Flat Concrete tile (SR13E83) on double batten system

Ceiling Heat Flux





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AtticSIM II Validations
S-Mission Clay Tile (SR54E90)

Heat flux through roof deck

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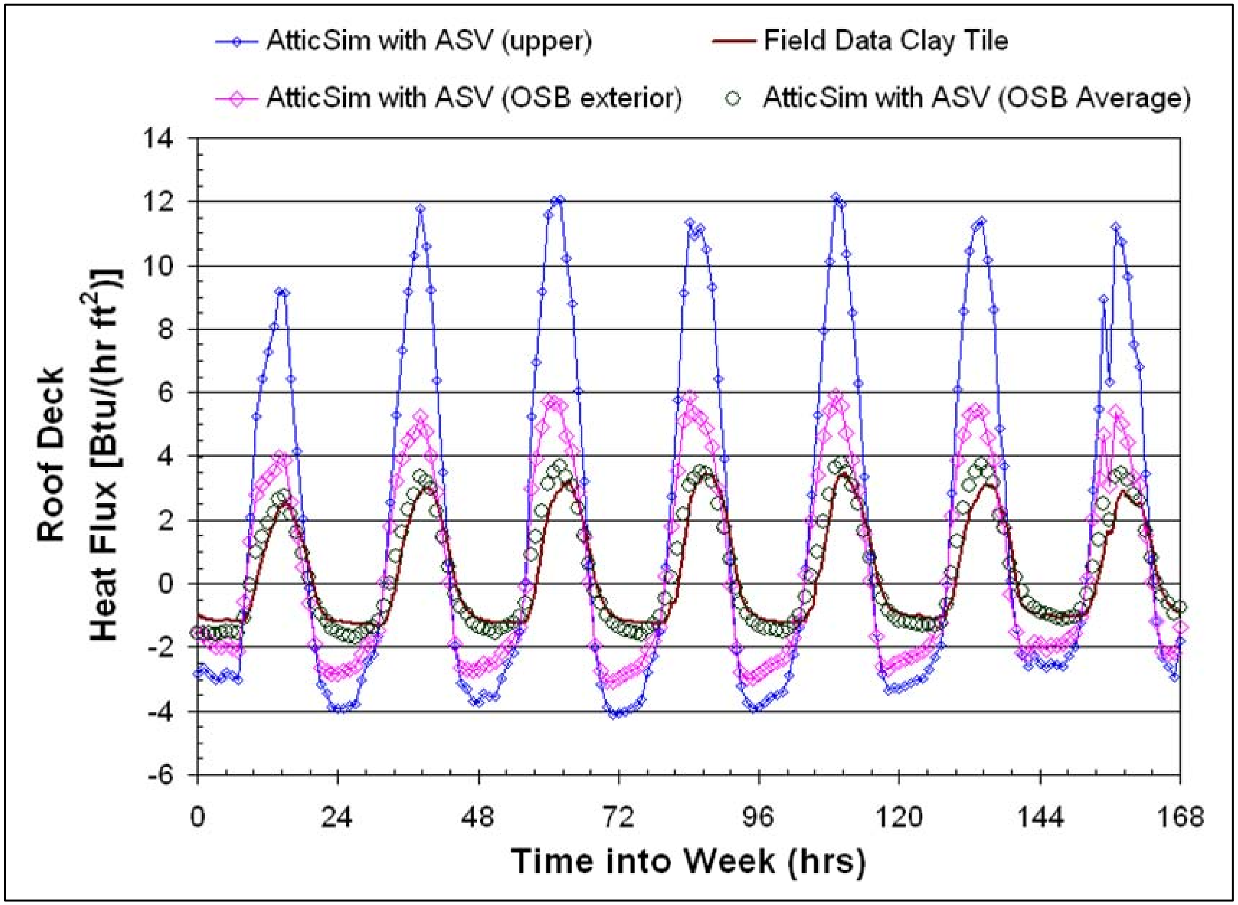
S-Mission Clay Tile (SR54E90) with 1¼-in EPS insulation on roof deck (Ecoset)

Heat flux through roof deck



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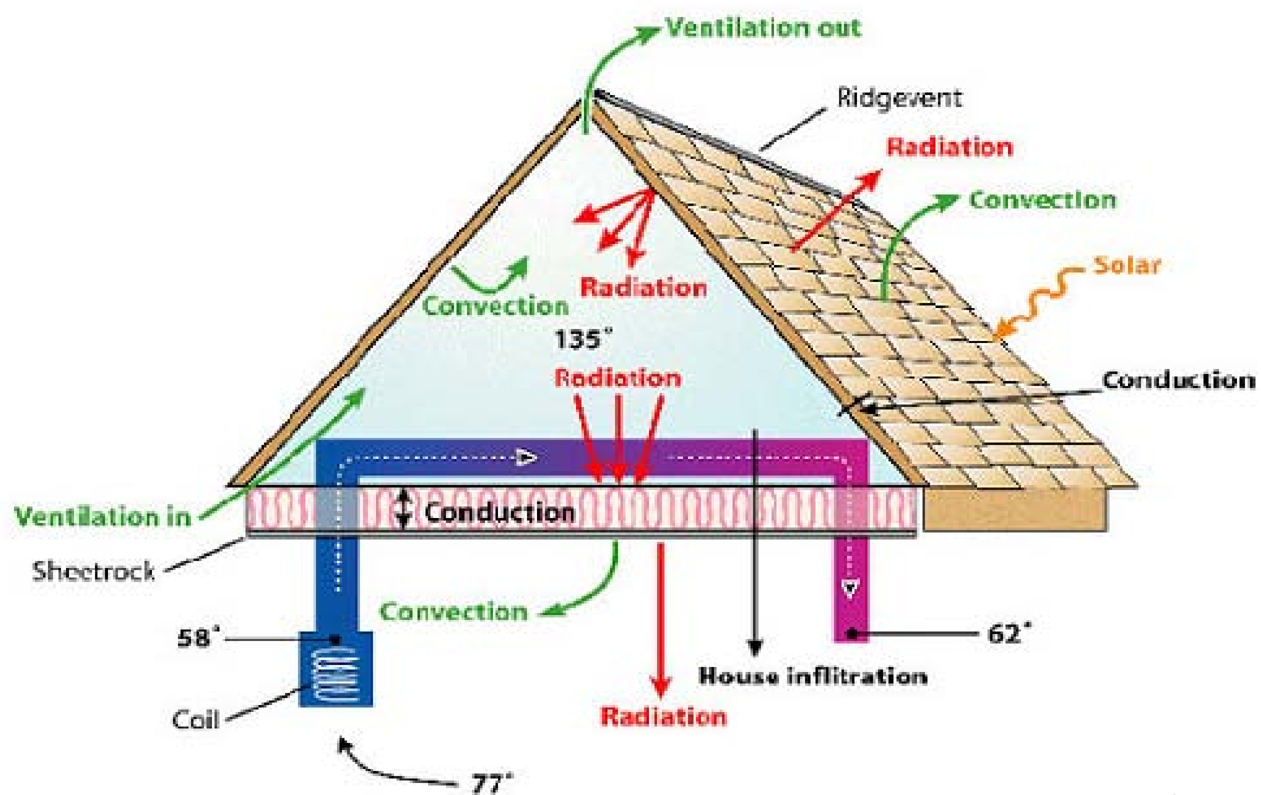
AtticSIM Simulations Include Duct System

Summer Duct Loss Cools Attic
Winter Duct Loss Heats Attic



Supply Duct 309 ft^2
Return Duct 176 ft^2

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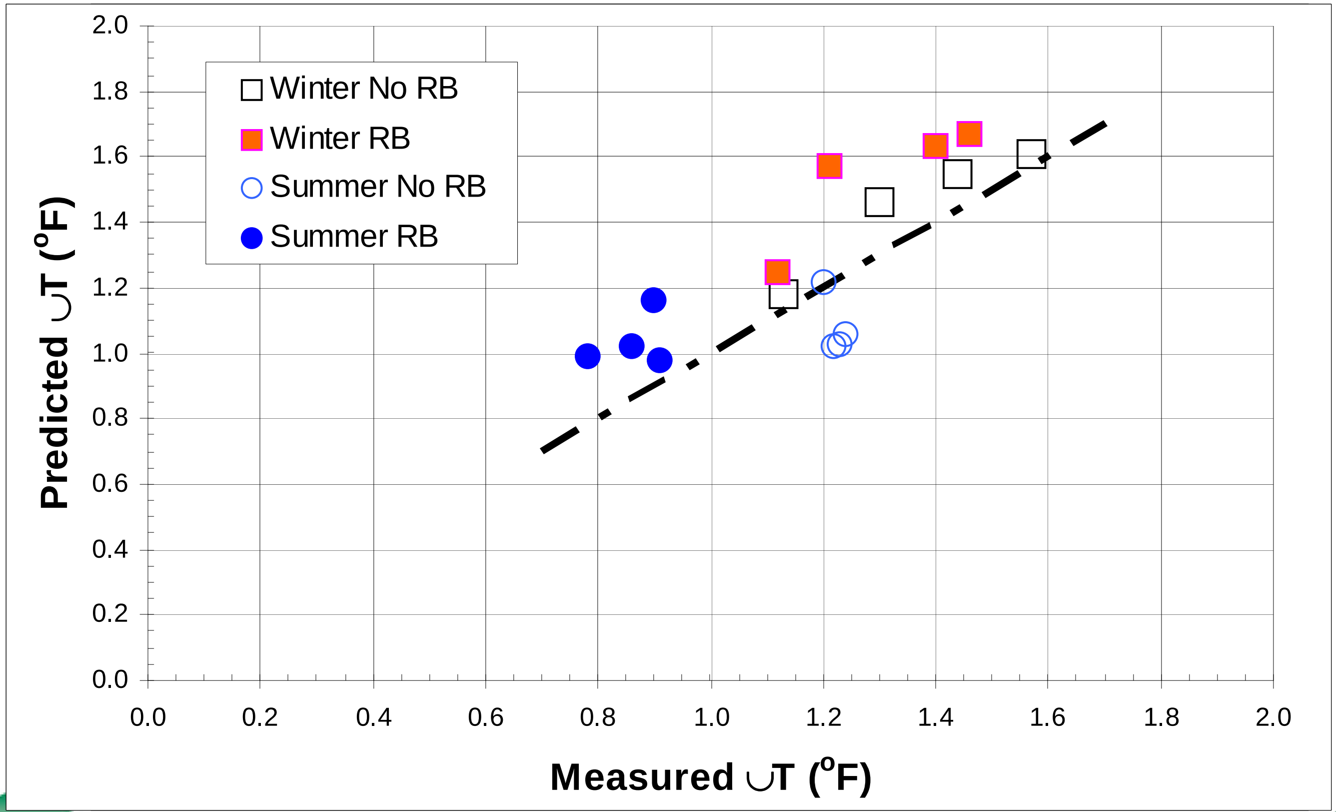
AtticSim Duct Validation

- Petrie, T.W., Wilkes, K.E. et al. (1998), "Effect of Radiant Barriers and Attic ventilation on Residential Attics and Attic Duct Systems: New tools for Measuring and Modeling."ASHRAE Transactions, June 1998.



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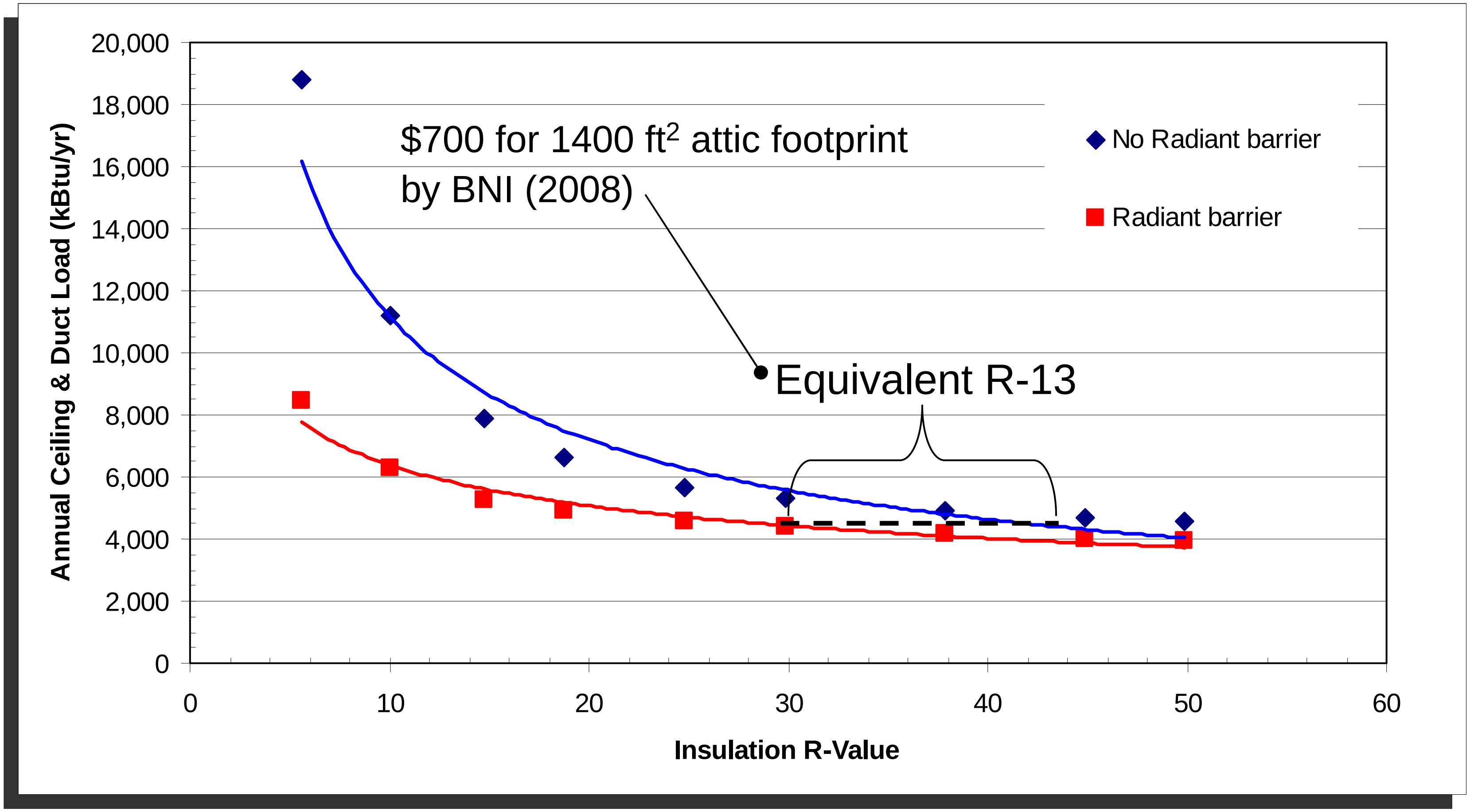
Equivalent R-Value of Ceiling Insulation for SR25E75 Roof with Inspected Ducts

Zone 09: **Attic Contains R-30 Insulation and AC Ducts with R-6 Insulation**



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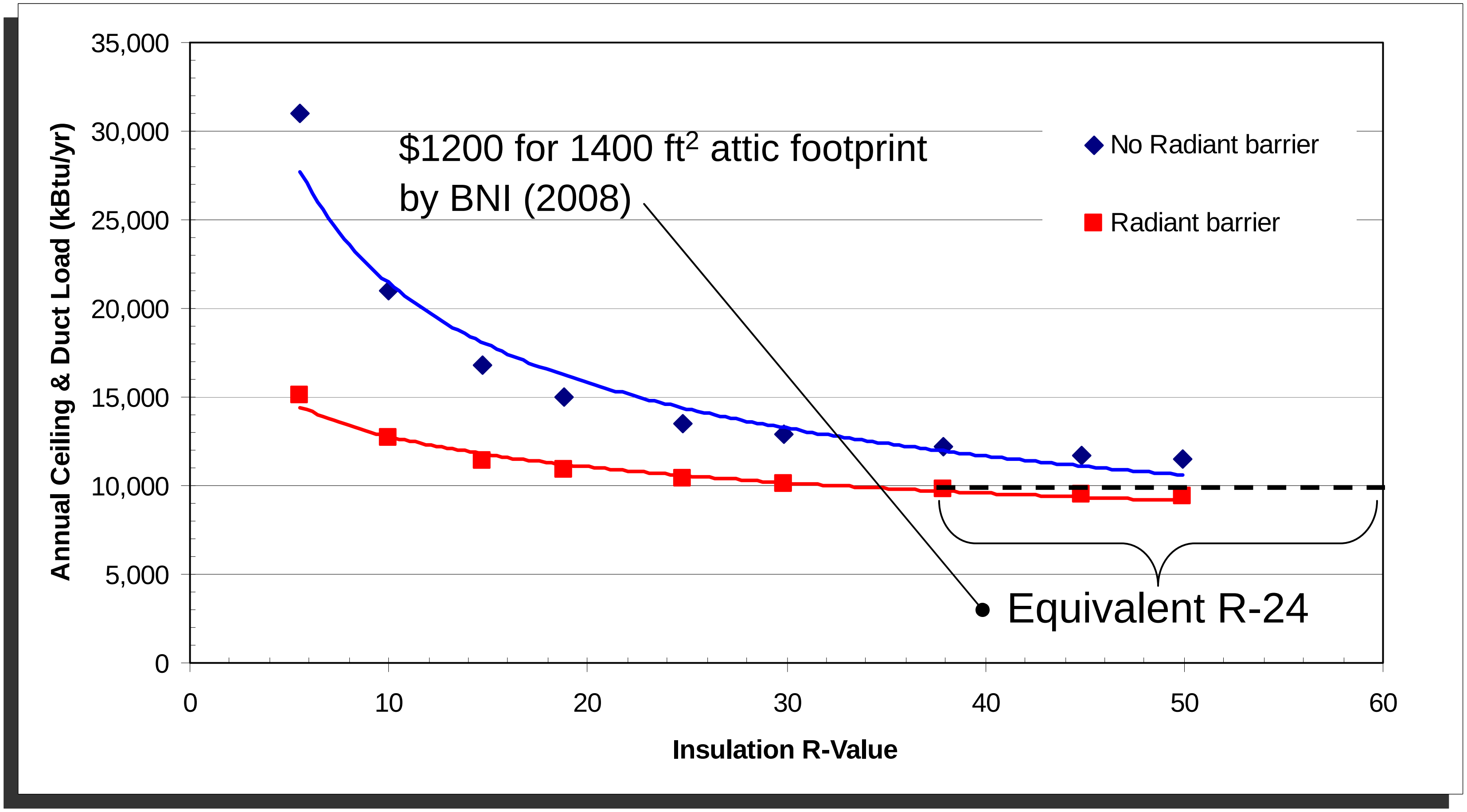
Equivalent R-Value of Insulation for SR25E75 Roof with Inspected Ducts

Zone 15: **Attic Contains R-38 Insulation and AC Ducts with R-8 Insulation**



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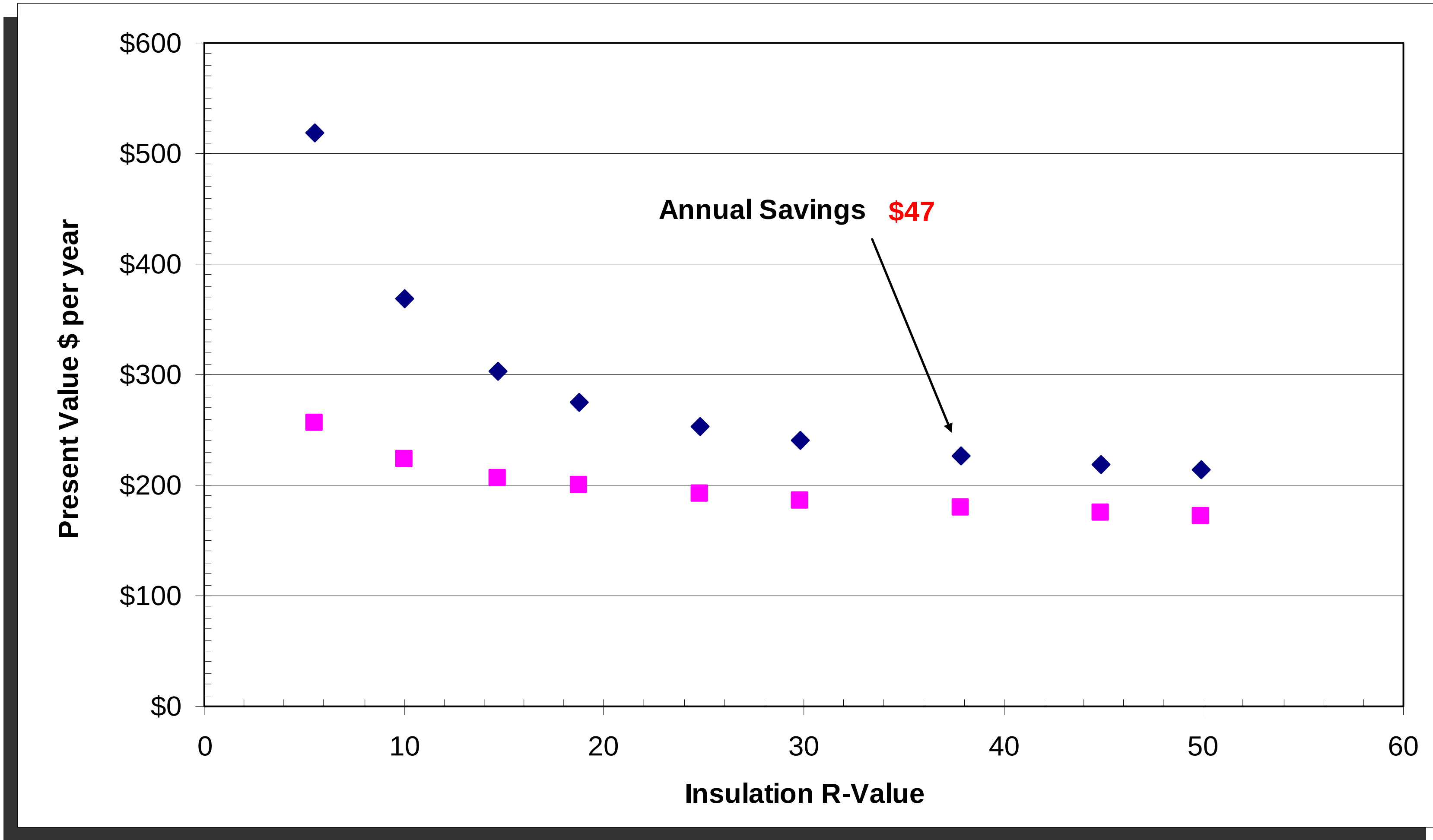
Annual Cost of Ceiling and Duct Energy based on TDV 30-yr forecast of $0.145 per kBtu $_{NG}$

Zone 15: **Attic Contains R-38 Insulation and AC Ducts with R-8 Insulation**



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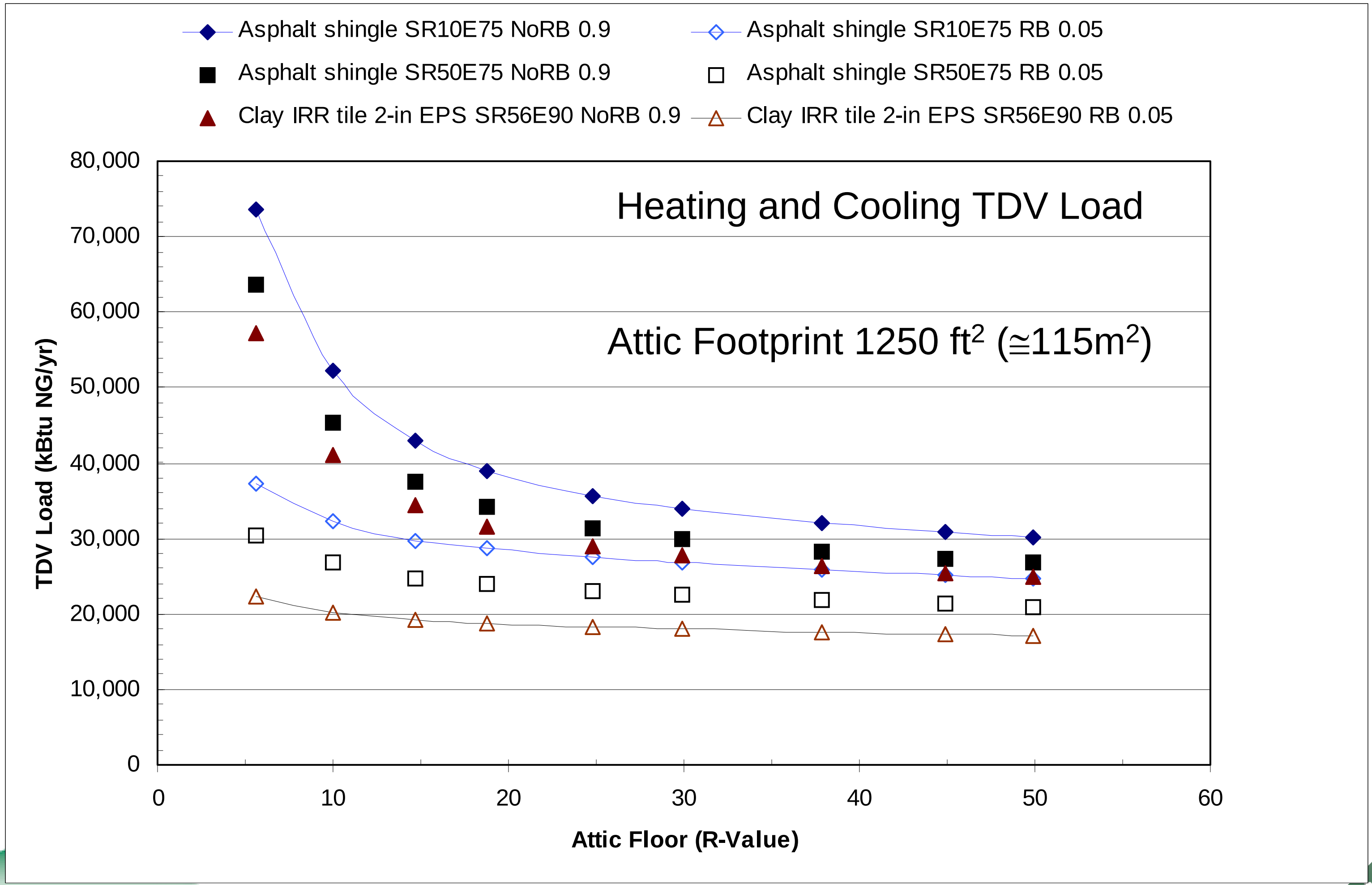
Radiant Barrier Yields Greater Return on Investment than ASV and or Low-E in Airspace

Zone 15: **Attic Contains R-38 Insulation and AC Ducts with R-8 Insulation**



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Retrofit Prototype Roof on Pre-1980 Construction Requires Attic Work

	ASHRAE		Above-Sheathing	Attic Plenum[2]		Duct System		Load Due to Roof & Attic		Energy[5] Costs Attributable to Roof & Attic	
City	Zone	SR / TE	Ventilation[1]	R-value	RB (TE)	R-Value	Air Leakage	Cooling (kWh/sq)	Heat (Therms/sq)	$NPV over 30-yrs per sq	PV$ per yr per sq
Chicago	05	0.05 / 0.75	NA	19	0.90	4.2	14%	25.6	17.9	$640	$33
		0.25 / 0.75	NA	19	0.90	4.2	14%	23.2	18.2	$639	$33
		0.28 / 0.81	1-in airspace	19	0.90	4.2	14%	18.7	18.0	$618	$32
		0.54 / 0.90	High profile[3]	19	0.90	4.2	14%	16.9	18.0	$614	$31
		0.54 / 0.90	High profile[3]	19	0.05	4.2	14%	8.2	14.5	$476	$24
		0.54 / 0.90	High profile[3]	38	0.05	4.2	14%	7.7	12.7	$417	$21
		0.54 / 0.90	High profile[3]	38	0.05	8	4%	6.0	10.4	$340	$17

[1] Air space fitted with one low-emittance surface. [2] Annual loads based on attic footprint of 1261 square feet (117.2 m^2).

[3] High profile clay tile spray adhered to 1¼-in (0.32-m) EPS foam; spray foam adhered EPS to roof deck.

[5] Energy is converted to a net present value cost ($NPV) using a 30-year projection based on EIA fuel price data for Chicago of 11.07¢ per kWh and $1.031 per therm NG.

Annual cost (PV$) computed using 3% discount rate over 30-yrs.

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Prototype Roof on Post-1980 Construction Yields Energy Savings of about 5 MBtu $_{NG}$ /yr

	Climate		Above-Sheathing	Attic Plenum[2]		Duct System		Annual Load (kBtu per yr)		TDV Energy[4] Costs	
City	Zone	SR / TE	Ventilation[1]	R-value	RB (TE)	R-Value	Air Leakage	Ceiling	Duct	$NPV over 30-yrs	PV$ per yr
Burbank	09	0.25 / 0.75	NA	30	0.05	6	4%	1,305	3,082	$1,266	$65
		0.28 / 0.81	1-in airspace	30	0.05	6	4%	1,162	2,425	$912	$47
		0.28 / 0.81	4-in airspace	30	0.05	6	4%	1,018	2,538	$976	$50
		0.25 / 0.75	NA	30	0.05	6	0%	1,316	2,574	$1,079	$55
Sacramento	12	0.25 / 0.75	NA	38	0.05	6	4%	1,988	6,356	$1,921	$98
		0.28 / 0.81	1-in airspace	38	0.05	6	4%	1,758	5,722	$1,655	$84
		0.28 / 0.81	4-in airspace	38	0.05	6	4%	1,729	5,599	$1,603	$82
		0.25 / 0.75	NA	38	0.05	6	0%	2,018	5,305	$1,636	$83
El_Centro	15	0.25 / 0.75	NA	38	0.05	8	4%	2,324	7,442	$3,528	$180
		0.28 / 0.81	1-in airspace	38	0.05	8	4%	1,950	6,354	$2,922	$149
		0.28 / 0.81	4-in airspace	38	0.05	8	4%	1,882	6,152	$2,819	$144
		0.54 / 0.90	High profile	38	0.05	8	4%	1,858	6,037	$2,771	$141
		0.54 / 0.90	High profile[3]	38	0.05	8	4%	1,751	5,744	$2,618	$134
		0.54 / 0.90	High profile[3]	38	0.05	NA	NA	2,159	0	$665	$34
		0.25 / 0.75	NA	38	0.05	8	0%	2,396	5,338	$2,649	$135

[1] Air space fitted with one low-emittance surface. [2] Annual loads based on attic footprint of 1261 square feet (117.2 m^2).

[3] High profile clay tile spray adhered to 1.25-in (0.32-m) EPS foam; spray foam adhered EPS to roof deck.

[4] TDV energy is converted to a net present value cost based on a 30-year fuel price forecast of $0.145 per kBtu $_{NG}$. Annual cost computed using 3% discount rate over 30-yrs.

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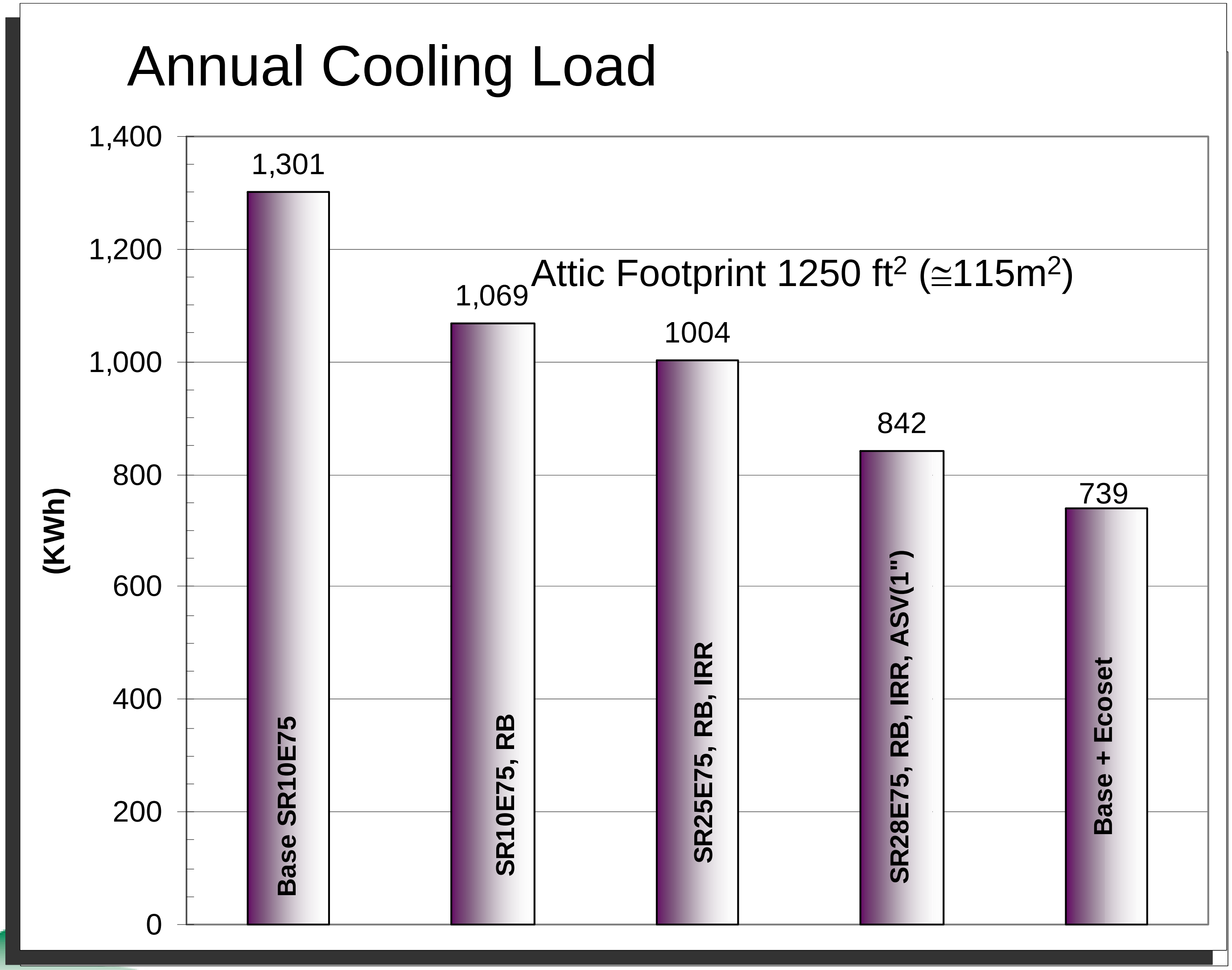
Space conditioning energy attributable to attics reduced almost by 50% of Post-1980 Constriuction

- Ranking of Roof and Attic Strategies



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CONCLUSIONS

Ductwork in Attics Are the Predominant Energy Loss

Radiant Barrier provides best opportunity for return on Investment

Smart Integration yields positive gains in roof and attic performance (regional design)

- **Reflective surfaces (low-e)**
- **Conventional insulations**
- **PCM insulations**
- **Above Sheathing Ventilation**
- **Cool Color Roofs**

GOAL → Reduce space conditioning attributable to attics by 50% of Building America regional benchmark (R50 Roof, R30 Wall.

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