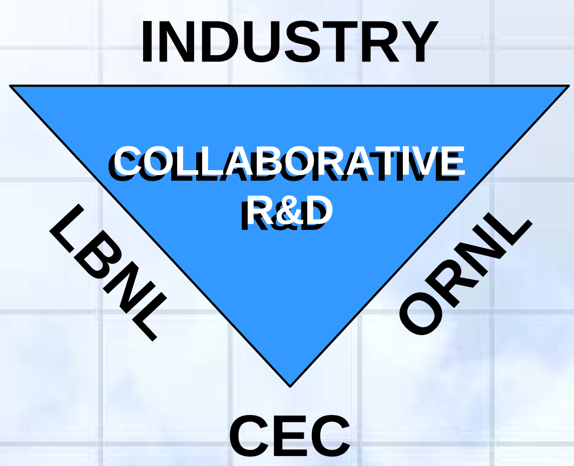
Market Deployment of Cool-Colored Roofing Materials

Project Advisory Committee (PAC) Meeting



Sponsored by the
California Energy Commission
(Project Manager: Chris Scruton)

13 September 2007
Hosted by MCA Tile at Ayres Inn Corona East, Corona, CA

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Project goals

- Help California utilities and public interest organizations develop incentive programs for residential cool roofs
- Help manufacturers of cool-colored materials deploy their products
- Measure the energy savings yielded by cool-colored roofing materials, and use these data to validate an energy savings calculator
- Educate consumers, contractors, engineers and architects by publicizing the results of the research

Project Advisory Committee (PAC) members

1. Asphalt Roofing Manufacturers Association (ARMA)
2. Cedar Shake and Shingle Bureau (CSSB)
3. Cool Roof Rating Council (CRRC)
4. Construction Engineering Research Lab (CERL/DOD)
5. Department of Energy (DOE)
6. Environmental Protection Agency (Energy Star/EPA)
7. EPA San Francisco Office
8. Florida Solar Energy Center (FSEC)
9. Pacific Gas and Electric Company (PG&E)
10. Roof Coating Manufacturers Association (RCMA)
11. Tile Roofing Institute (TRI)
12. Southern California Edison Company (SCE)

Industrial partners

- 3M Industrial Minerals
- Akzo Nobel Coatings
- American Rooftile Coatings
- BASF Industrial Coatings
- CertainTeed
- Custom-Bilt Metals
- Ferro
- GAF/Elk Corporation
- Hanson Roof Tile
- ISP Minerals
- MCA
- MonierLifetile
- Owens Corning
- Steelscape
- Shepherd Color

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Project team

- Lawrence Berkeley National Lab (LBNL)
  - Hashem Akbari (Project Director and Technical Lead) H_Akbari@LBL.gov
  - Paul Berdahl PHBerdahl@LBL.gov
  - Ronnen Levinson RMLevinson@LBL.gov
- Oak Ridge National Lab (ORNL)
  - André Desjarlais (Technical Lead) yt7@ORNL.gov
  - Bill Miller wml@ornl.gov

Technical tasks

- 2.4 Help California utilities develop cool roofing programs for their residential customers
- 2.5 Help manufacturers of cool-colored materials deploy their products
- 2.6 Technology transfer activities

2.4 Help California utilities develop residential cool roofing programs

- Objective
  - Help California utilities develop cool roofing programs for their residential customers
- Deliverables:
  - Work with California utilities to help them develop incentive programs
  - Documented in quarterly progress reports
- Schedule: 08/20/2006 – 06/20/2008
- Funds expended: 40%

Activities

- Provided answers to inquiries of the utilities and their customers

2.5 Help manufacturers of cool-colored materials deploy their products

- Objective: Continue working with roofing manufacturers to deploy and market their cool products
- Subtasks:
  - Enhance the solar reflectance of non-white roofing materials
  - Develop tools to measure solar reflectance for factory quality control
  - Correlate the solar reflectance of a shingle to that of its constituent granules
  - Develop industry-consensus energy-savings calculator
  - Conduct natural exposure testing in California
  - Conduct natural exposure testing at ORNL
  - Monitor building cooling energy use in Southern California to evaluate new cool-colored roofing materials for validation of the industry-consensus energy savings calculator

2.5.1 Enhance the solar reflectance of non-white roofing materials

- Objective: Continue working with roofing manufacturers to enhance the solar reflectance of their products
- Deliverables:
  - Prototype cool-colored roofing products with increased solar reflectance
- Schedule: 07/20/2006 – 07/20/2008
- Funds expended: 15%

Improving solar reflectance of roofing materials: methods under investigation

- Wood
  - Use clear surface coating (e.g., varnish) to protect wood roofing from UV damage (discoloration, loss of NIR reflectance)
- Concrete tiles
  - Evaluate cost effectiveness of replacing gray cement with white cement for through-the-body application of cool color pigments
  - Compare cost and durability of coating technologies (polymer, cementitious) for surface coloring tiles
- Granules & shingles
  - Check cost, availability of whiter aggregate
- Clay tiles
  - Characterize absorption, scattering coefficients of pigmented glazes to identify hot, cool coatings
  - Investigate effects of firing environment (e.g., O_2 availability) on chemistry, NIR reflectance of uncoated red clay tile

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

2.5.1 Status

- Several new prototypes have been produced by industry and characterized by LBNL
- Task 2.5.1 activity (solar reflectance improvement) has been limited by our focus on Task 2.5.2 (solar reflectance measurement)
- Over next 6 months, we will continue working with partners to
  - Develop workplans
  - Prepare samples
  - Characterize performance
  - Improve prototypes

2.5.2 Develop tool to measure solar reflectance for factory quality control

- Objective: Develop instrument to measure product solar reflectance for quality control in roofing factories
- Deliverables:
  - A prototype instrument and protocol for measuring solar reflectance of variegated products in the factory
- Schedule: 07/20/2006 – 07/20/2008
- Funds expended: 20%

Tool design proposal and feedback from March 2007 PAC meeting

- Proposal: LBNL to design new reflectometer to measure product solar reflectance in factories
  - inexpensive (<$5K)
  - self-illuminated
  - fast (< 1 min)
  - medium-area samples (~ 0.5 - 1 m^2)
  - modest accuracy (±0.05?) sufficient to distinguish between cool and conventional products of similar appearance
- Response: industrial partners asked for more accurate instrument
  - want accuracy (±0.01?) sufficient to measure and report solar reflectance of product

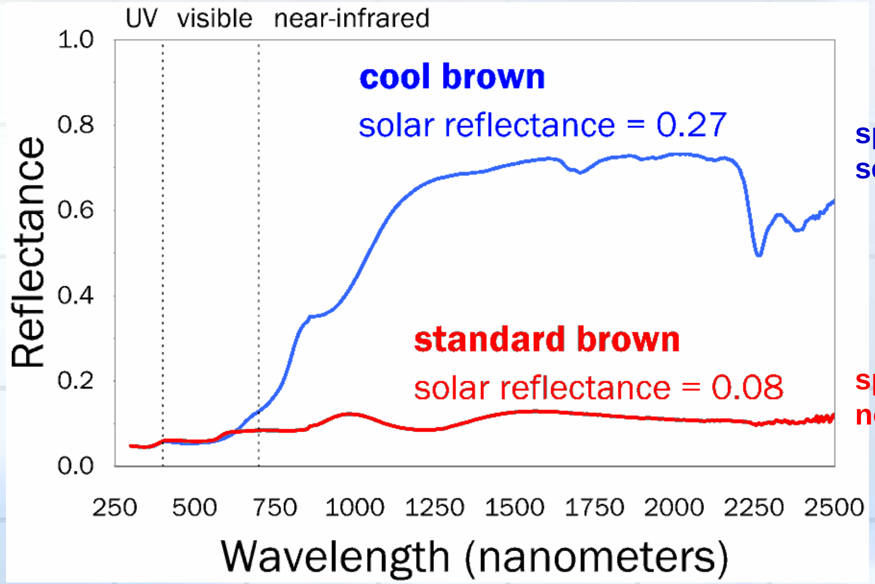
UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

New design: build tool that uses D&S Solar Spectrum Reflectometer

- Use Devices & Services Solar Spectrum Reflectometer (SSR) to accurately and rapidly measure solar reflectance of medium-area cool-color surfaces
- Advantages:
  - many of our industrial partners already own an SSR
  - SSR is rapid, self-illuminated, and accurately measures solar reflectance of conventional surfaces
- Challenges
  - SSR can mischaracterize the solar reflectance of "spectrally selective" surfaces (e.g., cool colors)
  - SSR samples small area (about 5 cm^2)

Approach: improve SSR accuracy, enlarge SSR sample area

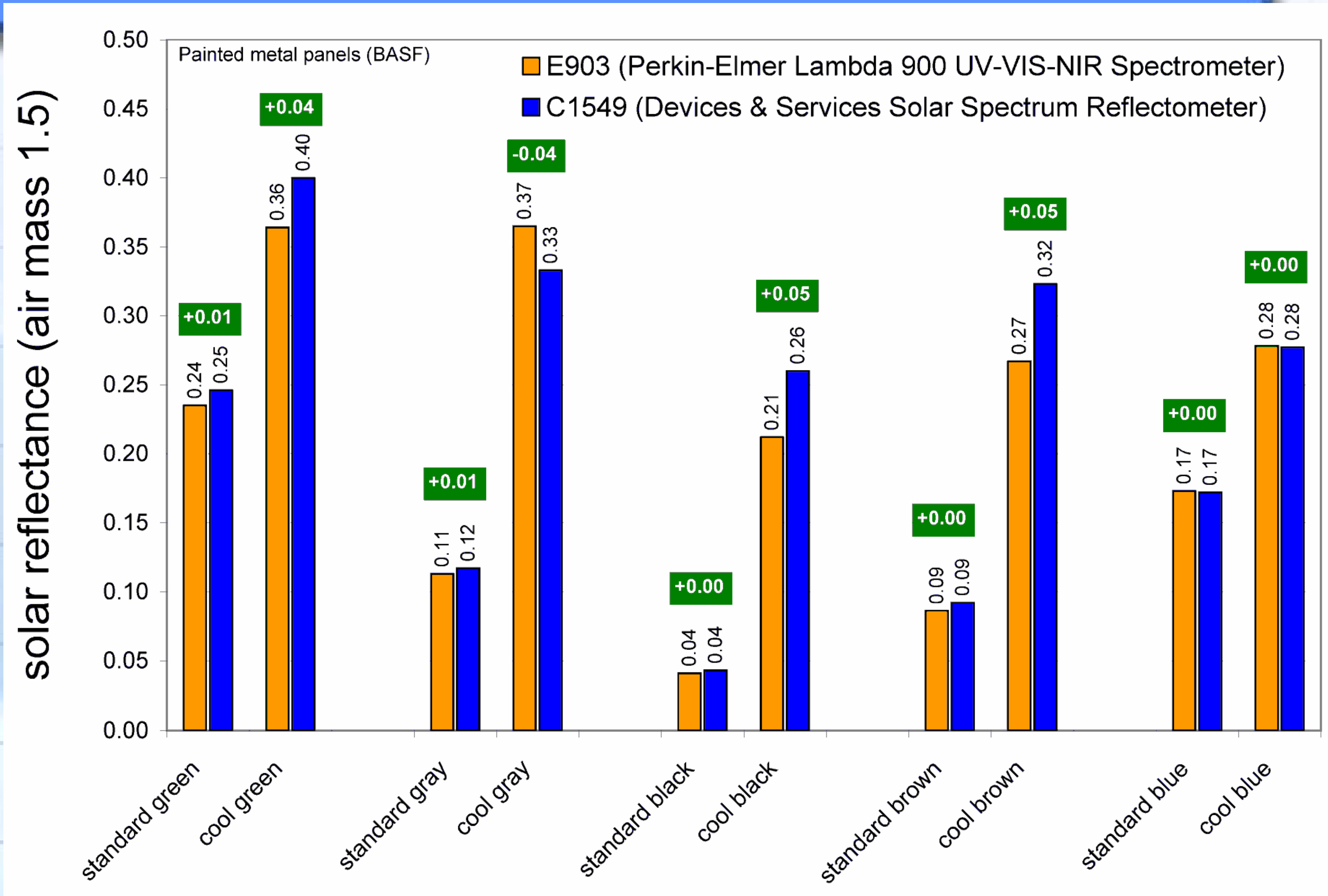
A. Diagnose and correct error in SSR that can cause inaccurate measurement of the solar reflectance of spectrally selective surfaces (cool colors)



B. Enlarge area sampled by SSR to better characterize nonuniform surfaces (e.g., shingles surfaced with blended granules)

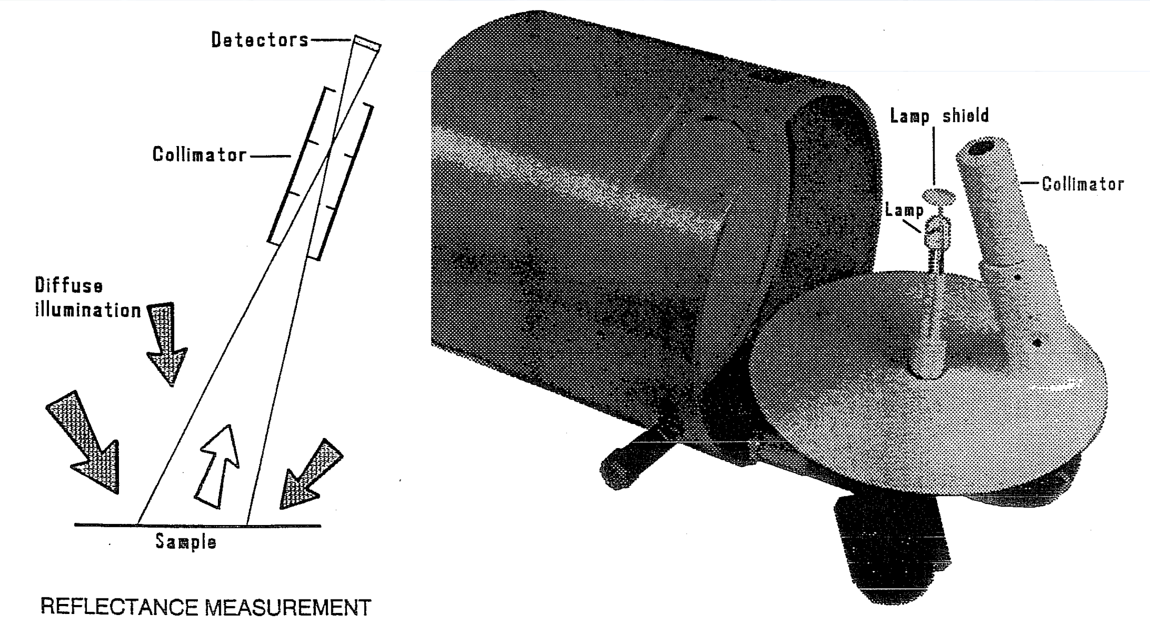
blended-granule fiberglass asphalt shingle

SSR (ASTM C1549) can significantly misread solar reflectances of cool colors



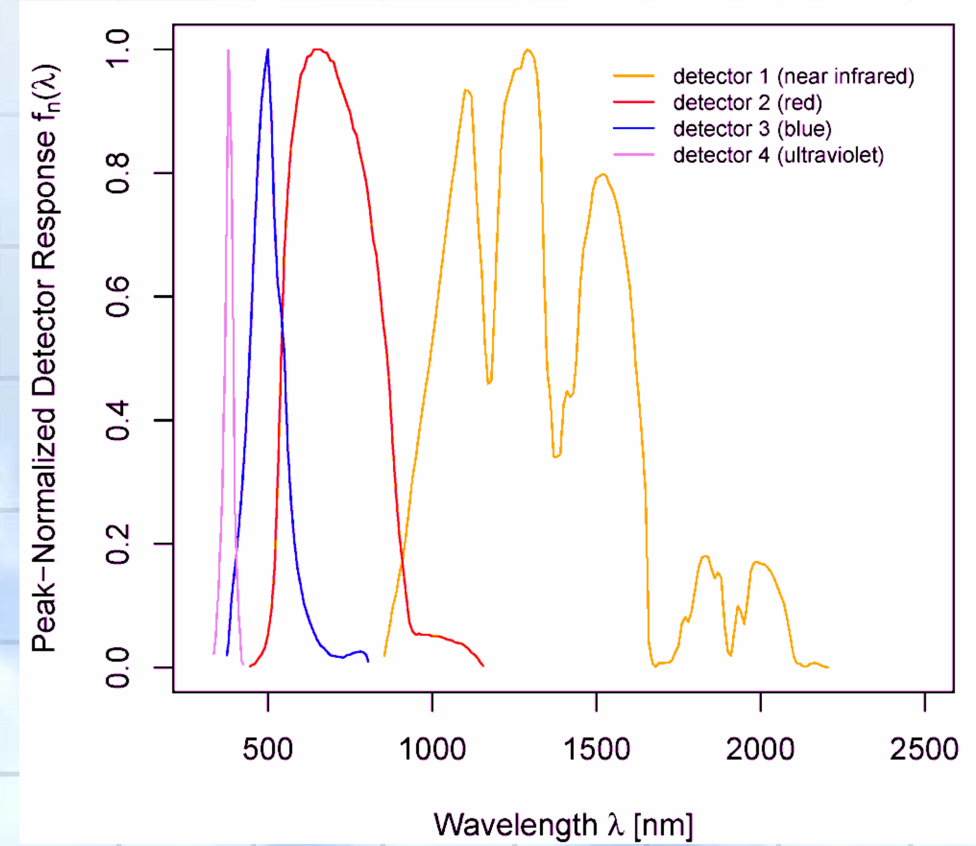
Design of Devices & Services
Solar Spectrum Reflectometer

- Sample illuminated w/lamp light diffusely reflected from white cavity
- Reflected irradiance measured by four filtered detectors
- Lamp, white cavity, filtered detectors simulate pyranometer measurement of reflected sunlight

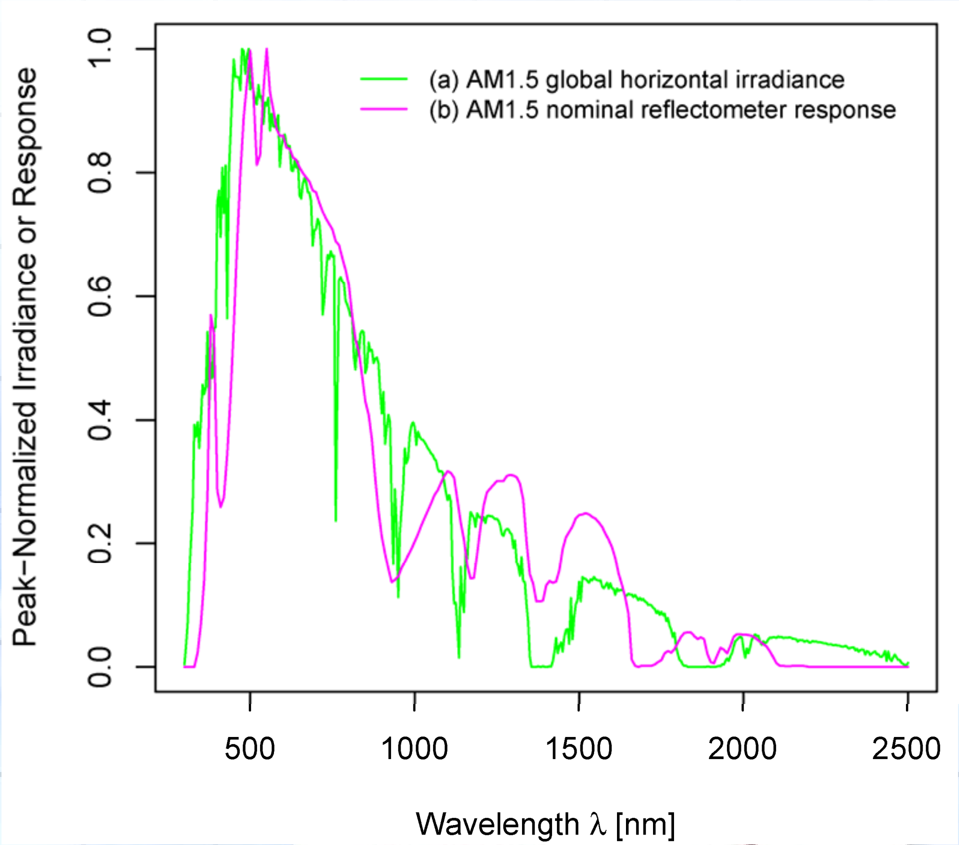


Combined responses of 4 filtered detectors mimic shape of solar spectral irradiance

SSR detector responses, left to right:
L4 (UV), L3 (blue), L2 (red), L1 (NIR)



SSR AM1.5 response =
0.343 L1 + 0.416 L2 + 0.210 L3 + 0.031 L4



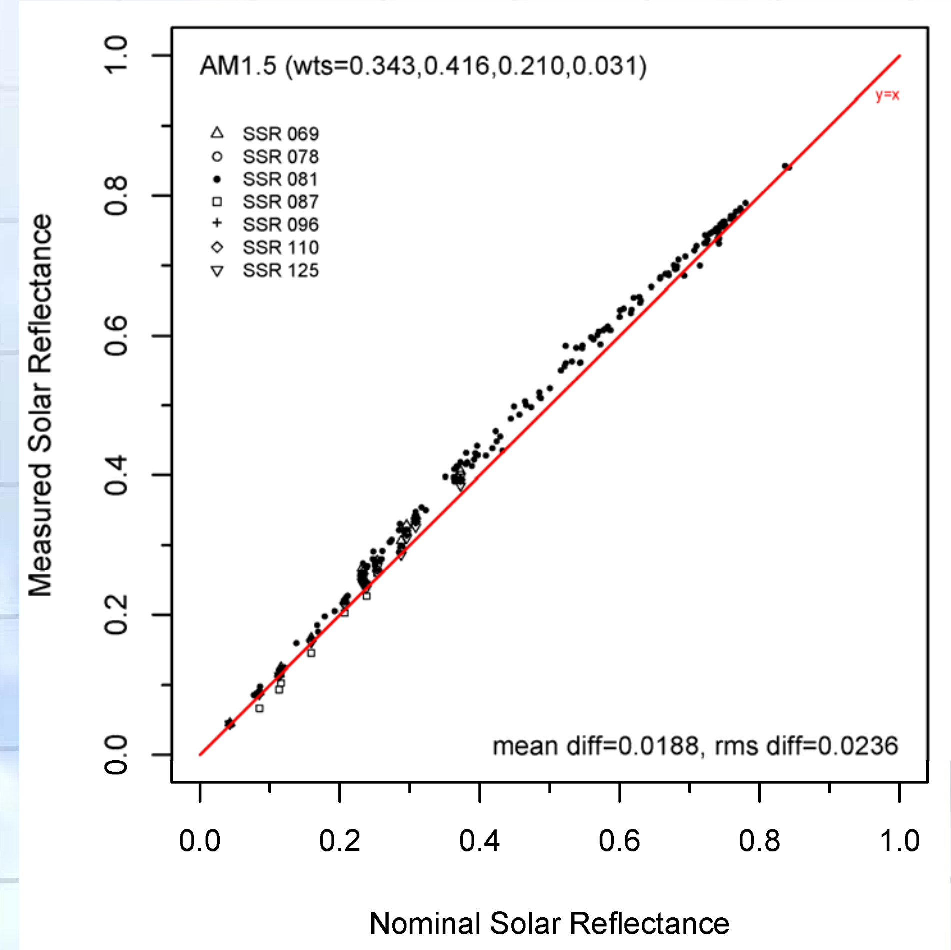
Round-robin tests of SSR (ASTM C1549)

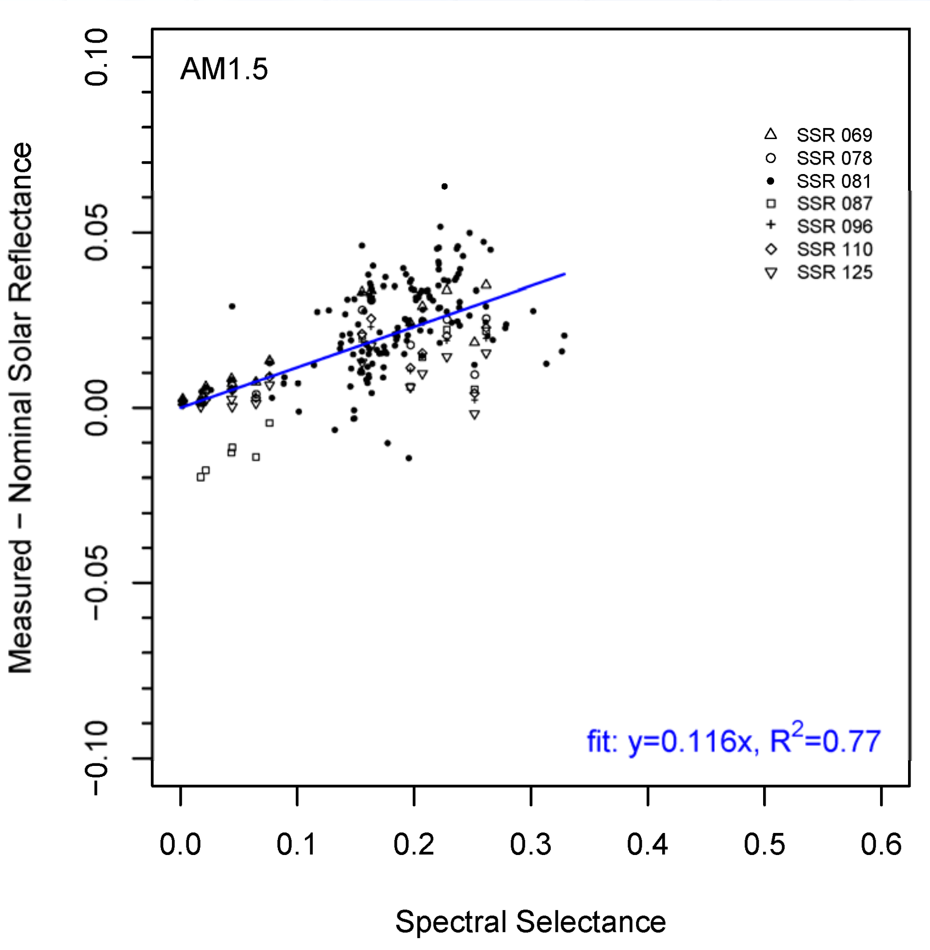
- LBNL measured solar spectral, SSR reflectances of 150+ samples
- LBNL also organized unofficial round-robin test of SSR
  - Seven SSRs (LBNL, ORNL, ISP, MCA Tile, BASF, Certainteed [2])
  - 14 painted metal samples (seven standard, seven cool)
  - Participants reported L1, L2, L3, L4, AM1.5
- SSRs well estimated AM1.5 solar reflectance of conventional colors (measured solar reflectance ~ nominal solar reflectance)
- SSRs overestimated AM1.5 solar reflectance of most cool colors (measured solar reflectance > nominal solar reflectance)

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

SSR solar reflectance measurement error increases with spectral selectance

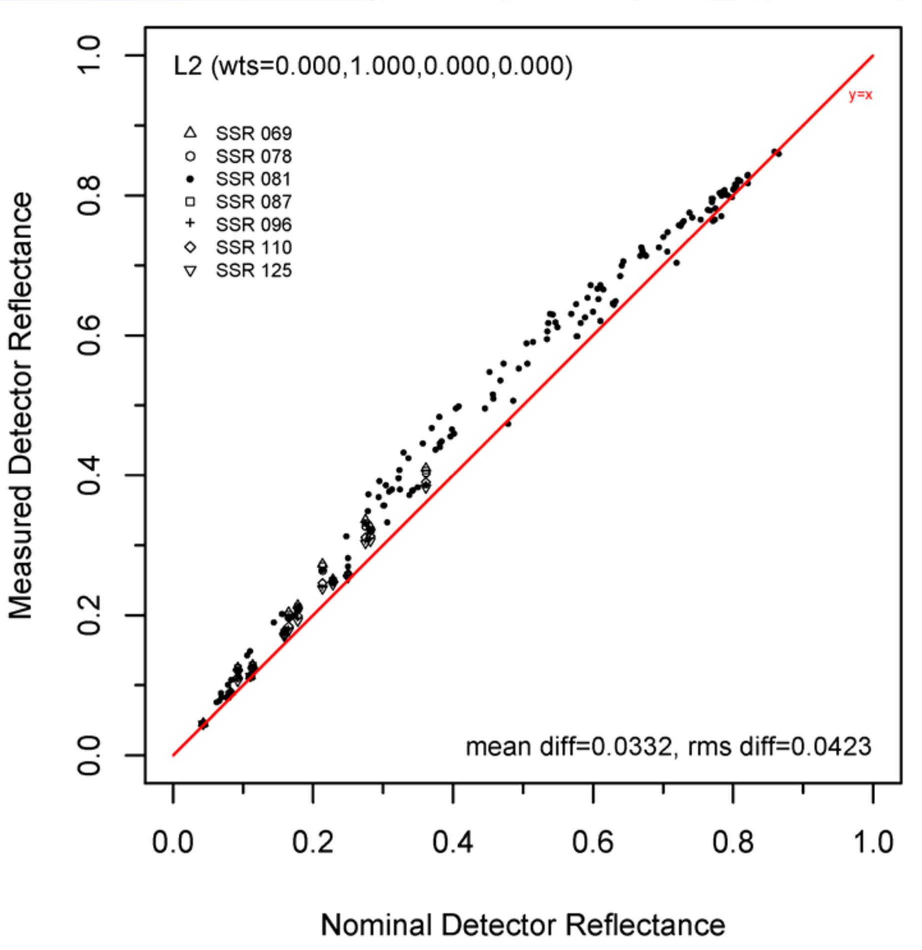
spectral selectance = $\mathrm{RMS}\left(r[\lambda_i] - \bar{r}\right)$; is greatest for cool colors

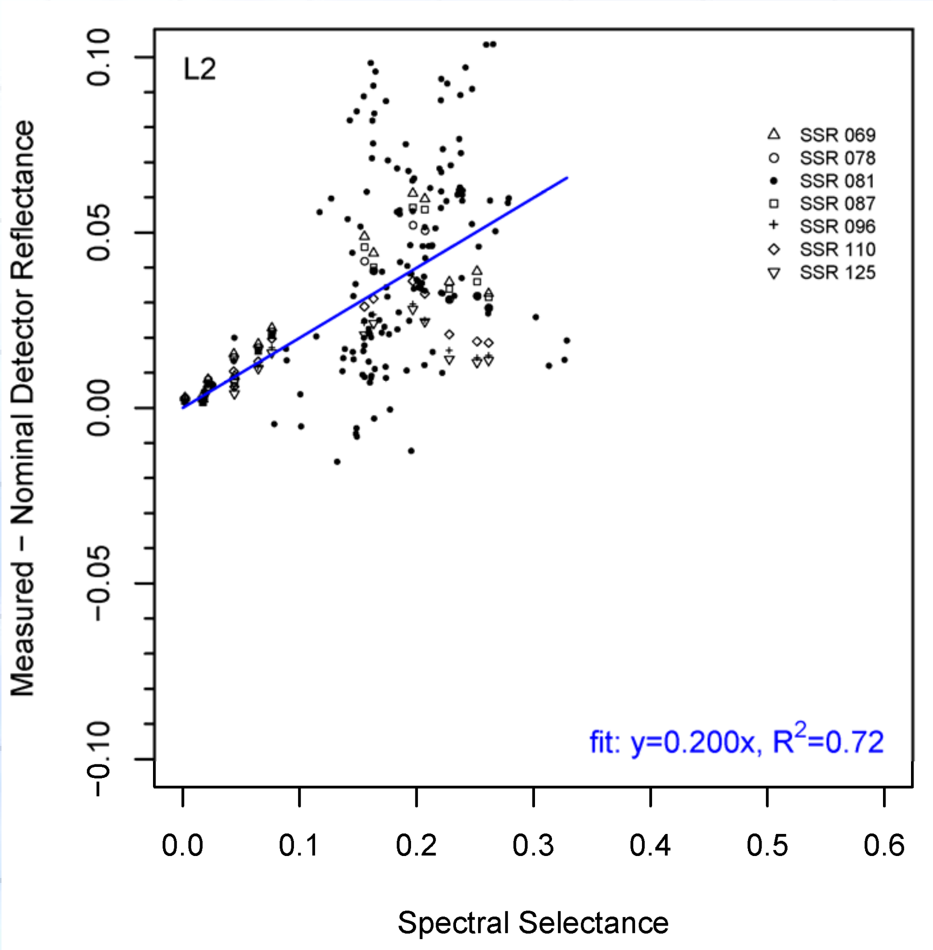




LBNL traced problem to performance of SSR's L2 ("red") detector

L2 detector is overly responsive to NIR light; other detectors OK

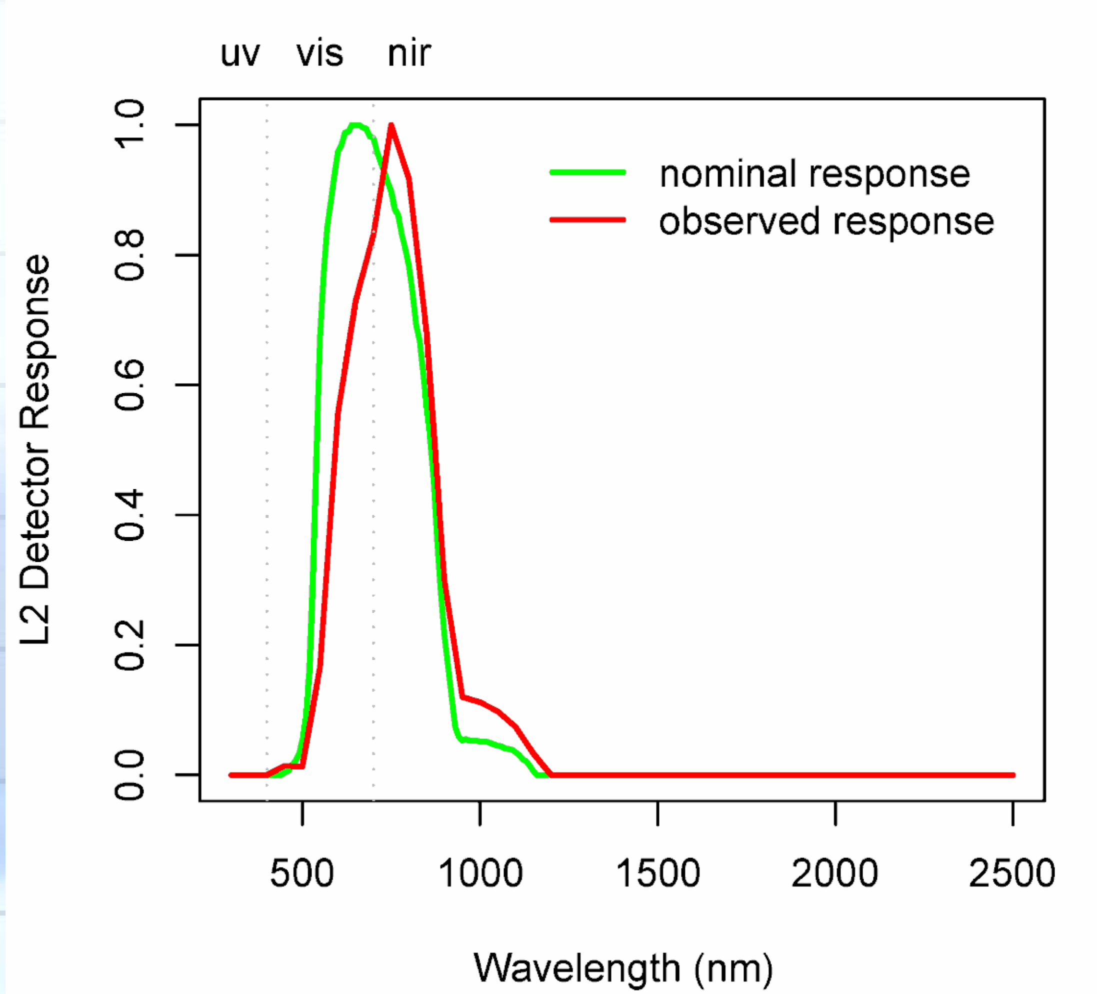




UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Devices & Services confirmed, identified problem with response of SSR's L2 detector

- LBNL shared measurements and collaborated with SSR manufacturer Devices & Services (Dallas, TX)
- D&S determined that the L2 detector is less responsive to red light and more response to NIR light than intended (see figure)
- D&S thinks that a firmware error reduces lamp current, making the filament cooler and the light more NIR-rich than intended

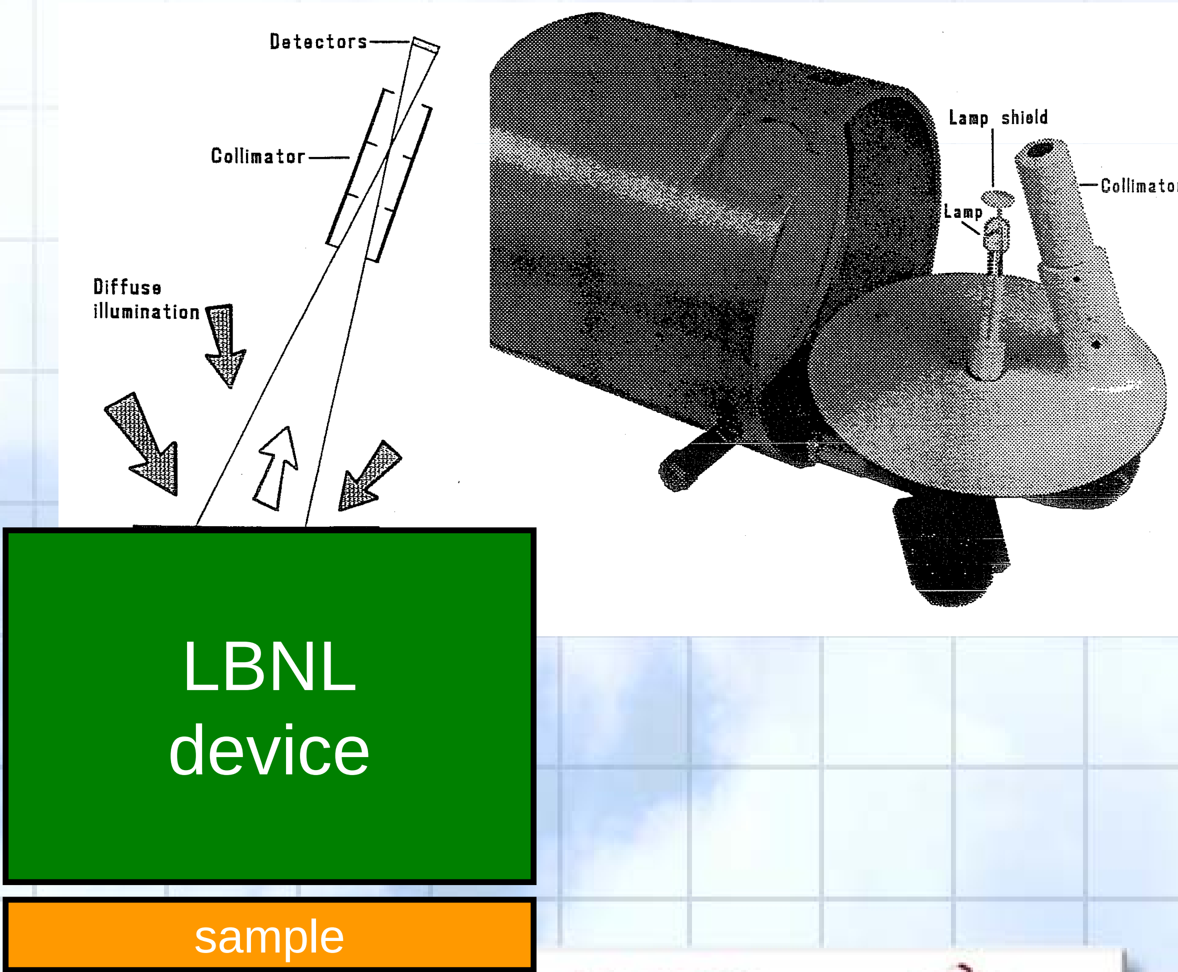


Devices & Services will update SSR to correct reflectance measurements

- D&S proposes to replace the firmware and some resistors to (a) correct the lamp output and (b) revise the detector weights
- LBNL will help D&S test the performance of the updated SSR
- Hardware update kit expected to be available by November
- Update could be self-installed by electronically savvy customer, or performed at D&S as part of routine maintenance
- Service turnaround time expected to be short (days)
- Price of update hardware/service not yet determined

Enlarging SSR sample area

- SSR detectors view small sample area (Ø ~ 2.5 cm) though collimated detector
- LBNL is building optical device to enlarge sample area by two orders of magnitude (Ø ~ 25 cm)
- Removable device would attach to SSR aperture
- Sample would be placed below device



UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

2.5.2 Status

- Devices & Services to issue SSR hardware update this fall
- LBNL will help D&S test the updated SSR
- LBNL is building attachment to enlarge SSR sample area

2.5.3 Correlate the solar reflectance of a shingle to that of its constituent granules

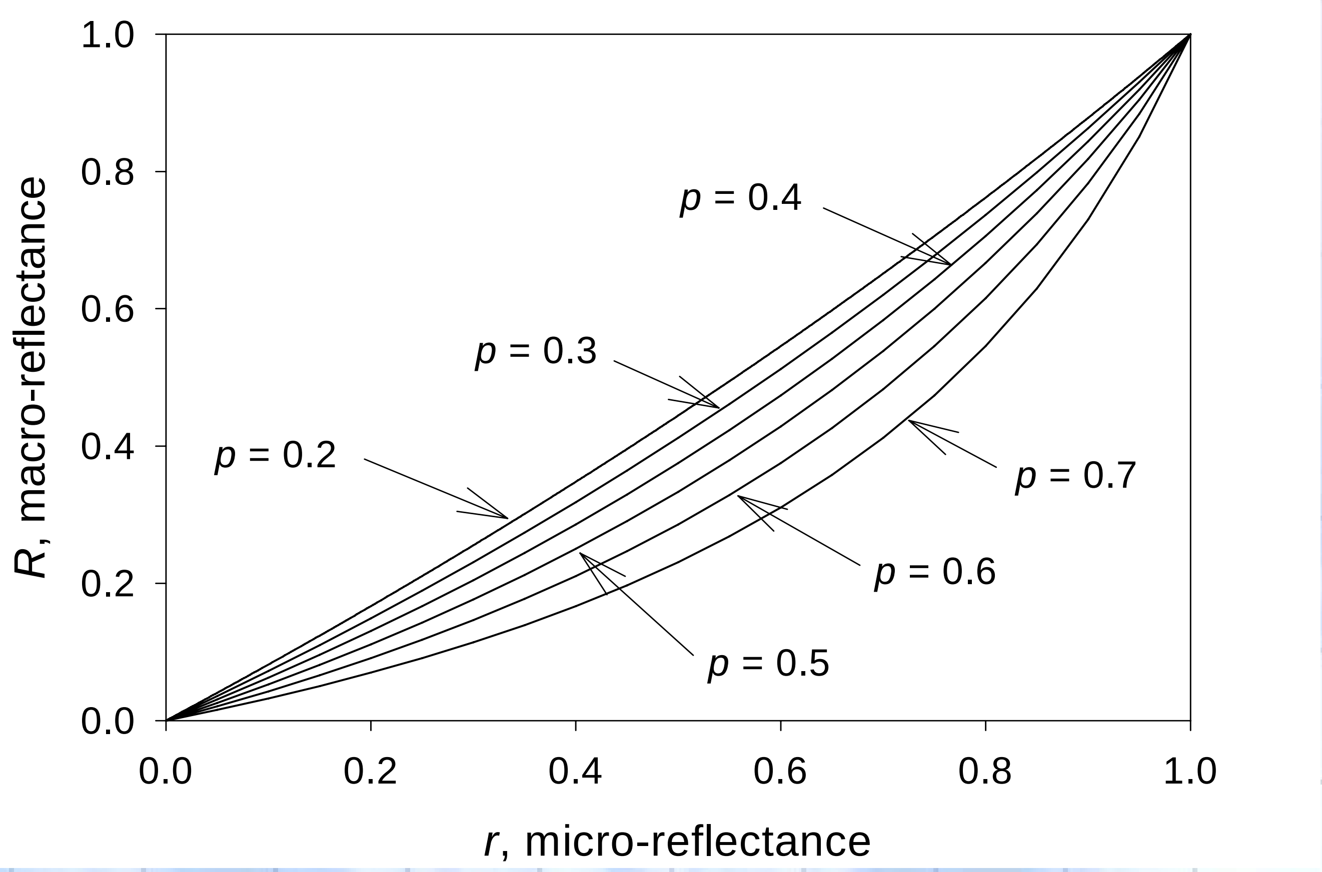
- Objective: Relate the solar reflectance of a roofing shingle to that of its granules
- Deliverable:
  - A technique for correlating the reflectance of a cool-colored shingle to that of its surface granules
- Schedule: 07/20/2006 – 07/20/2008
- Funds expended: 35%

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Effects of surface roughness on solar reflectance

- Method to connect “macro” shingle reflectance *R* to “micro” granule reflectance *r*
- Techniques for using reflectances of monocolor shingles to compute reflectance of blends

Macro-reflectance *R* as a function of micro-reflectance *r*



Asphalt shingle, $p \approx 0.5$
Curved roof tile, $p \approx 0.2$

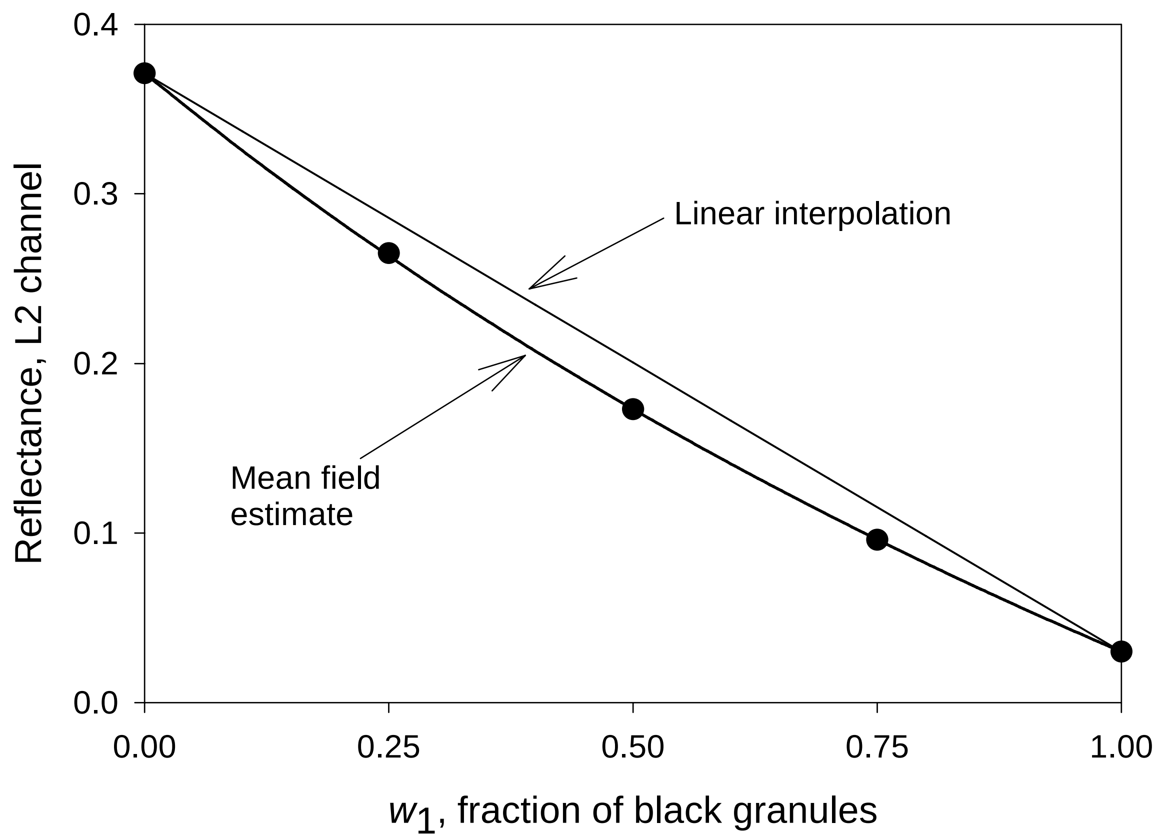
Reflectance of blends: measured and computed

Blend	Solar reflectance	Simplest method	Refined method
Weathered wood-Standard	0.106	0.105	0.102
Weathered wood-Cool	0.280	0.286	0.284
Black & White 50:50	0.144	0.160	0.145

- Excellent agreement for commercial-type blends
- Refined method better for “salt and pepper” blend

Mixtures of high and low reflectance granules permit measurement of small non-linearity

Curve fitting yields $p = 0.54$, close to the expected value



Asphalt shingle reflectance - future work

- Results submitted for publication
- Estimate reflectance changes due to granule loss
  - If 5% granule loss, how much reflectance loss?
- Examine how texture (granule orientation due to rolling process) affects reflectance
- Perform 3 year natural exposure testing with 3M
  - Interpret results in terms of weathering, granule loss, soiling

An aside: Photo-Catalytic Oxidation (PCO) Technology

- Popular in Japan, recent activity in Europe
- Uses titanium dioxide nanoparticles
- UV photon makes an electron-hole pair
- Photo-excited hole reacts with water molecule on surface to form an OH radical
- OH radical can oxidize (break down) most organic molecules

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

PCO applications

- Self-cleaning surfaces
  - Oxidize organic contaminants
  - Super hydrophilicity
- Self-sterilizing surfaces
- Air-cleaning surfaces, remove
  - volatile organic compounds (VOCs)
  - nitrogen oxides (NO_x)

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Self-cleaning tent

Self-cleaning tent material

These small test-size tents were located on the grounds of a factory in Saitama prefecture, north of Tokyo, where they were exposed to significant air pollution. After a three-month exposure, the conventional tent material, seen on the left, had become severely stained. On the right, the photocatalytic tent material has remained clean, having been washed off periodically by rainwater.

ordinary white tent

(Courtesy of Taiyo Kogyo Corporation)

photocatalytic white tent

This tent, located in Tsukuba Science Center, is a full-size storage tent made from the photocatalytic tarpaulin material. Also having been washed by rainwater, it remains clean.

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

2.5.4 Develop industry-consensus energy-savings calculator

- Objective: Develop a web-based calculator (and a PC-based version) with which consumers, contractors and distributors can estimate the cooling energy savings and peak demand reduction achieved by installing cool roofing on specific buildings
- Deliverables:
  - Industry-consensus energy calculator
- Schedule: 07/20/2006 – 07/20/2008
- Funds expended: 15%

Energy-savings calculator

- Methodology
  - Developed by LBNL and ORNL
  - Approved by CEC, EPA, and DOE
  - Was presented to a national advisory committee (via web)
  - Their comments were incorporated
- We are reviewing the available roof/attic algorithms
- DOE continues to be interested and co-fund the task

Technical approach

- Use hourly building energy simulation models and building prototypes
- Use advanced algorithms to calculate heat transfer through the roof
  - Existing residential- and commercial-building roof algorithms
  - New algorithms developed in this program
  - Fully documented algorithms
- Integrate the adopted algorithms in hourly simulation models
- Use EnergyPlus or DOE2
- Use MICROPAS if source code is available AND we conclude MICROPAS is suitable
- Evaluate and modify available prototypes

2.5.5 Conduct natural exposure testing in California

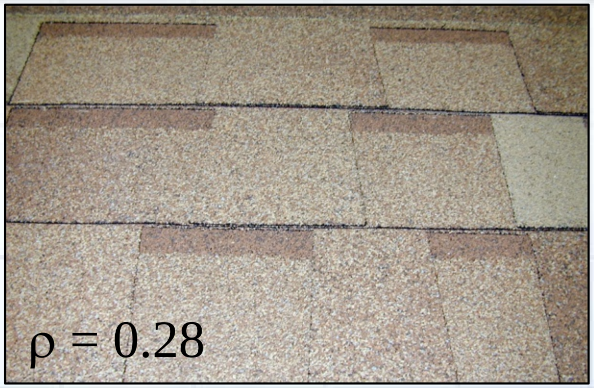
- Objective: Conduct natural exposure testing of currently tested roofing samples and new roofing materials
- Deliverables:
  - A technical report summarizing the results of the exposure testing
- Schedule: 07/20/2006 – 07/20/2009
- Funds Expended: 30%

Asphalt shingles with and without IRR pigments under exposure testing

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

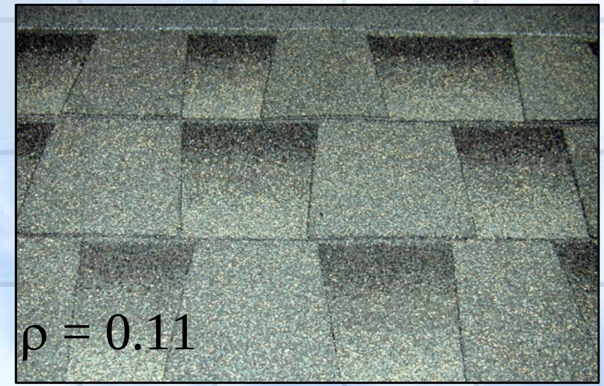
Cool color asphalt shingles under exposure at weathering sites

A. Cool Color Shingle



B. Cool Color Shingle

C. Cool Color Shingle

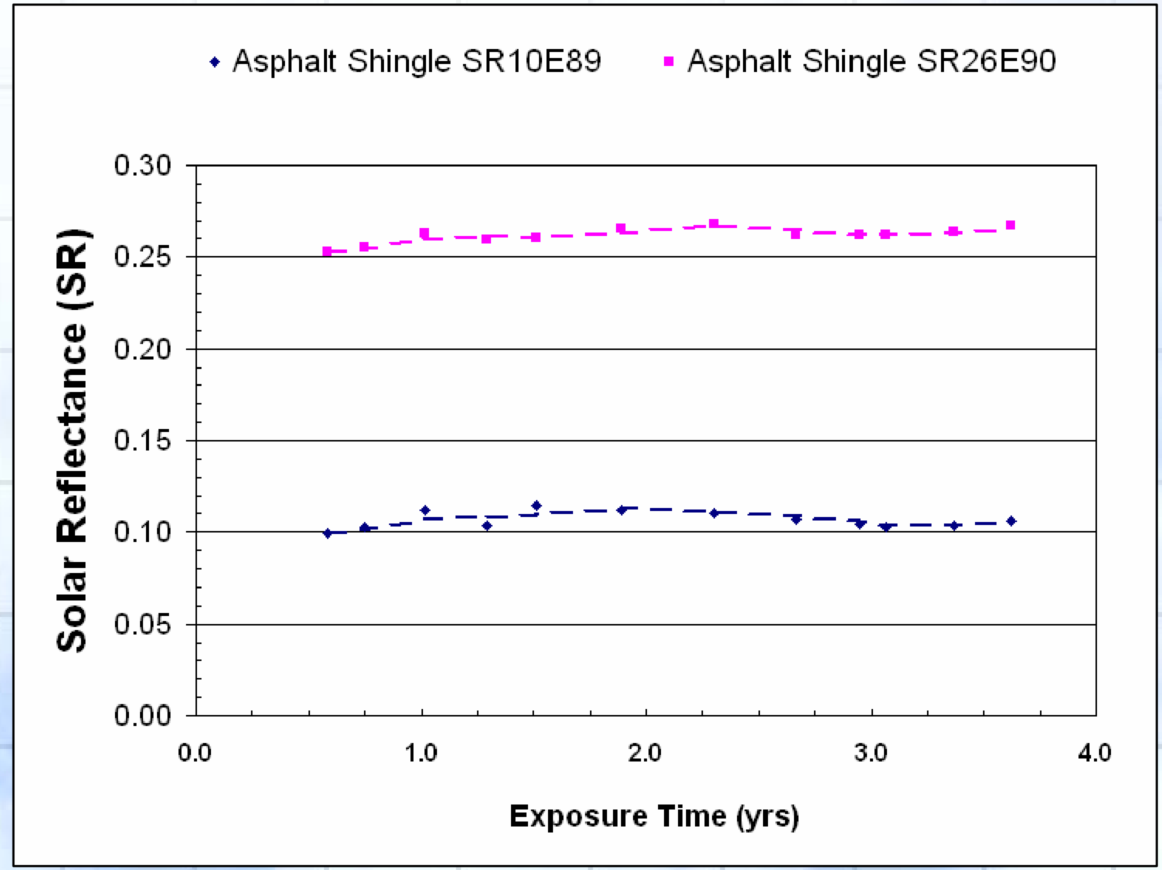


D. Conventionally Pigmented Shingle

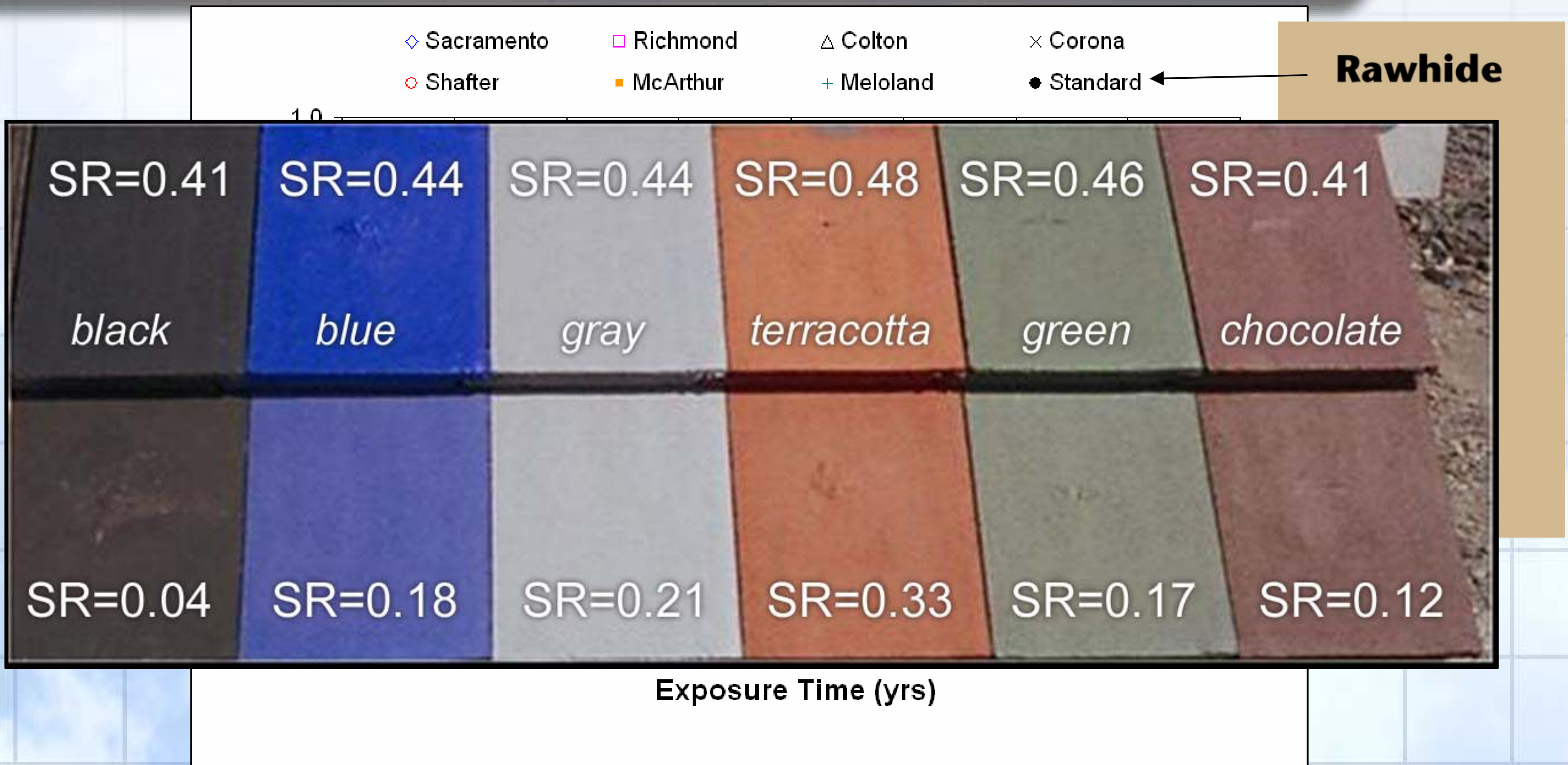
E. Cool Color Shingle

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Solar reflectance remains almost level after 3-½ yrs of exposure at ORNL campus



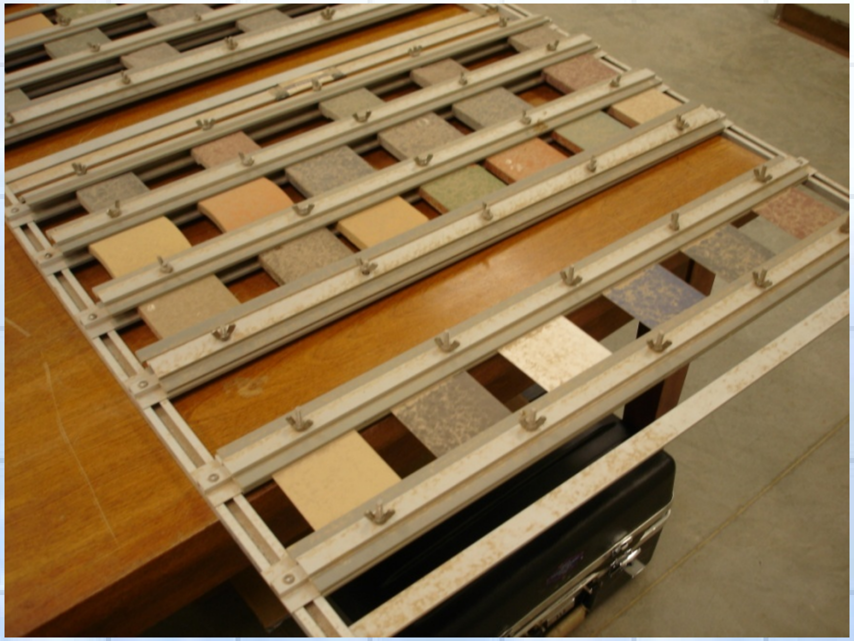
COOLTILE IR COATING™
by American Rooftile Coatings



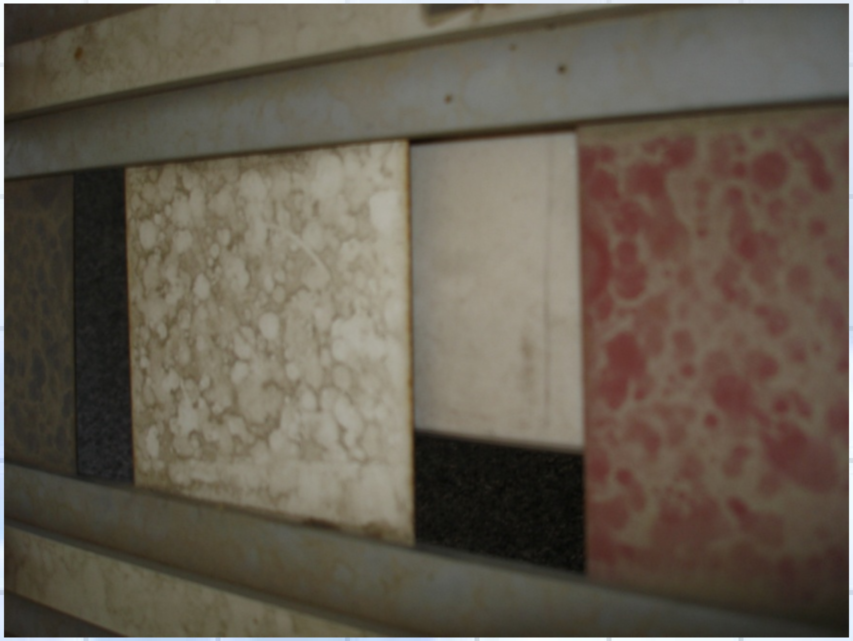
Deposition of airborne particles analyzed after 1.6 yrs exposure and now after 4.1 yrs of exposure

Chemical composition to be analyzed and journal article published.

El Centro Mar 07



Colton Aug 07



2.5.6 Conduct field exposure testing at ORNL

- Objective: conduct field exposure testing of new cool roofing materials at ORNL
- Deliverables:
  - Use data to validate industry-consensus energy savings calculator
  - A technical report summarizing the results of field exposure testing at ORNL
- Schedule: 07/20/2006 – 07/20/2009
- Funds Expended: 40%

ESRA utilized for testing of clay and concrete tile, painted metal, asphalt shingle, stone-coated metal roofs

Formulate and validate AtticSim for cool colors and above-sheathing ventilation

AtticSIM II *(Attic Simulation)* Model

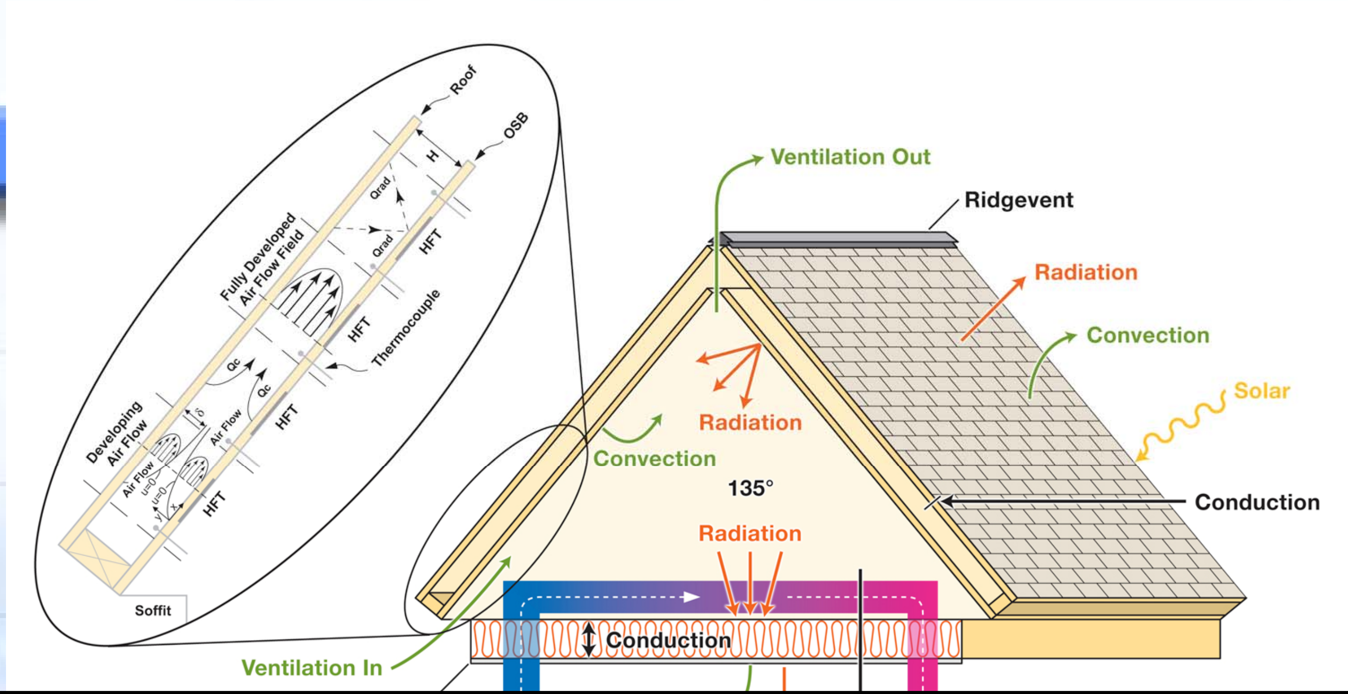
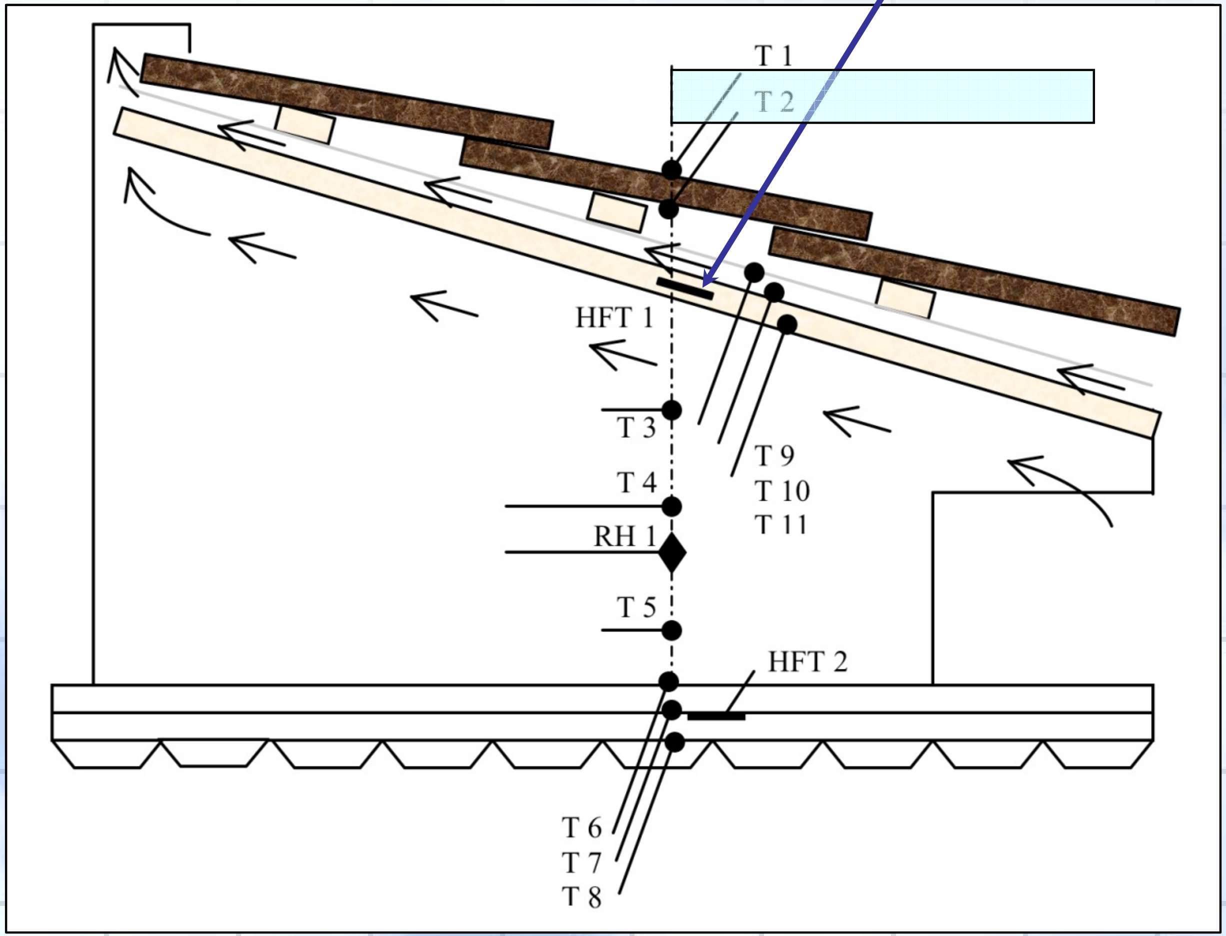


Table 1. Data for solar noon with outdoor air temperature of 86°F.						
System	Temperature (°F)		Heat Flux (Btu/hr ft^2)			
	Roof Underside	Roof deck	Roof Underside	Radiation	ASV	Roof Deck
Open Cavity	145.7	133.1	20.8	14.2	4.0	16.8
RB Roof Underside	148.1	117.0	15.2	2.2	3.3	11.8
Closed Cavity	147.1	135.4	17.6	13.3	0.0	17.6

Solar reflectance 0.26, emittance 0.95; air space 0.75-in.

UT-BATTELLE
OAK RIDGE NATIONAL LABORATORY
BERKELEY LAB

AtticSim predicts above-sheathing ventilation (ASV) shown at previous PAC

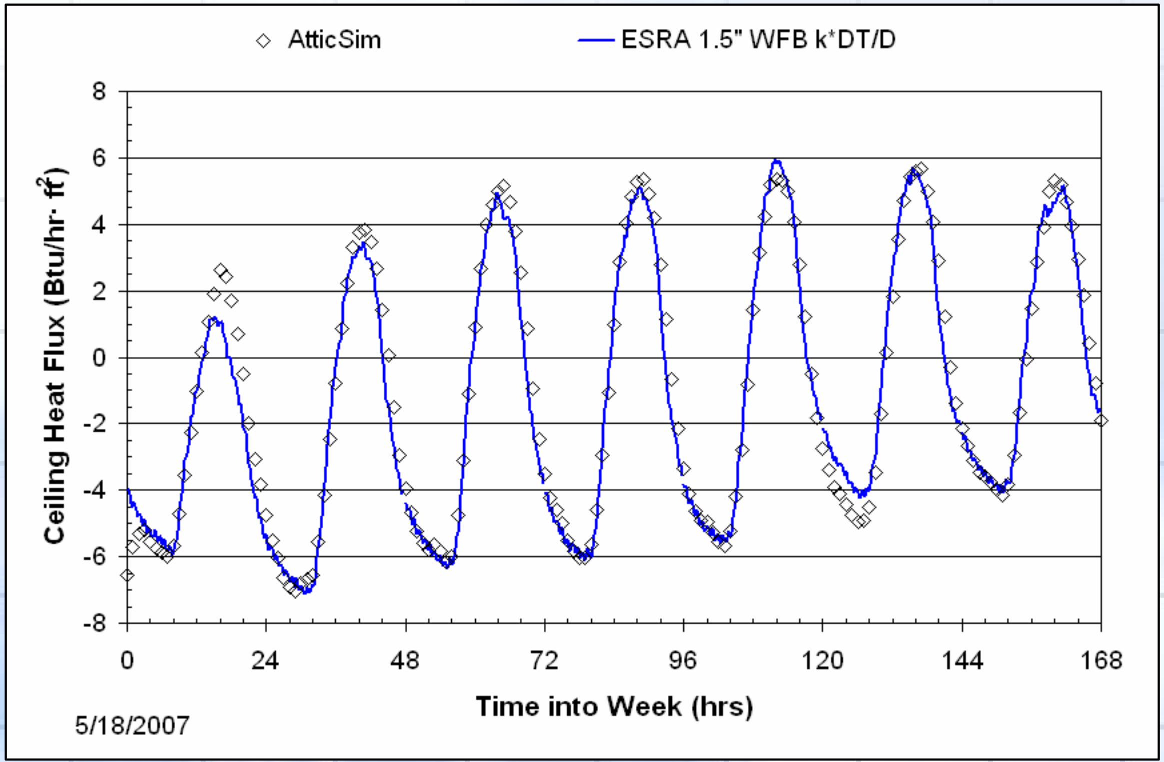


UT-BATTELLE
Oak Ridge National Laboratory

Berkeley Lab

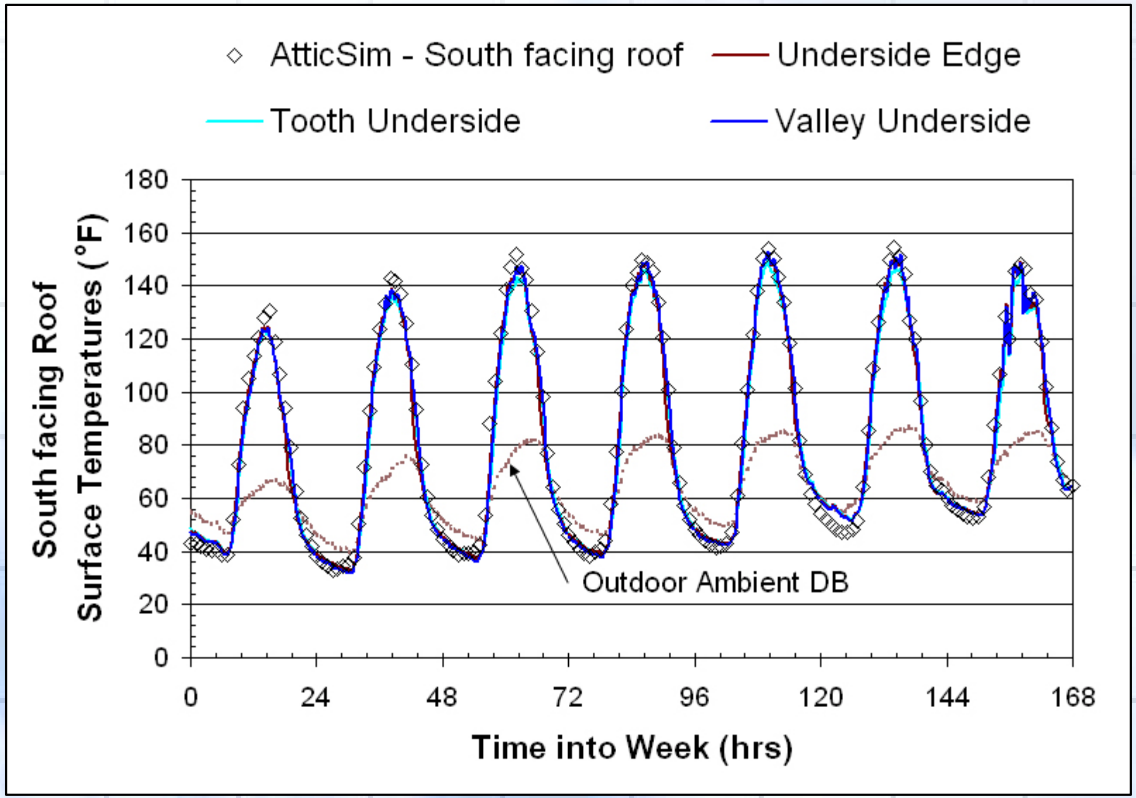
Asphalt shingle (SR093E89)

Ceiling Heat Flux



Cool pigmented shingle (SR28E94)

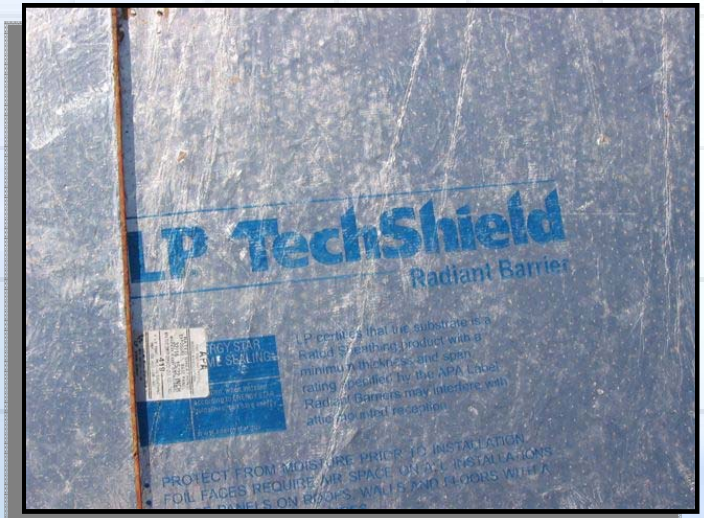
Shingle Surface Temperature

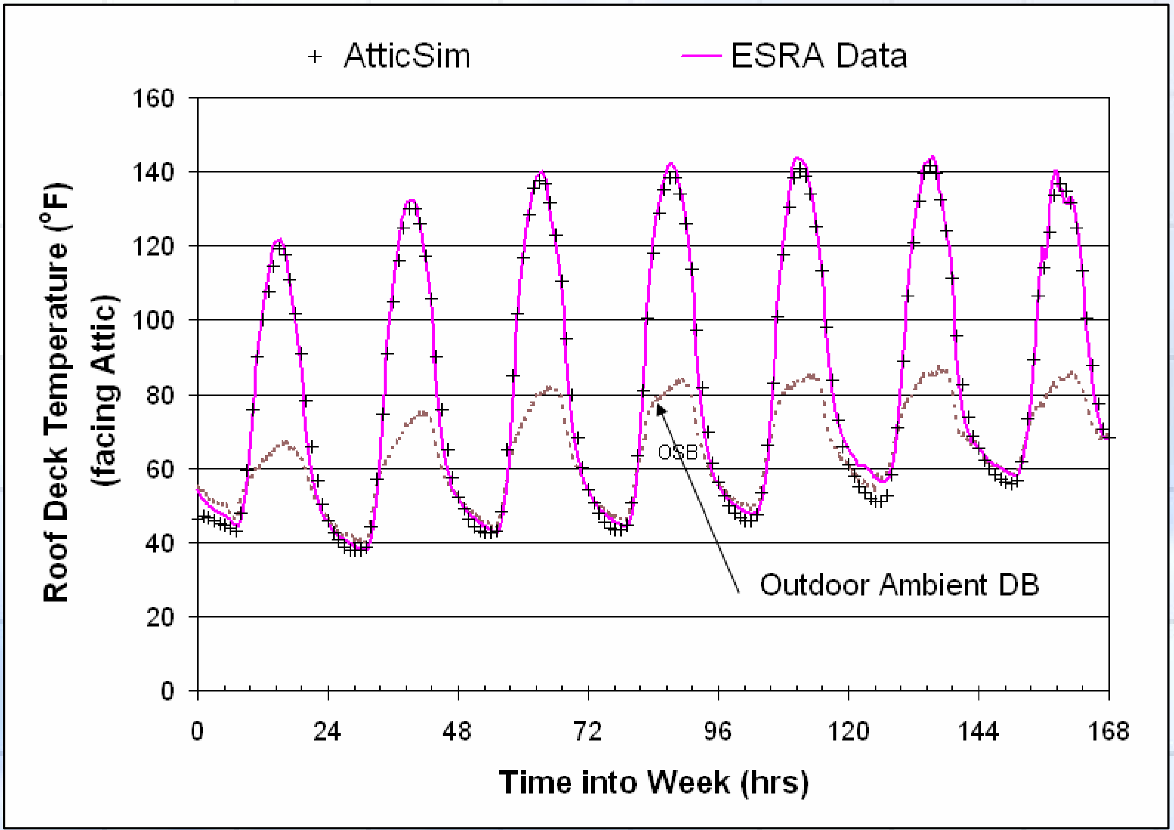


UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Asphalt Shingle (SR093E89) with radiant barrier facing attic space

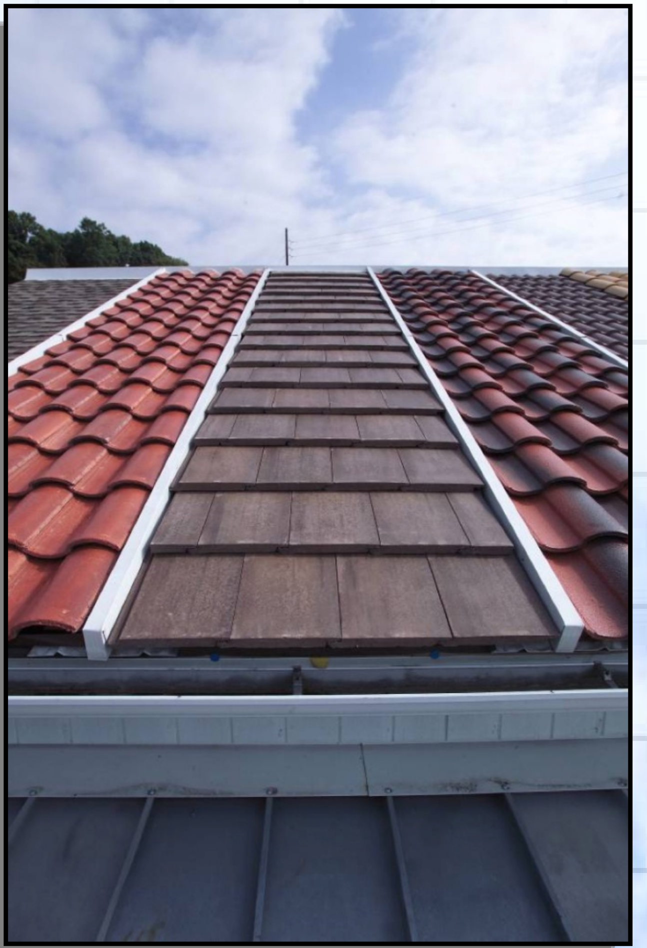
OSB with RB facing attic

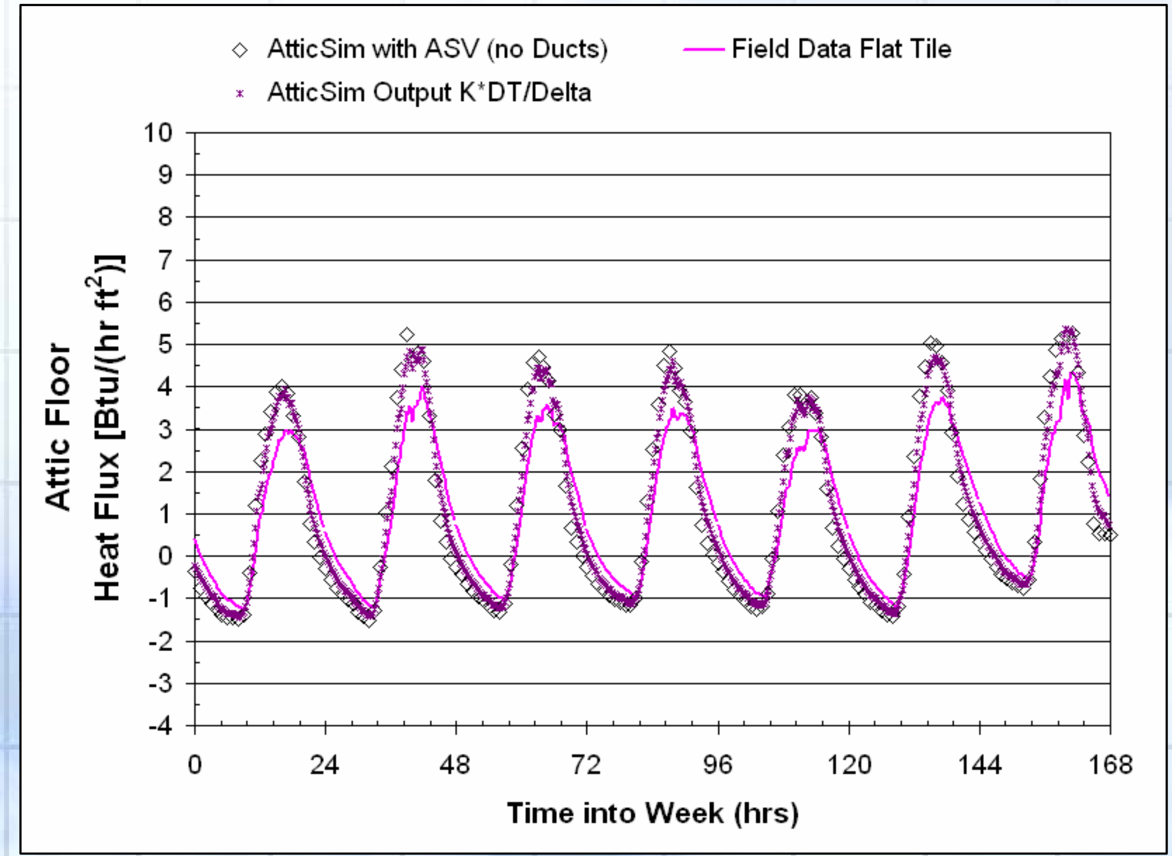




Flat concrete tile (SR13E83) on double batten system

Ceiling Heat Flux



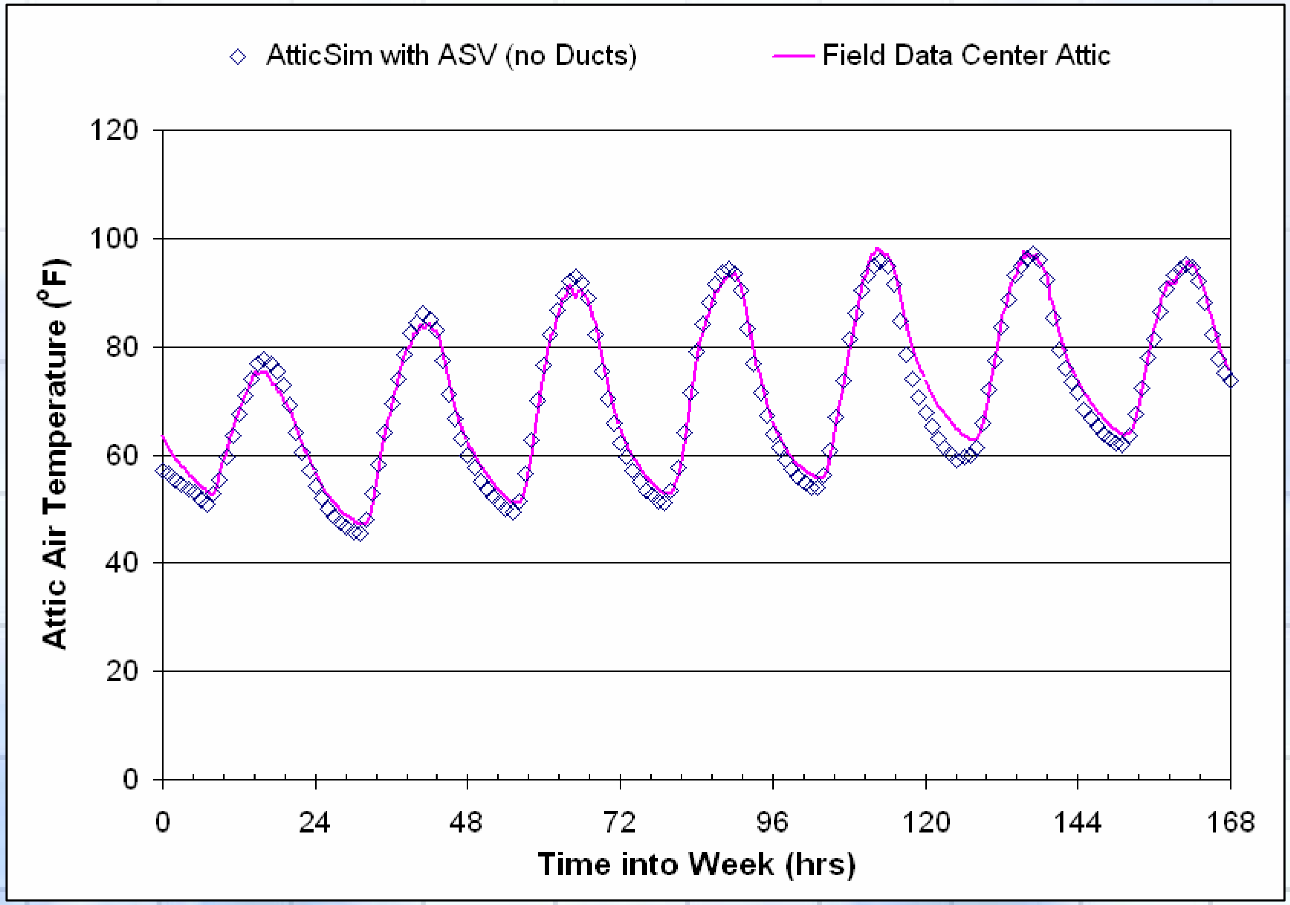


Medium profile concrete tile

Same setup used at Fair Oaks Demonstration

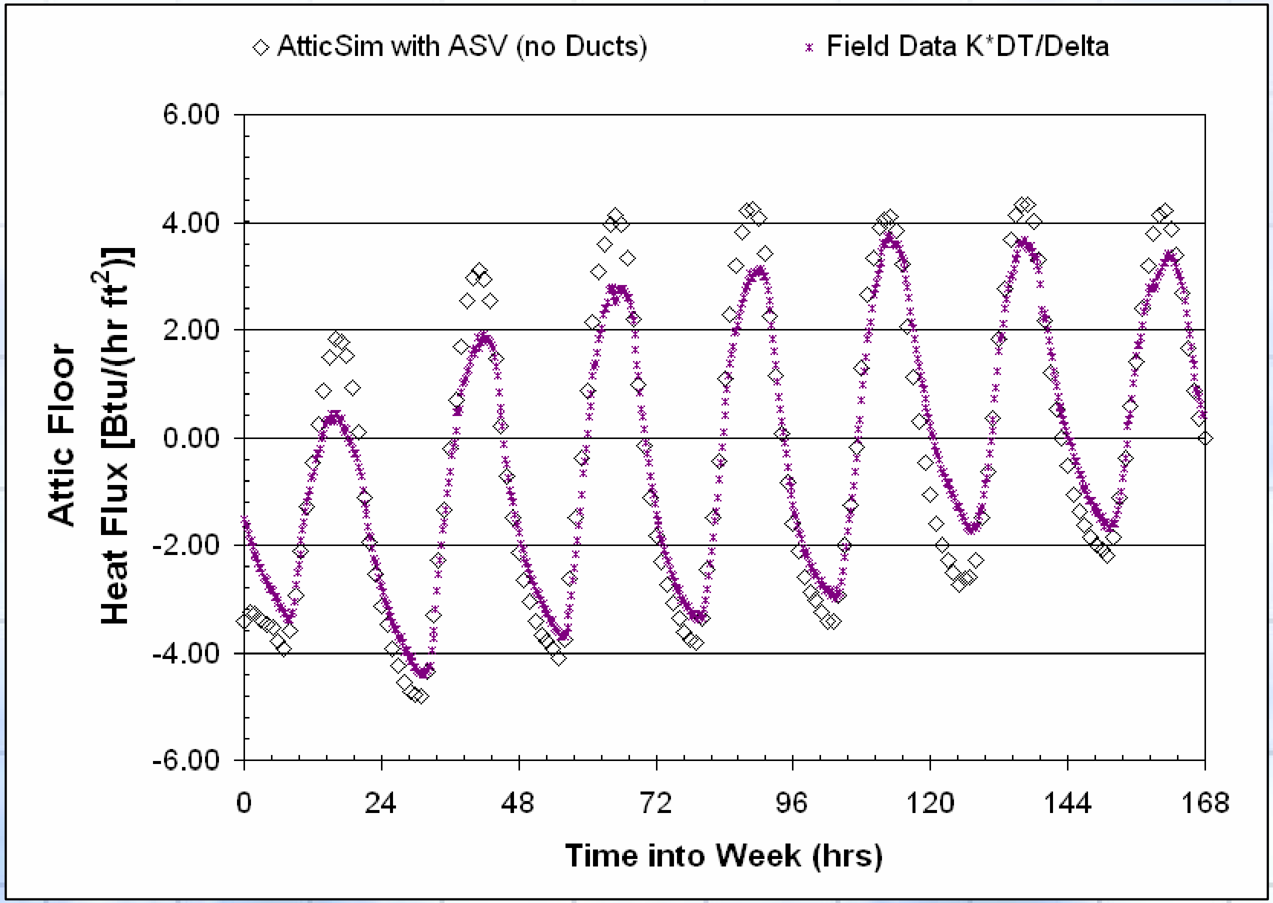
Medium profile tile (SR10E93) on batten and counter-batten

Attic air temperature



Medium profile tile (SR10E93) on batten and counter-batten

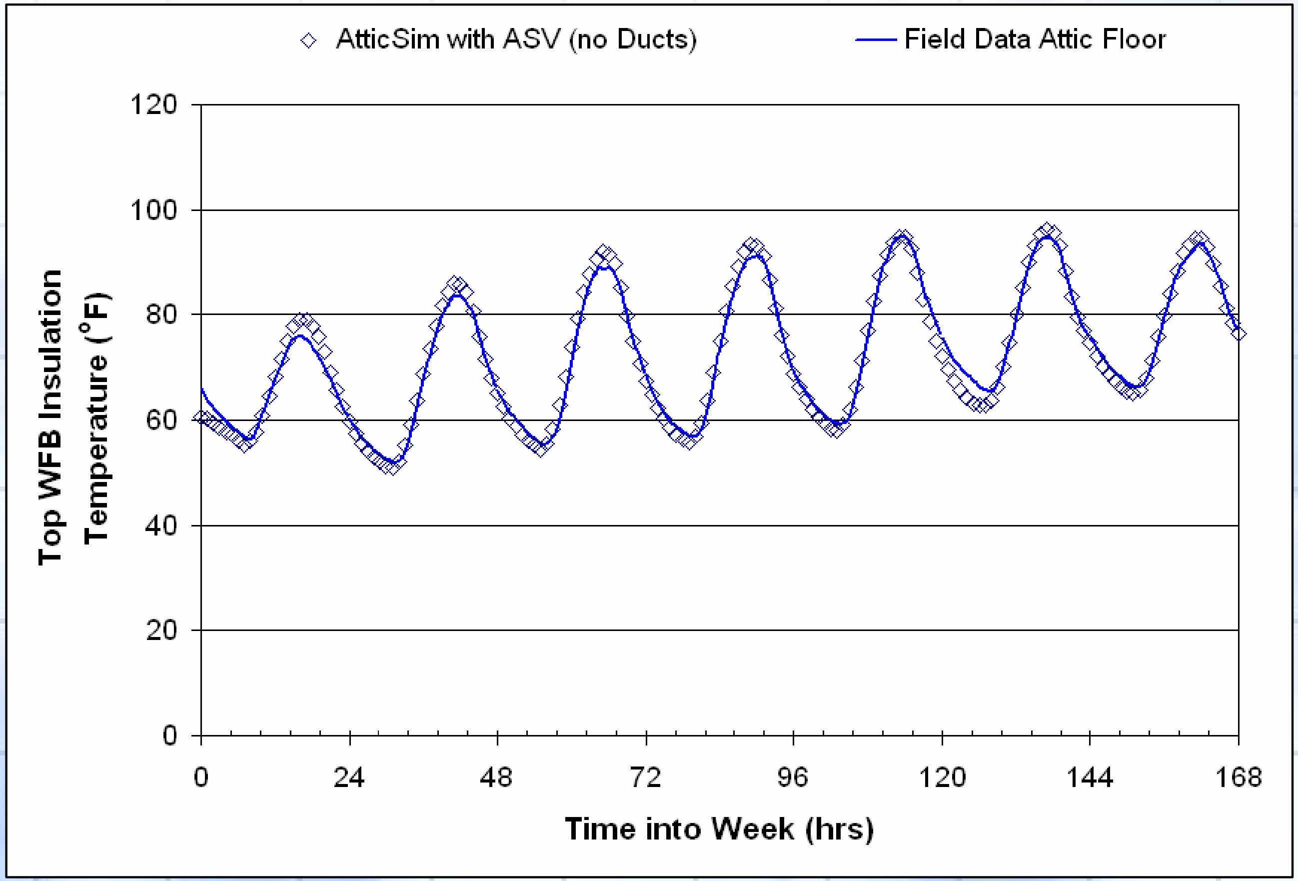
Attic floor Heat Flux



UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

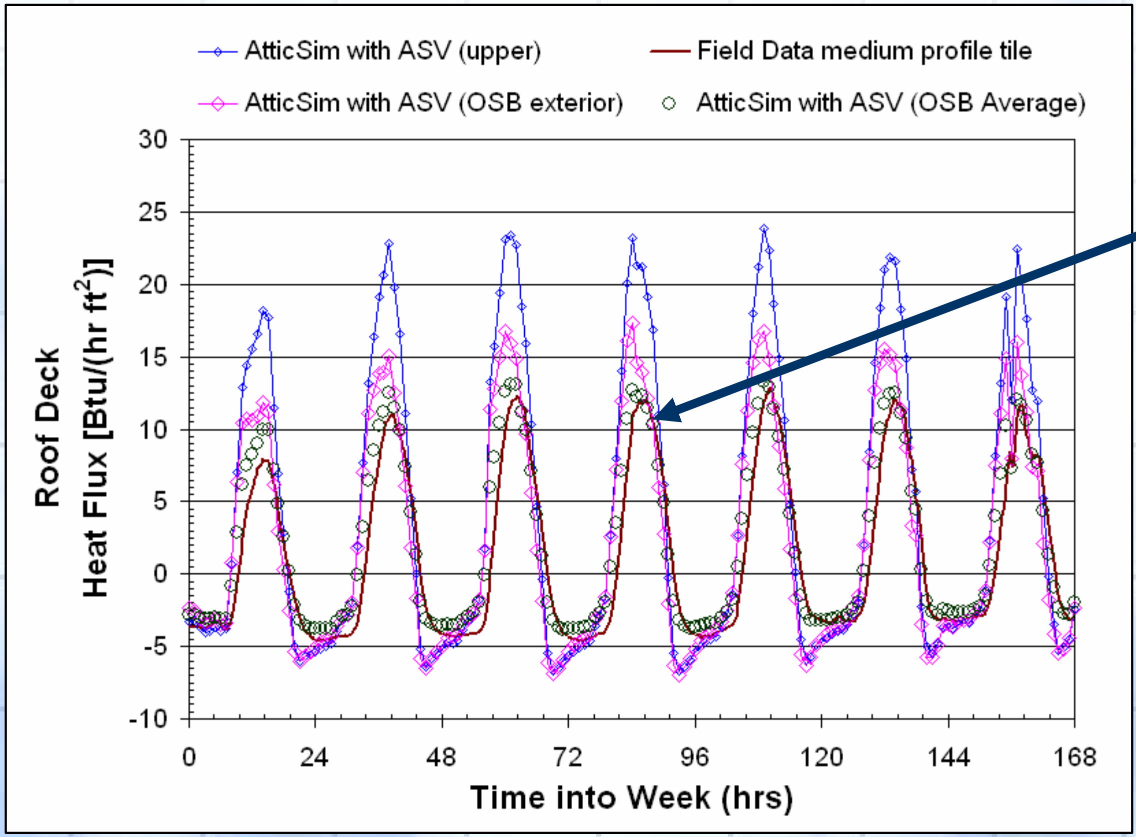
Medium profile tile (SR10E93) direct-to-deck

Temperature of Attic Floor



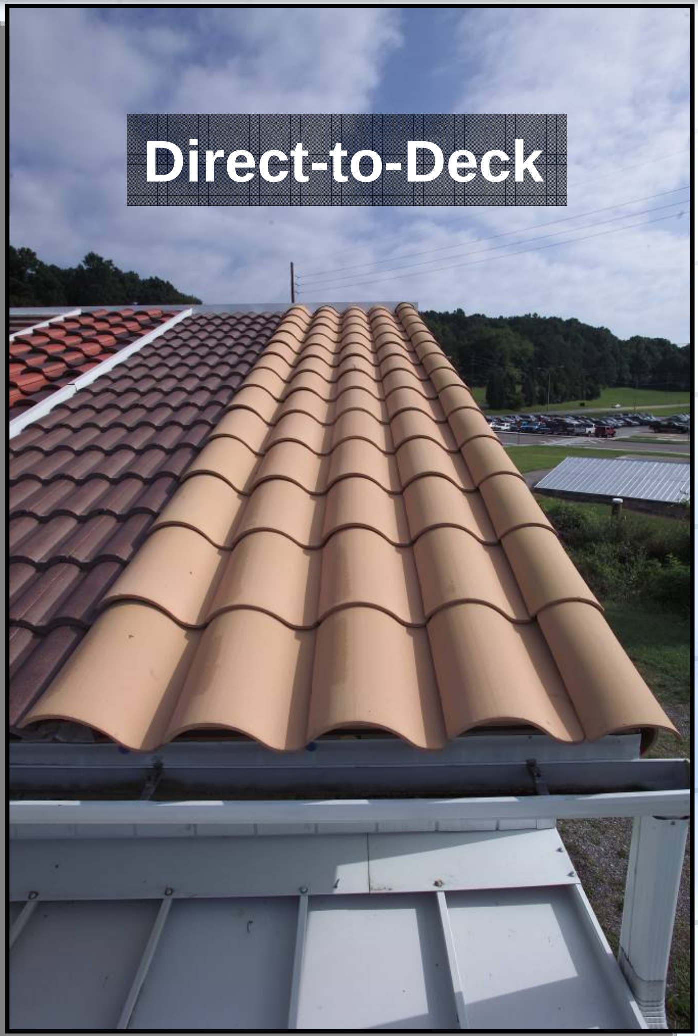
Medium profile tile (SR10E93) on batten

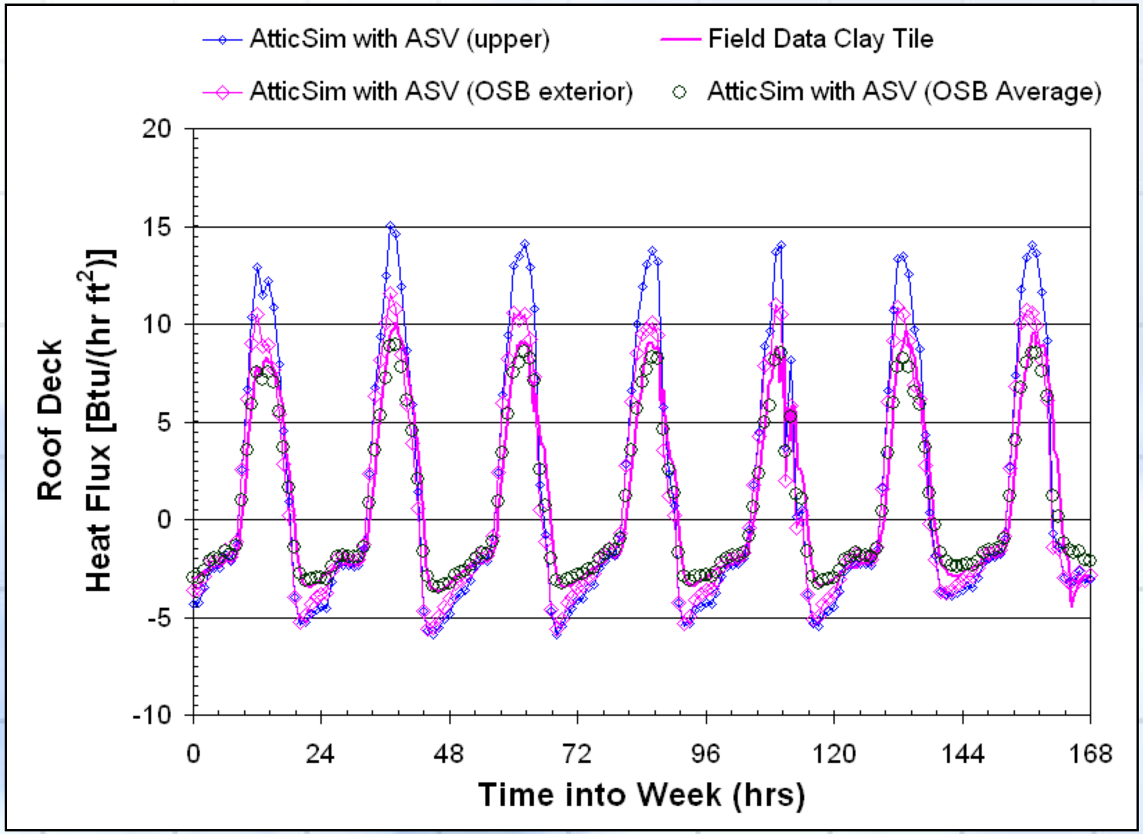
Heat flux through roof deck



S-mission clay tile (SR54E90)

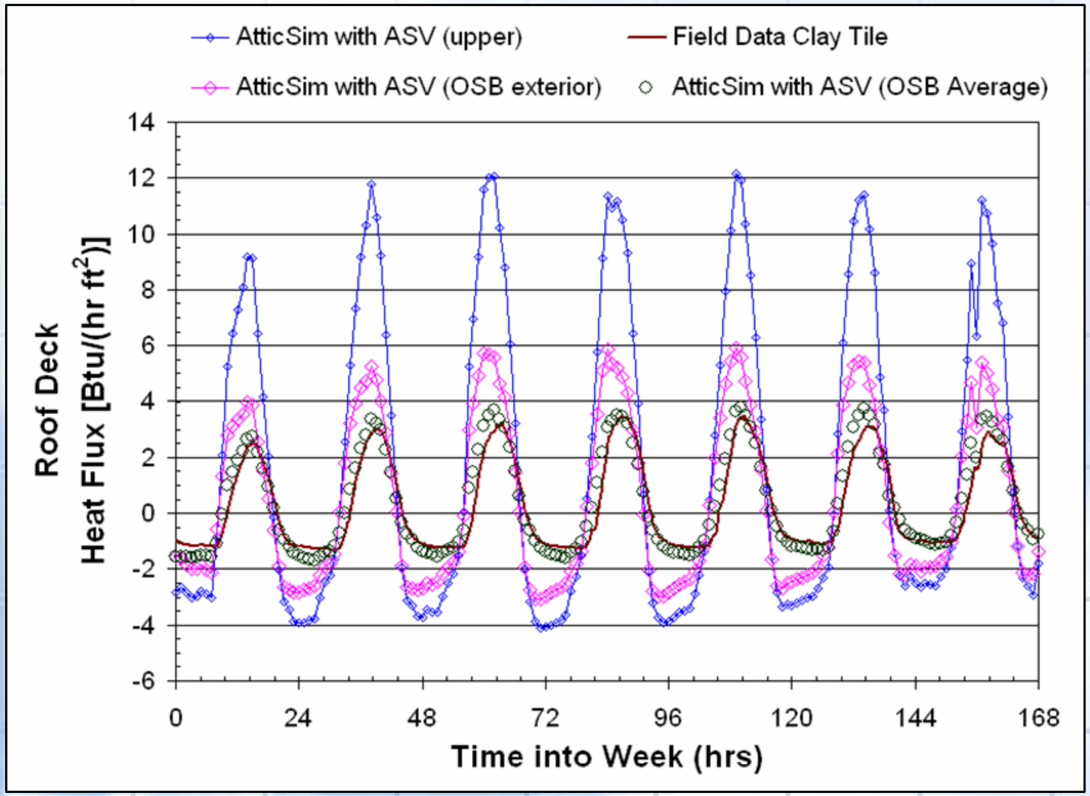
Heat flux through roof deck





S-mission clay tile (SR54E90) with 1 ¼-in EPS insulation on roof deck (Ecoset)

Heat flux through roof deck



2.5.7 Carry out field experiments in S. CA for validation of the energy savings calculator

- Objective: Carry out field experiments to evaluate new cool-colored roofing materials in Southern California for validation of the industry-consensus energy savings calculator
- Deliverables:
  - Comparison of validated steep-slope roof calculator to demonstration data
  - A technical report summarizing the results of the field experiments and comparison of the energy-savings calculator
- Schedule: 07/20/2006 – 07/20/2009
- Funds Expended: 30%

Southern CA field experiments at Fort Irwin, CA

Located in the High Mojave Desert

Excellent Demonstration Opportunity

ARMY providing safe, secure, reliable, environmentally compliant, and cost-effective energy and water services on ARMY installations.

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Data acquisition

Parameters to measure to assess cool roof performance

- Roof surface temperatures
- Roof underside temperatures
- Indoor and plenum air temperatures
- Weather conditions (10-min data on Internet[1])
- Air-conditioner energy use.

One-time observations

- Solar reflectance and thermal emittance of roof tile
- Wall and roof insulation levels.
- Measure free flow area of soffit, gable and roof vents.
- A/C nameplate and power draw of the indoor blower
- Air tightness of the return duct system verified by duct blower tests.
- Window area, U-value, solar heat gain coefficient, layers of glass, thickness of air space

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Demonstration homes testing protocol

All home thermostats set at 68°F

All home thermostats set at 70°F

All home thermostats set at 72°F

Cool color pigments spray painted on two homes (N4 and N5)

Field testing of unoccupied homes; thermostat set at 70°F

Field testing of occupied homes; thermostat set at 70°F

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Schedule for commissioning Field Experiments at Fort Irwin

- Test Plan submitted to the CEC
- Memorandum of Understanding in place
- Wiring of 4 homes completed in May 07
- Waiting for construction crews to complete exterior finishing details

2.6 Technology transfer activities

- Objective: Make the knowledge gained, experimental results and lessons learned available to key decision-makers
- Deliverables:
  – Publish results in trade magazines and academic journals
  – Participate in building-product exhibitions
  – Develop a brochure summarizing the research results and characterizing the benefits of cool colored roofing materials
- Schedule: 07/20/2006 – 07/20/2008
- Funds expended: 30%

UT-BATTELLE
OAK RIDGE NATIONAL LABORATORY
BERKELEY LAB

Technology transfer

- Four journal/conference papers in press (see next page)
- California's Public Interest Energy Research (PIER) program issued technical brief on cool colored roofing
- LBNL Heat Island Group received PG&E *Flex Your Power* award in May for cool colored roofing (photo at right)

UT-BATTELLE
Oak Ridge National Laboratory
Berkeley Lab

Publications

- Akbari, H., S. Menon, and A. Rosenfeld. 2007. Global cooling: effect of urban albedo on global temperature. To be published in proceedings of *Building Low Energy Cooling And Advanced Ventilation Technologies In The 21st Century*, Sep 27-29, Crete, Greece.
- Akbari, H. and R. Levinson. 2007. Status of cool roof standards in the United States. To be published in proceedings of *Building Low Energy Cooling And Advanced Ventilation Technologies In The 21st Century*, Sep 27-29, Crete, Greece.
- Berdahl, P., H. Akbari, J. Jacobs and F. Klink. 2007. Surface roughness effects on the solar reflectance of cool asphalt shingles. Submitted for journal publication.
- Miller, W. A., Keyhani, M., Stovall, T. and Youngquist, A. 2007. Natural convection heat transfer in roofs with above-sheathing ventilation. Accepted for presentation in *Thermal Performance of the Exterior Envelopes of Buildings, IX*, proceedings of ASHRAE THERM X, Clearwater, FL., Dec. 2007.

Schedule of PAC meetings

	Date	Location
PAC-1	**Sep. 7, 2006**	**CEC**
PAC-2	**Mar. 15, 2007**	**LBNL**
PAC-3	**Sep. 6, 2007**	**Corona, CA**
PAC-4	Mar. 6, 2008	ORNL
PAC-5	Sep. 4, 2008	?
PAC-6	Mar. 5, 2009	?

Cool colors project website

- Project information (including copies of this presentation) available online at

http://CoolColors.LBL.gov