

Market Deployment of Cool-Colored Roofing Materials

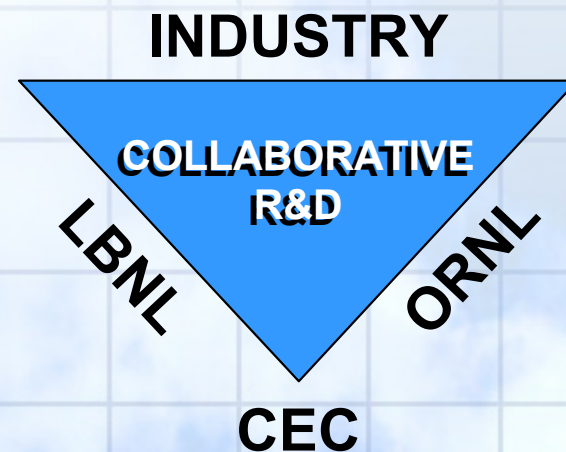
Project Advisory Committee (PAC) Meeting

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

6 March 2008

Oak Ridge National Laboratory

Oak Ridge, TN



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

Industrial partners

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

Project team

- Lawrence Berkeley National Lab (LBL)
 - Hashem Akbari
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 - Paul Berdahl
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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: **75%**

Activities

- Answered inquiries from 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: **65%**

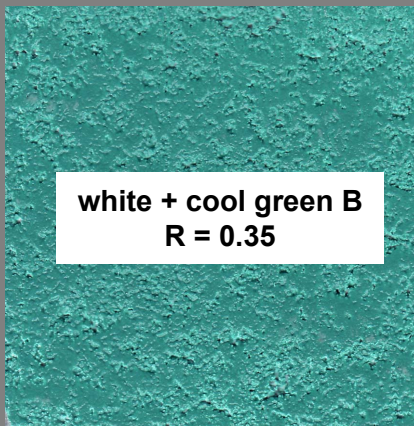
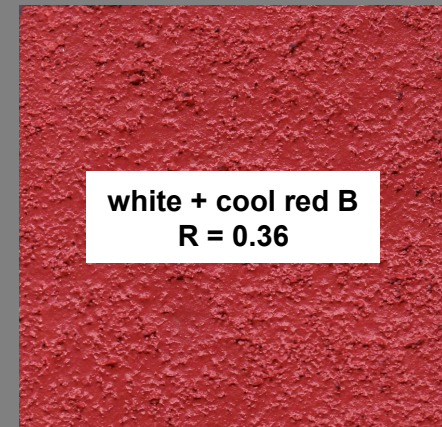
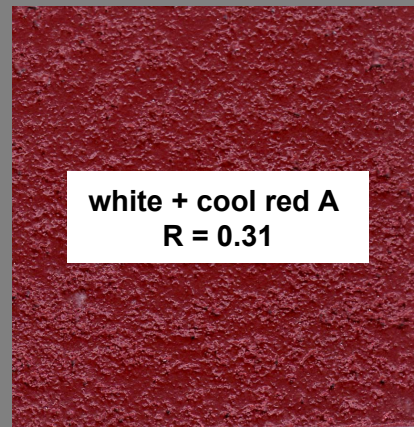
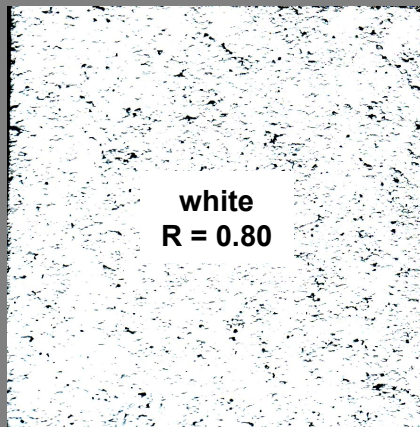
Improving solar reflectance of roofing materials: methods under investigation

- Concrete tiles
 - Apply cool-pigmented polymer surface topcoat, optional white basecoat to gray-cement concrete
 - Apply cool-pigmented cementitious surface topcoat, optional white basecoat to gray-cement concrete
- Clay tiles
 - Add white basecoat below color glaze
 - Seek cooler pigments for glazes
- Asphalt shingles
 - Apply cool-pigmented polymer surface topcoat, optional white basecoat to bare-granule shingles
- Metal
 - Extensively characterized metal substrates and pigmented coatings in Phase 1
 - Seek metal-industry suggestions for Phase 2 work *to improve solar reflectance*

New surface coatings for concrete tiles

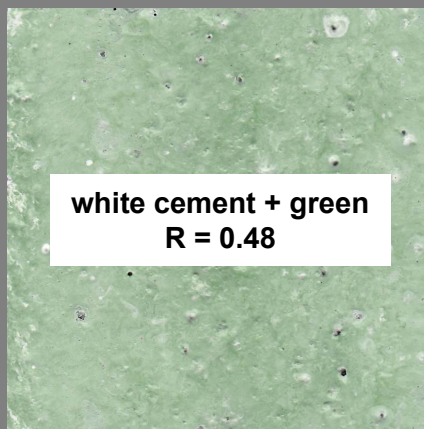
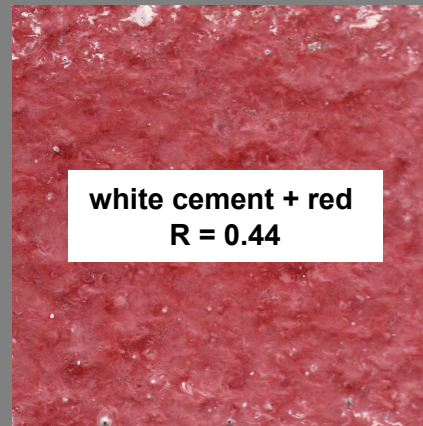
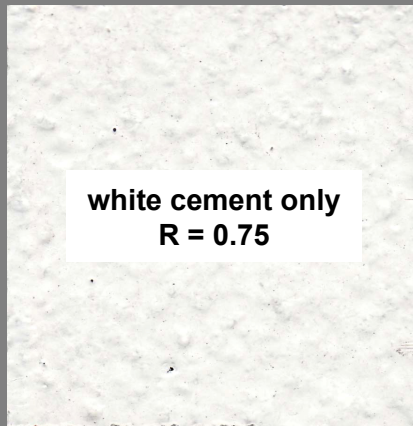
- **Goals**
 - increase solar reflectance of concrete tiles
 - develop durable, cool-pigmented, soil-resistant surface coatings to color gray-cement concrete tiles
- **Approach 1:
apply polymer coating**
 - Arkema testing cool-pigmented, water-based Kynar Aquatec® polymer coatings
 - Have created 34 prototypes in 5 different cool colors using tiles supplied by Eagle Roofing
- **Approach 2:
apply cementitious coating**
 - Eagle Roofing testing cool-pigmented white-cement slurry coatings
 - Have made prototypes in 5 cool colors using Eagle's standard pigments

Examples of Kynar Aquatec[®] cool surface coatings on gray-cement concrete



R is E903 AM1.5 global solar reflectance

Examples of Eagle's white cement + pigment surface coatings on gray-cement concrete



Red, green, and apricot samples were colored with Eagle Roofing's **standard** pigments sprayed over white cement slurry

R is E903 AM1.5 global solar reflectance

New surface coatings for asphalt shingles

- **Goals**

- increase solar reflectance of asphalt shingles
- develop durable, cool-pigmented surface coatings to color bare-granule asphalt shingles

- **Concept**

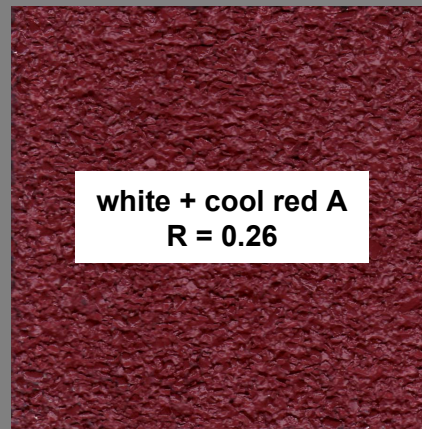
- color granules *after* they are pressed into asphalt shingle
- increase coating thickness, but...
- coat only exposed half of granule's surface

- **Approach:**

- apply polymer coating**

- Arkema testing cool-pigmented Kynar Aquatec® polymer coatings
- Have created 22 prototypes in 1 cool color
- Approximately 20 prototypes in 4 other cool colors in preparation

Examples of Kynar Aquatec[®] surface coatings on bare-granule asphalt shingles



(prototypes based on four other cool pigments under preparation)

R is E903 AM1.5 global solar reflectance

New surface coatings for clay tiles

- **Goal**
 - improve solar reflectance of glazed clay tiles (MCA Clay Tile)
- **Approach 1:
add white basecoat**
 - identified four most promising glazes for addition of white basecoat
 - white basecoat did not appreciably increase solar reflectance
 - red clay tile substrate already NIR reflective
 - glazes not especially transparent in NIR
- **Approach 2:
reformulate glaze**
 - characterized solar spectral reflectances of 32 cool-colored glazed clay tiles
 - obtained glaze compositions from manufacturer
 - seek to reduce NIR absorption in glazes by changing components (e.g., pigments)

2.5.1 Status

- Many new prototypes produced by industry, characterized by LBNL
- Kynar Aquatec® coatings promising for concrete tiles, asphalt shingles
- White-cement + pigment slurry coatings promising for concrete tiles
- Over next 6 months, we will continue working with partners to
 - Test cool slurry coats for concrete tiles
 - Test Kynar Aquatec® coatings for concrete tiles
 - Test alternative pigments for clay-tile glazes
 - Review options for other technologies

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: **50%**

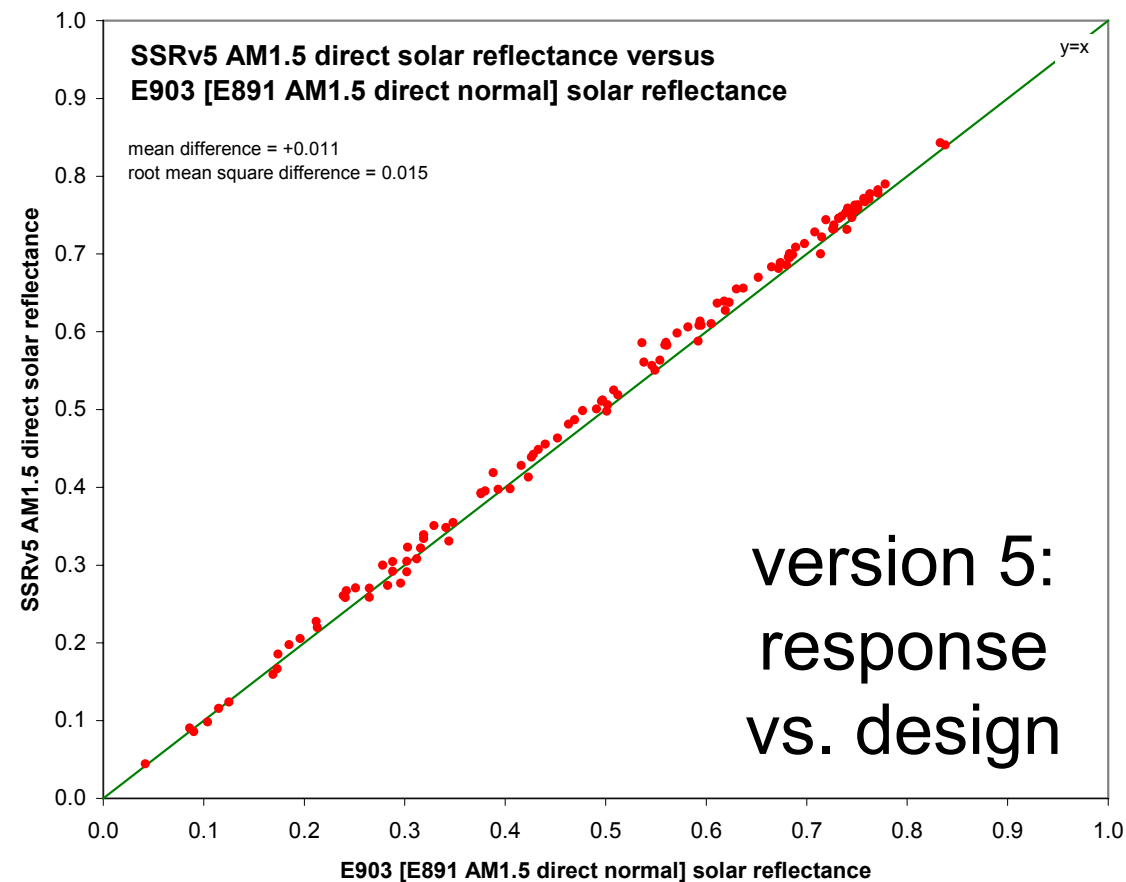
Design: build tool that uses D&S Solar Spectrum Reflectometer

- Use Devices & Services Solar Spectrum Reflectometer (SSR) to accurately and rapidly measure solar reflectance of medium-area cool-color surfaces
- Task 1: correct error in SSR version 5 characterization of cool colored surfaces
- Task 2: apply SSR to measurement of medium-area surfaces

Task 1: Correcting SSR (i)

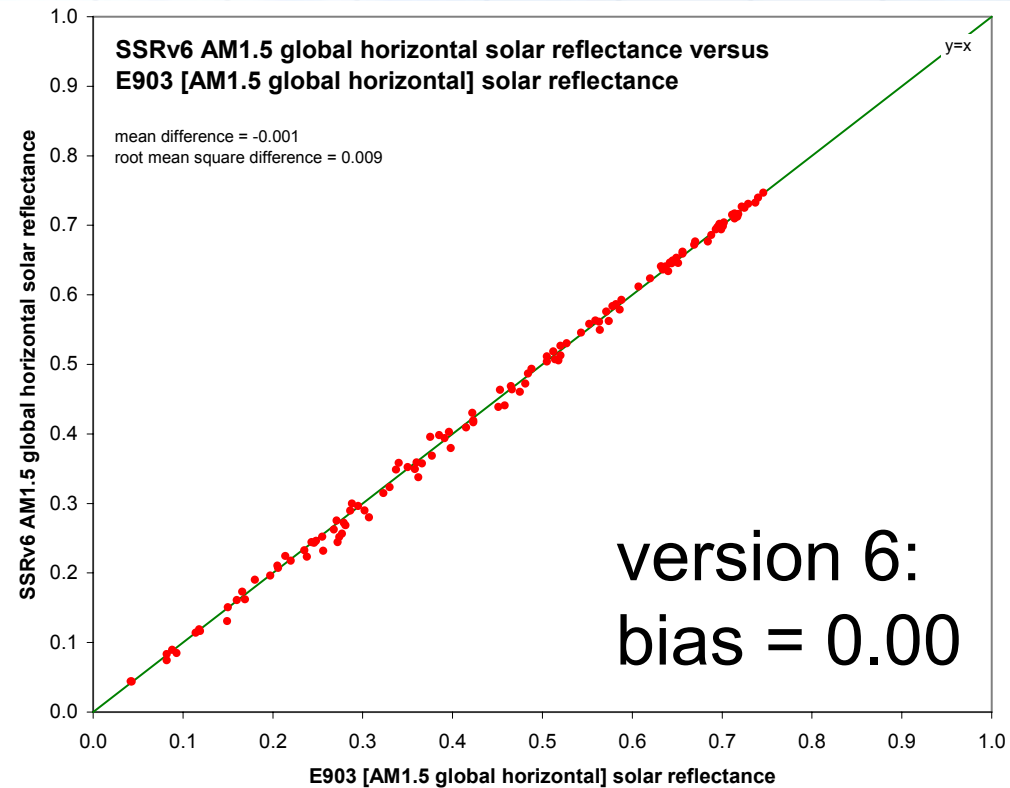
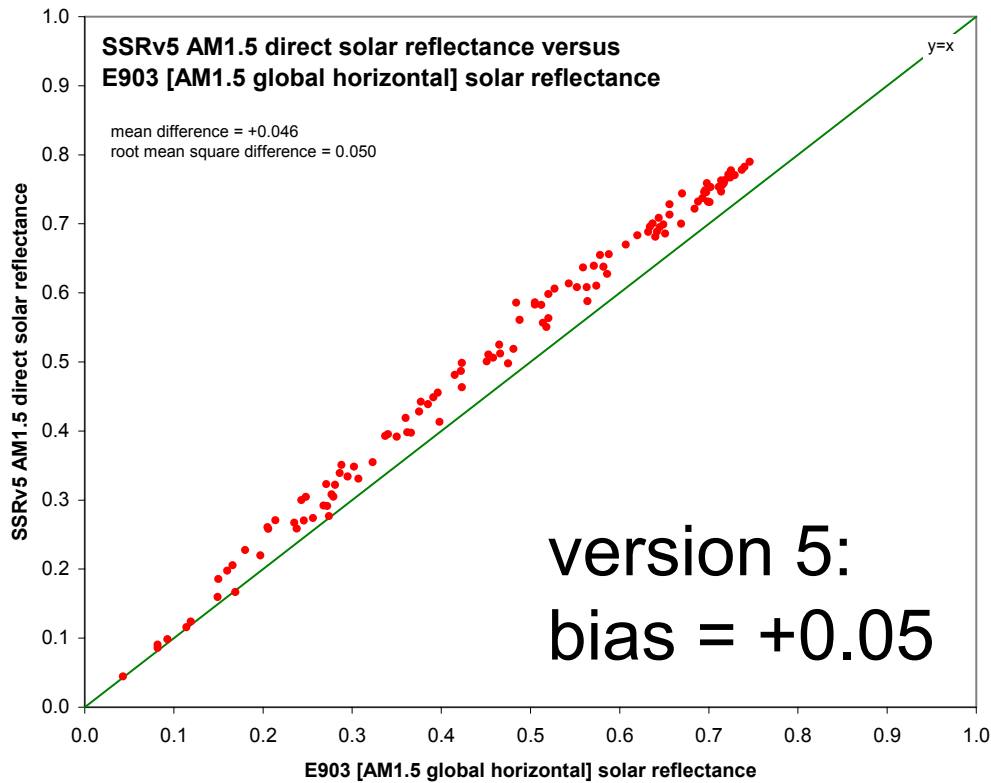
- Issue 1: SSRv5 was designed to measure *direct*, rather than global, solar reflectance
 - direct sunlight has more NIR energy (58%) than does global sunlight (52%)
 - for NIR-reflective cool colors, direct solar reflectance > global solar reflectance
- Issue 2: SSRv5 (especially “red” sensor L2) did not respond quite as designed

- **LBLN helped Devices & Services develop SSR version 6**



Task 1: Correcting SSR (ii)

AM1.5 solar reflectances measured with SSRv5, SSRv6 compared to E903 global



Task 1: Correcting SSR (iii)

- Version 6 makes SSR agree well with E903 AM1.5 global solar reflectance (SR)
 - v5: bias +0.05, rms diff 0.05
 - v6: bias +0.00, rms diff 0.01
- Upgrade details
 - Cost: \$2.5K
 - Turnaround time: 1 week
 - Available mid-April 2008
- Version 6 to measure
 - AM1.5 global SR
 - AM1.5 direct SR
 - AM1.5 diffuse SR
 - AM0 SR
- For comparison, v6 may also emulate v5 measurements of
 - AM0 direct SR
 - AM1 direct SR
 - AM1.5 direct SR
 - AM2 direct SR

Task 1: Correcting SSR (iv)

What's included in upgrade to SSRv6?

- Refurbish SSR-ER to factory specs (excludes major repairs)
- Replace firmware
- Replace Acrylic IR Filter with the 0.156" thick UV-transmissive filter and new spacer ring
- Update the UV detector amplifier circuit to reduce noise by an order of magnitude
- Install a tighter tolerance current sense resistor if not already present (0.1% or better)
- Calibrate and re-mark standards; provide new calibration certificate
- Include Ferro tile or equivalent samples for tracking detector response
- Update labeling according to safety lab report
- Install a separate grounding post
- Other miscellaneous hardware upgrades depending on serial number
- Software updates to improve error reporting

Task 2: Measure solar reflectance of medium-area surface

- Task more challenging than anticipated
 - have evaluated 3 different instrument designs
 - converging on “scanning” technique
- LBNL working with Devices & Services to develop “Scanning SSR”
- Expected scan rate about 1500 cm²/min [1.6 ft²/min]
 - About 4 min to measure 6 ft² shingle board
- May also be useful to measure reflectance of variegated product samples for CRRC rating
 - CRRC requires minimum sample area 2.5 ft²
 - scan time ~ 2 min

2.5.2 Status

- Upgrade to SSR version 6 available mid-April
- Scanning SSR under development this spring

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: **70%**

Published study detailing effects of surface roughness on shingle reflectance



Available online at www.sciencedirect.com



Solar Energy Materials & Solar Cells 92 (2008) 482–489

Solar Energy Materials
and Solar Cells

www.elsevier.com/locate/solmat

Surface roughness effects on the solar reflectance of cool asphalt shingles

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Received 16 February 2007; accepted 19 October 2007



New data on surface roughness

- Paper concluded that granule orientation “texture” is important for high solar reflectance
- Now we have confirmation from additional samples: non-optimal texture can reduce solar reflectance of cool shingle by up to 0.03

Left shingle has preferred texture

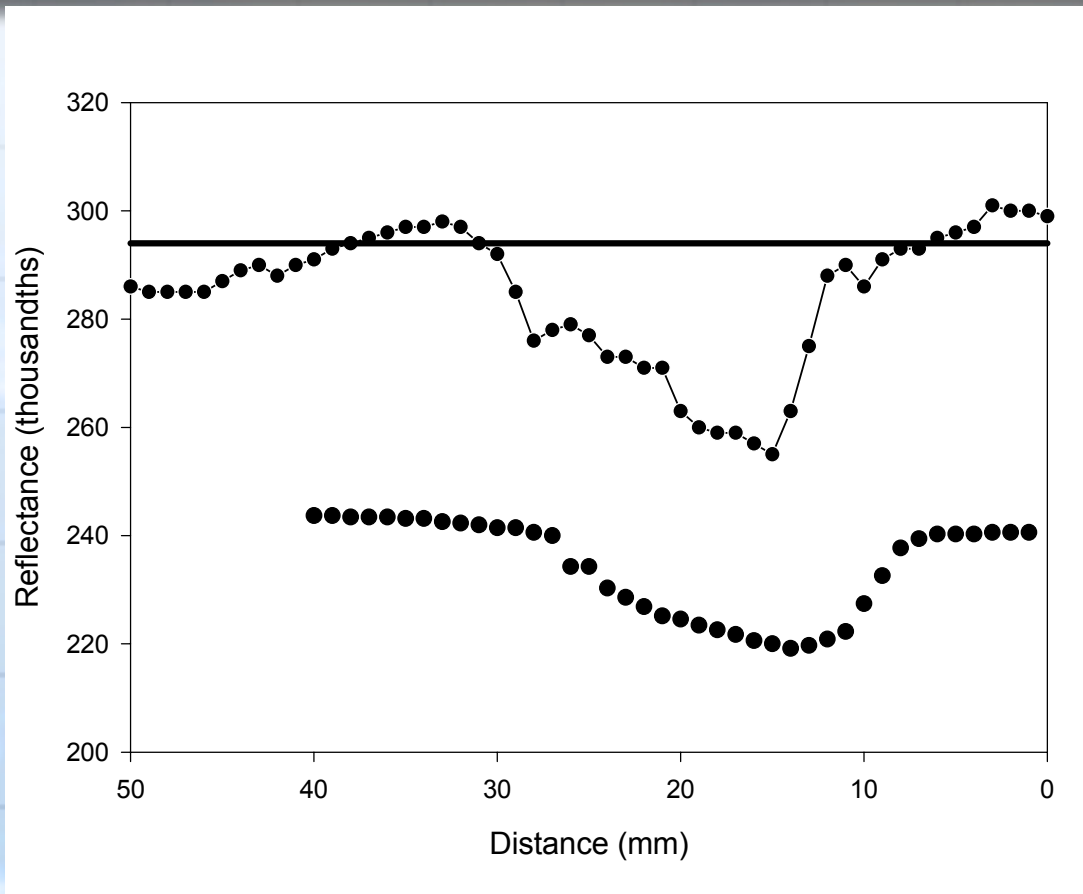


3-year exposure tests now underway at Berkeley Lab (February 2008)



How much does a lap reduce the solar reflectance?

Scan of lap joint with SSR



Mean reflectance 0.294

Size of dip 0.039

FWHM: 10 mm

Scan of 1 mm black line on
paper (divided by 3.5)

FWHM: 13 mm

Effects of laps

- For a 2.5 mm high lap, the size of the reflectance dip is about 1/7 of the total reflectance
- Maximum lap correction for our panels is about -0.0014
- For a typical cool 3-tab shingle layout, the reflectance loss due to laps is roughly -0.007

Asphalt shingle reflectance - future work

- Estimate reflectance changes due to granule loss
 - By how much does a 5% granule loss reduce reflectance?
- Extend our study of texture effects on reflectance
 - Flatbed scans of shingle samples
 - Brightness frequency distributions
 - Collaborate more closely with a shingle manufacturer
- Perform 3 year natural exposure testing with 3M
 - Interpret results in terms of weathering, granule loss, soiling

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: **35%**

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 in 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 DOE-2 to simulate buildings with for low-sloped roofs
- Use MICROPAS if source code is available AND we conclude MICROPAS is suitable
- Evaluate and modify available prototypes

Calculator design

- Building simulation inputs and outputs results stored in relational database
- User defines characteristics of base-case building
- Calculator estimates base-case annual heating energy use, cooling energy use, and peak demand
- User defines characteristics of modified-case building
- Calculator estimates modified-case annual heating-energy use, cooling-energy use, and peak demand
- Calculator estimates the heating- and cooling-energy and peak demand difference between the base and modified case
- Calculator estimates the annual heating- and cooling-energy expenditure difference between the base and modified case

Prototype simulations for buildings with low-sloped roofs

- Three prototypes (two non-residential, one residential)
- Two levels of internal load for non-res building (standard, high)
- Two levels of roof thermal mass for non-res building (standard, high)
- Two stocks of buildings and HVAC systems (pre-1980, post-1980)
- Two types of heating (gas furnace, electric heat pump)
- Six levels of roofing/ceiling insulation (R0, R3, R7, R11, R19, R38)
- Five levels of roof solar reflectance (0.10, 0.20, 0.40, 0.60, 0.80)
- Three levels of roof thermal emittance (0.10, 0.50, 0.90)
- 250 climates (approx)
- **Total simulations: 450,000**
- Simulations outputs: annual heating- and cooling-energy uses, peak demand

Simulation cities (climates)



simulation cities



Base- and modified-case inputs for building with low-sloped roof

- Building location (e.g., ZIP code)
- Building type (three choices)
- Building stock (pre-1980, post-1980)
- Cooling system EER
- Heating system (gas, HP)
- Heating system efficiency (for gas) or EER (for HP)
- Days of operation per week
- Conditioned space under the roof (only the top floor)
- Roof insulation
- Roof thermal mass (high, standard)
- Roof solar reflectance
- Roof thermal emittance
- Internal load (high, standard)
- Gas and electricity unit costs

Prototype simulations for buildings with steep-sloped roofs

- Two prototypes (one non-residential, one residential)
- Two level of internal load for non-res building (standard, high)
- Two level of roof thermal mass (standard, high)
- Two duct location cases (attic, conditioned space)
- Two choices for radiant barrier (yes, no)
- Two choices for above-sheathing ventilation (yes, no)
- Two stock of buildings and HVAC systems (pre-1980, post-1980)
- Gas and heat pump electric heating
- Six roofing/ceiling insulation (R0, R3, R7, R11, R19, R38)
- Five roof solar reflectance (0.10, 0.20, 0.40, 0.60, 0.80)
- Three roof thermal emittance (0.10, 0.50, 0.90)
- 250 climates (approx)
- Total simulations: 4,320,000
- Simulations output: annual heating- and cooling energy uses, peak demand

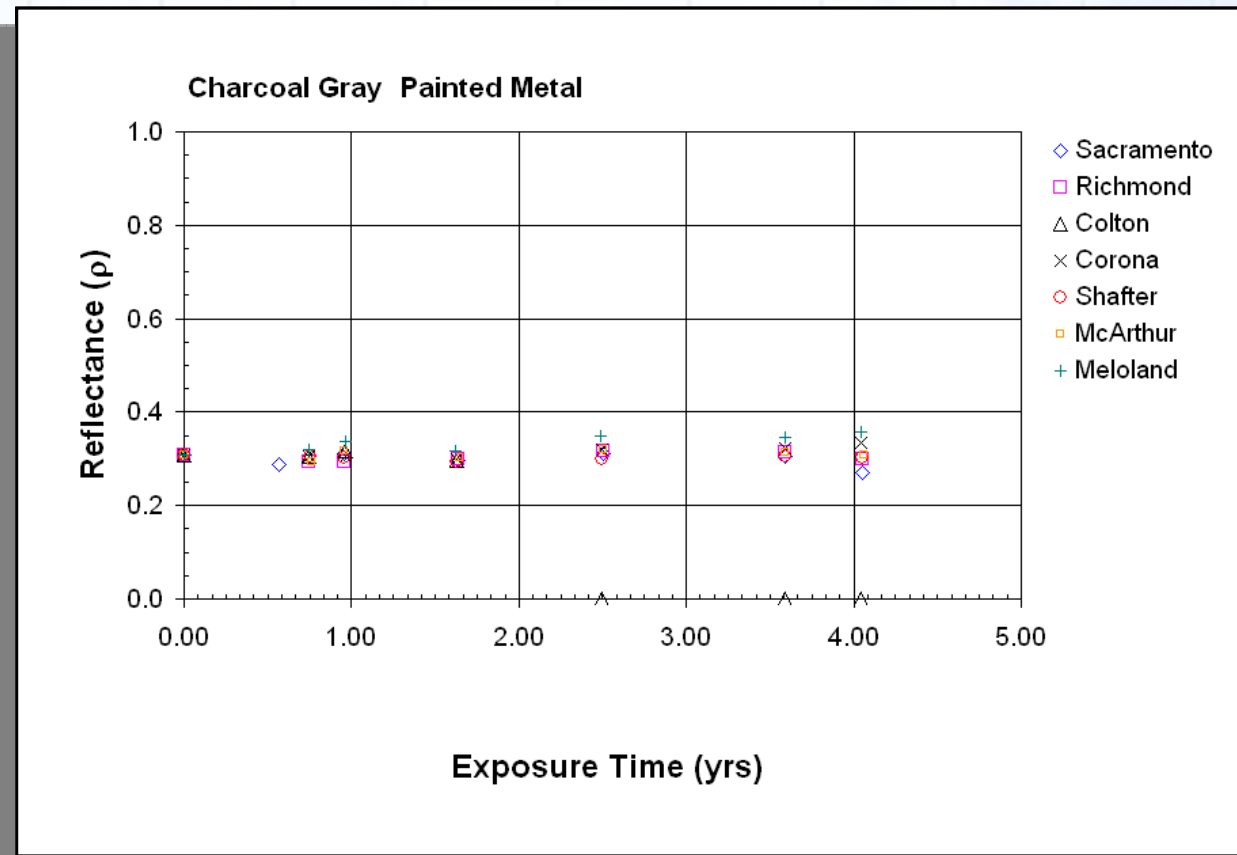
Base- and modified-case building steep-sloped roof input data

- Building location or zip code
- Building type (choice of two)
- Building stock (Pre-1980 and Post-1980)
- Cooling system EER
- Heating system (gas or HP)
- Heating system efficiency (for gas) and EER (for HP)
- Duct location (in attic or conditioned space)
- Radiant barrier (yes, no)
- Above-sheathing ventilation (yes, no)
- Days of operation per week
- Conditioned space under the roof (only the top floor)
- Roof insulation
- Roof thermal mass (high, standard)
- Roof solar reflectance
- Roof thermal emittance
- Internal load (high or standard)
- Gas and electricity unit cost

2.5.5 Conduct natural exposure testing in California

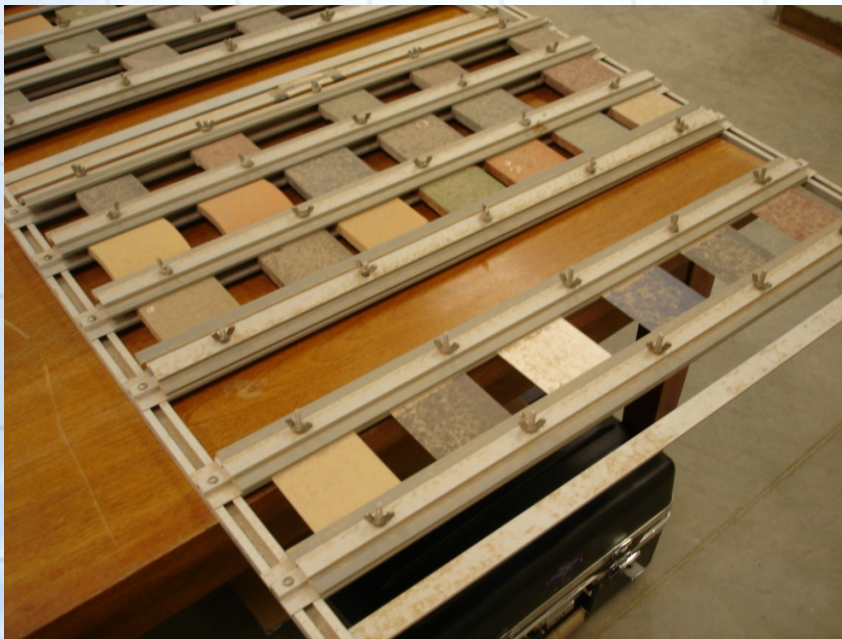
- Objective: Conduct natural exposure testing of currently tested roofing samples and new roofing materials
- Deliverables:
 - A technical report summarizing the results of the exposure testing
- Schedule: 07/20/2006 – 07/20/2009
- Funds expended: 60%

Painted metal, clay tile, and concrete tile maintain solar reflectance after 4 yrs



Deposition of airborne particles analyzed after 1.6, 4.1 yrs of exposure

El Centro Mar 07

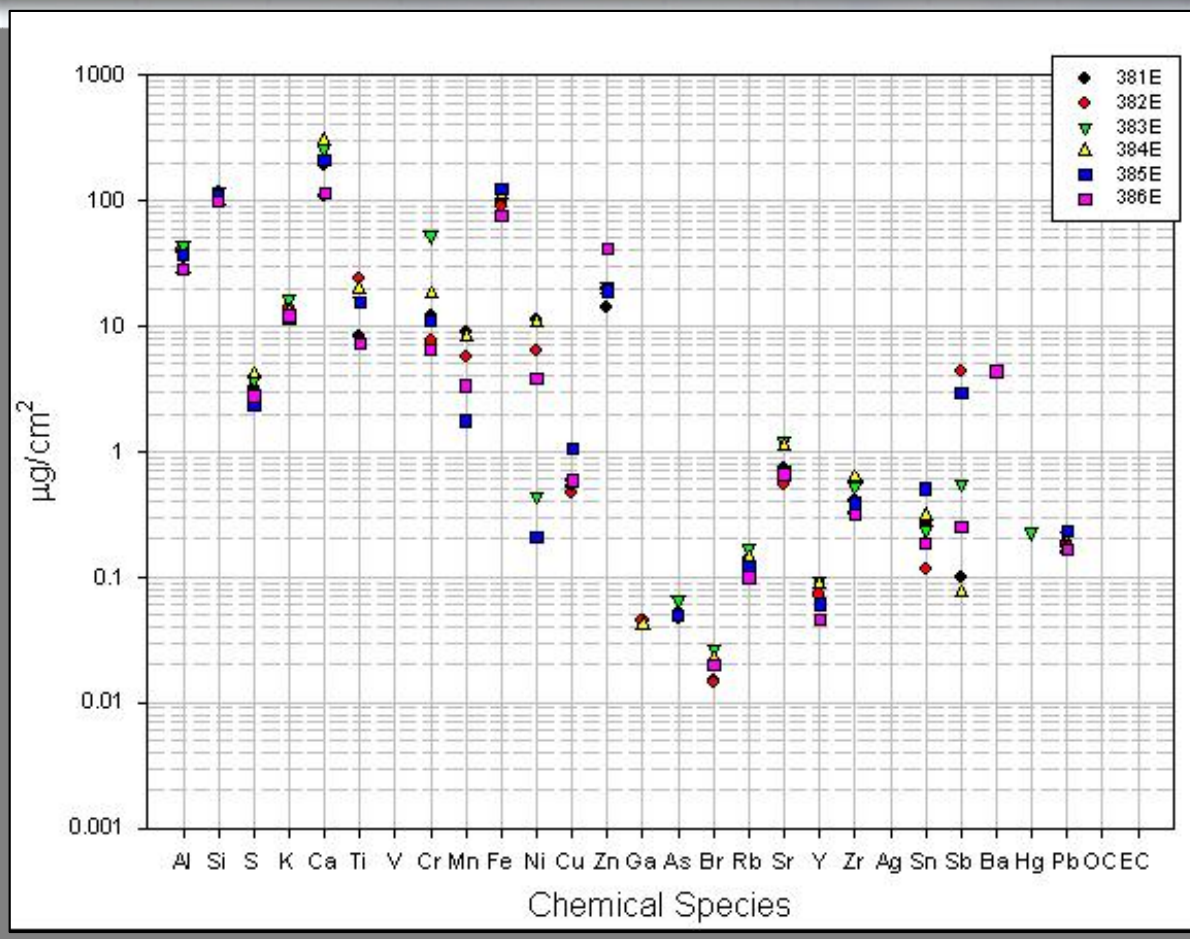


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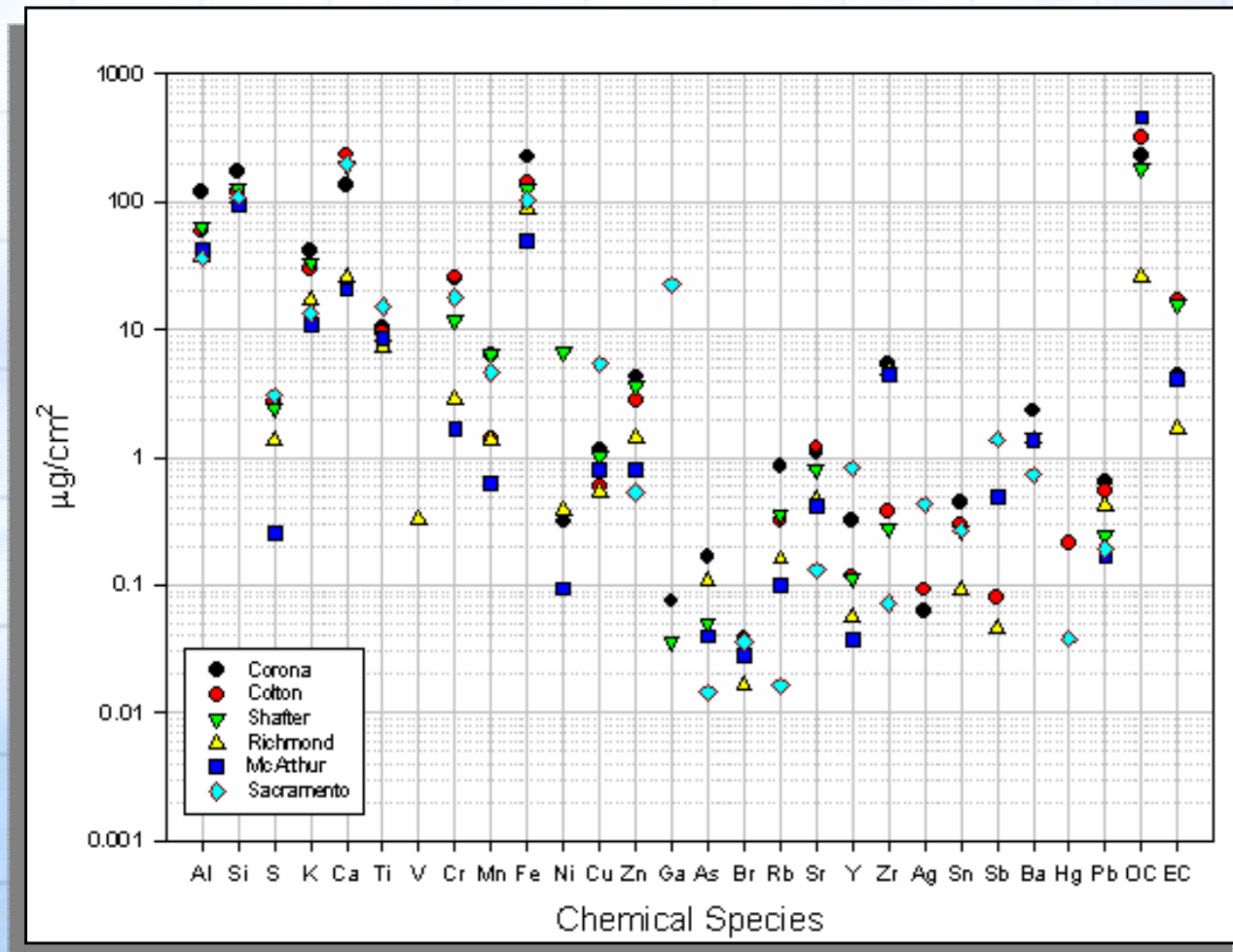


COOLTILE IR COATING™ by American Rooftile Coatings

Contaminants soiling samples at Sacramento



Elemental compositions and carbon content of particulate matter on samples



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: 60%

Clay tile, concrete tile, painted metal, asphalt shingle, and stone-coated metal roofs tested on ESRA

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



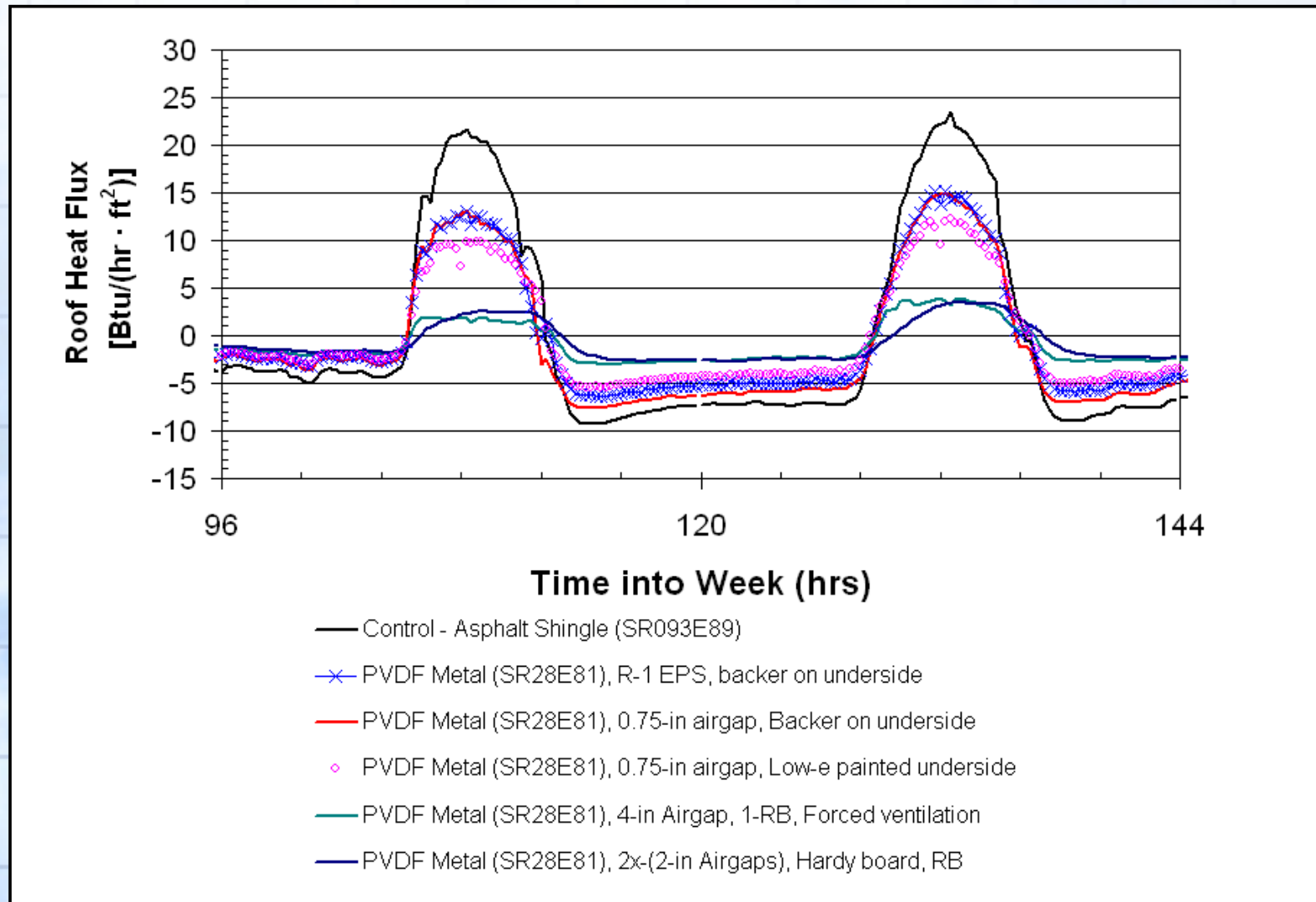
MCA field testing of painted metal



| Lane | Installation | Surface emittance | 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 0.75-in using clips | Backer on metal underside | No insulation above deck |
| 12 | Direct-to-Deck (option for variable space) | 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 |

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

Roof with R-1 insulation placed above deck yields similar thermal performance to roof with $\frac{3}{4}$ -in airspace above deck



AtticSIM II (Attic Simulation) Model

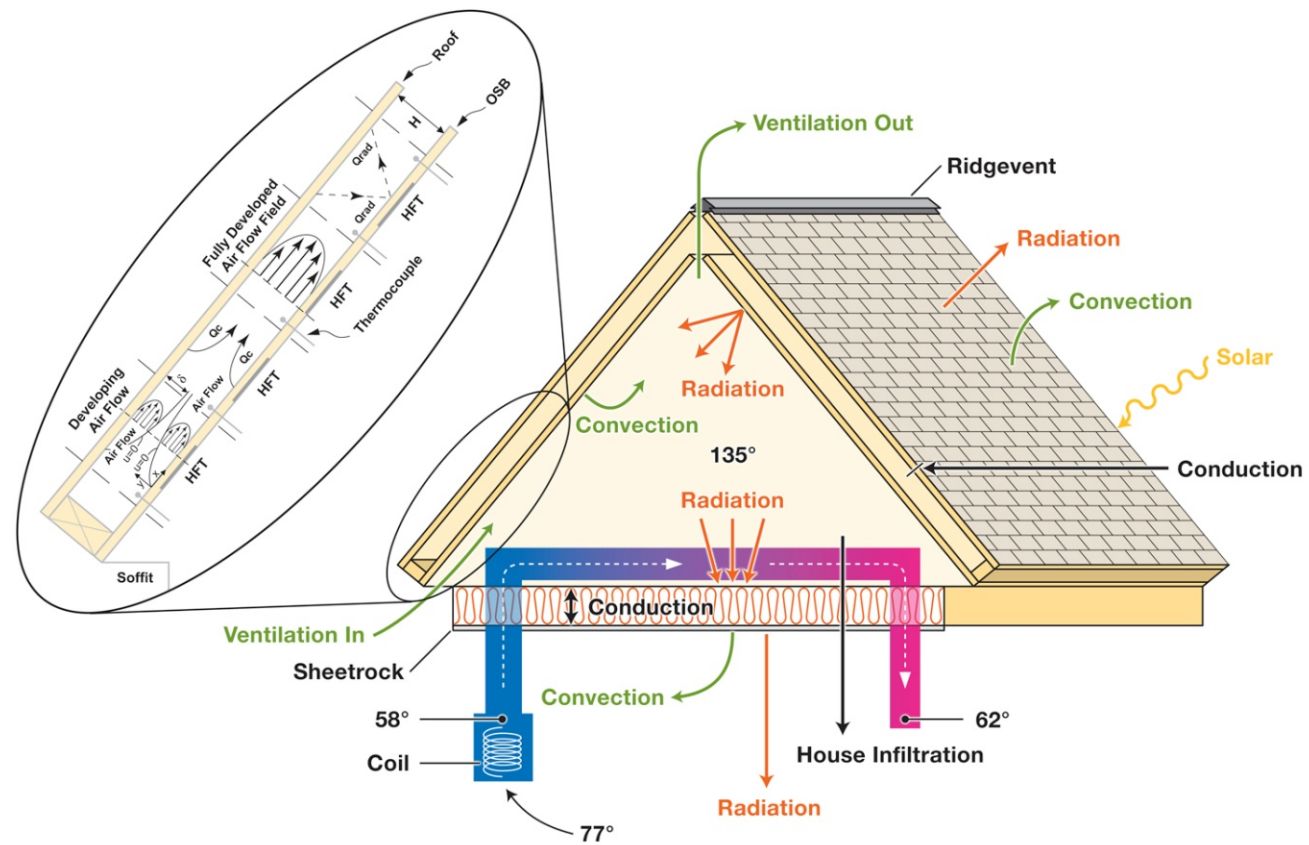


Table 1. Data for daylight hours with average outdoor air temperature of 84°F; 0.75-in air space above sheathing.

| System | Nu number | Temperature (°F) | | | Heat Flux (Btu/hr ft ²) over Day light hours | | | | |
|-------------------|-----------|------------------|----------------|-----------|--|----------------|------------------------|-------------------------|-------------------------|
| | | Roof Underside | Roof Underside | Air Space | Roof deck | Roof Underside | Radiation to sheathing | Convection to air space | Convection to sheathing |
| Open Cavity | 0.9 | 137.9 | 124.9 | 123.5 | 19.0 | 15.7 | 3.3 | 0.3 | 16.0 |
| RB in Open Cavity | 1.1 | 141.7 | 116.9 | 97.8 | 10.2 | 3.0 | 7.3 | 5.3 | 8.3 |

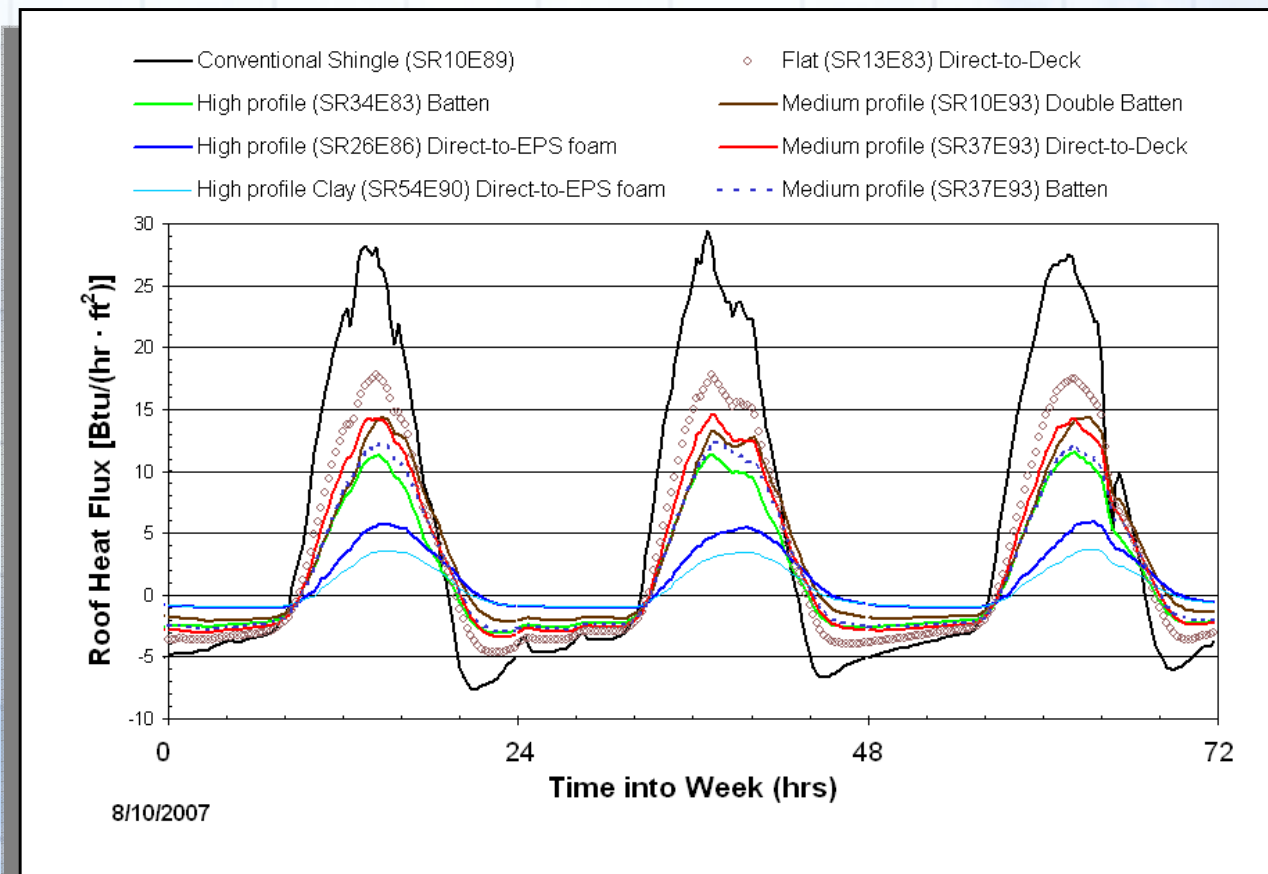
$$h = \frac{k}{\Delta}$$

Medium-profile concrete tile

Same setup used at Fair Oaks Demonstration



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



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

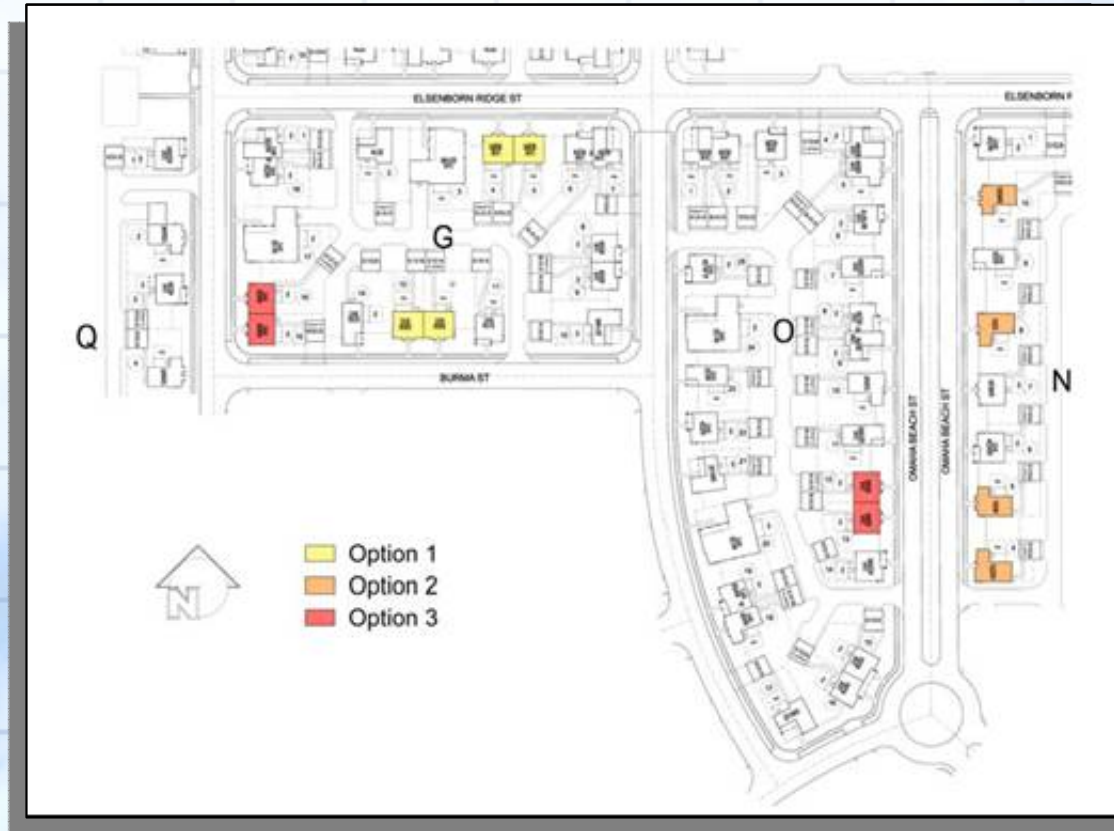
- Objective: Carry out field experiments to evaluate new cool-colored roofing materials in Southern California for validation of the industry-consensus energy savings calculator
- Deliverables:
 - Comparison of validated steep-slope roof calculator to demonstration data
 - A technical report summarizing the results of the field experiments and comparison of the energy-savings calculator
- Schedule: 07/20/2006 – 07/20/2009
- Funds expended: 60%

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



Field experiments collecting data at Fort Irwin

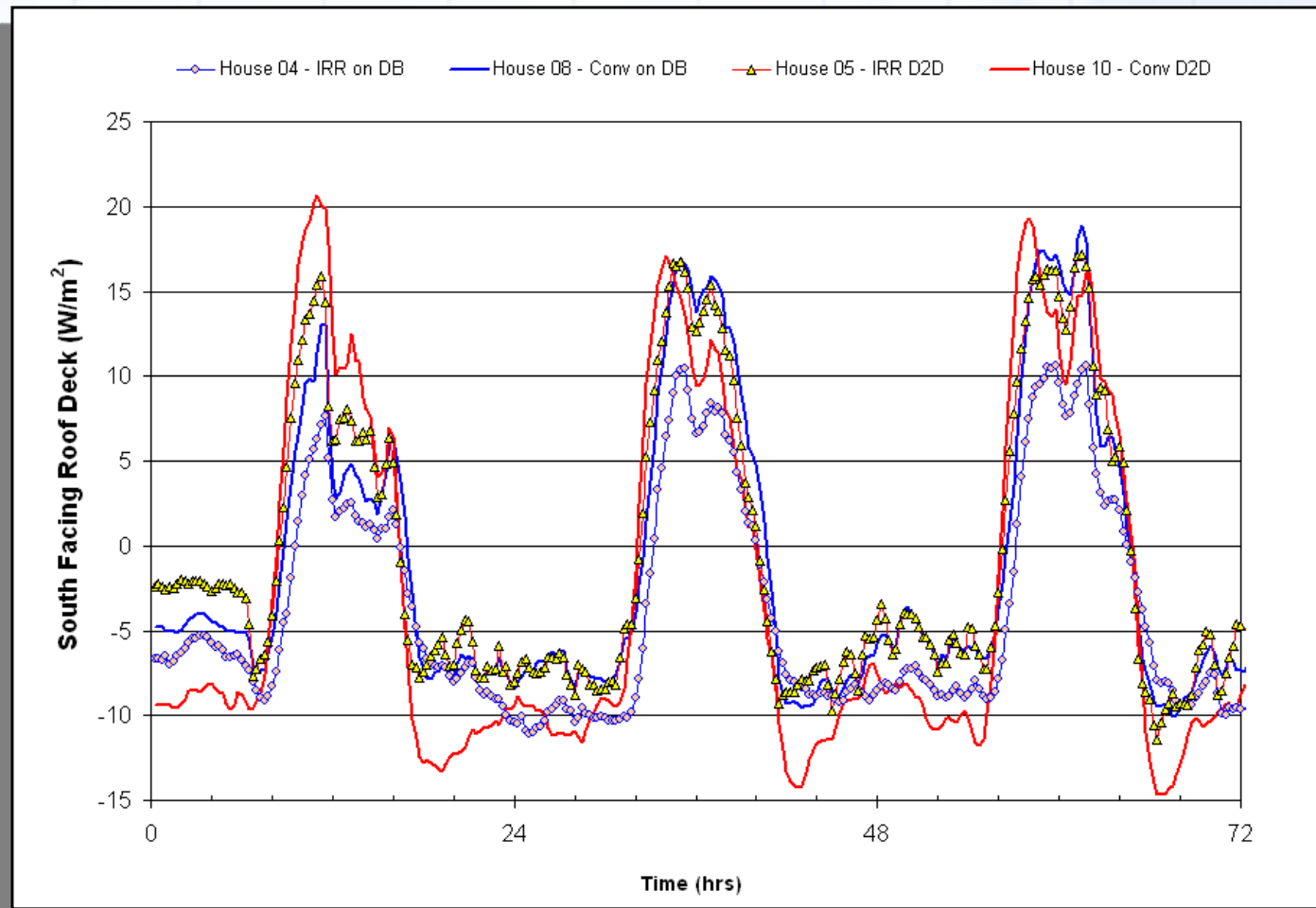
- Test Plan submitted to the CEC
- Memorandum of Understanding in place
- Wiring of 4 homes completed in May 07
- DAS Commissioned Nov. 07
- Energy Star Homes
 - International Residential Code (IRC)
 - 15% more efficient than homes built 2004



South- and north-facing roof deck heat flux

Heat pumps operating in heating mode.

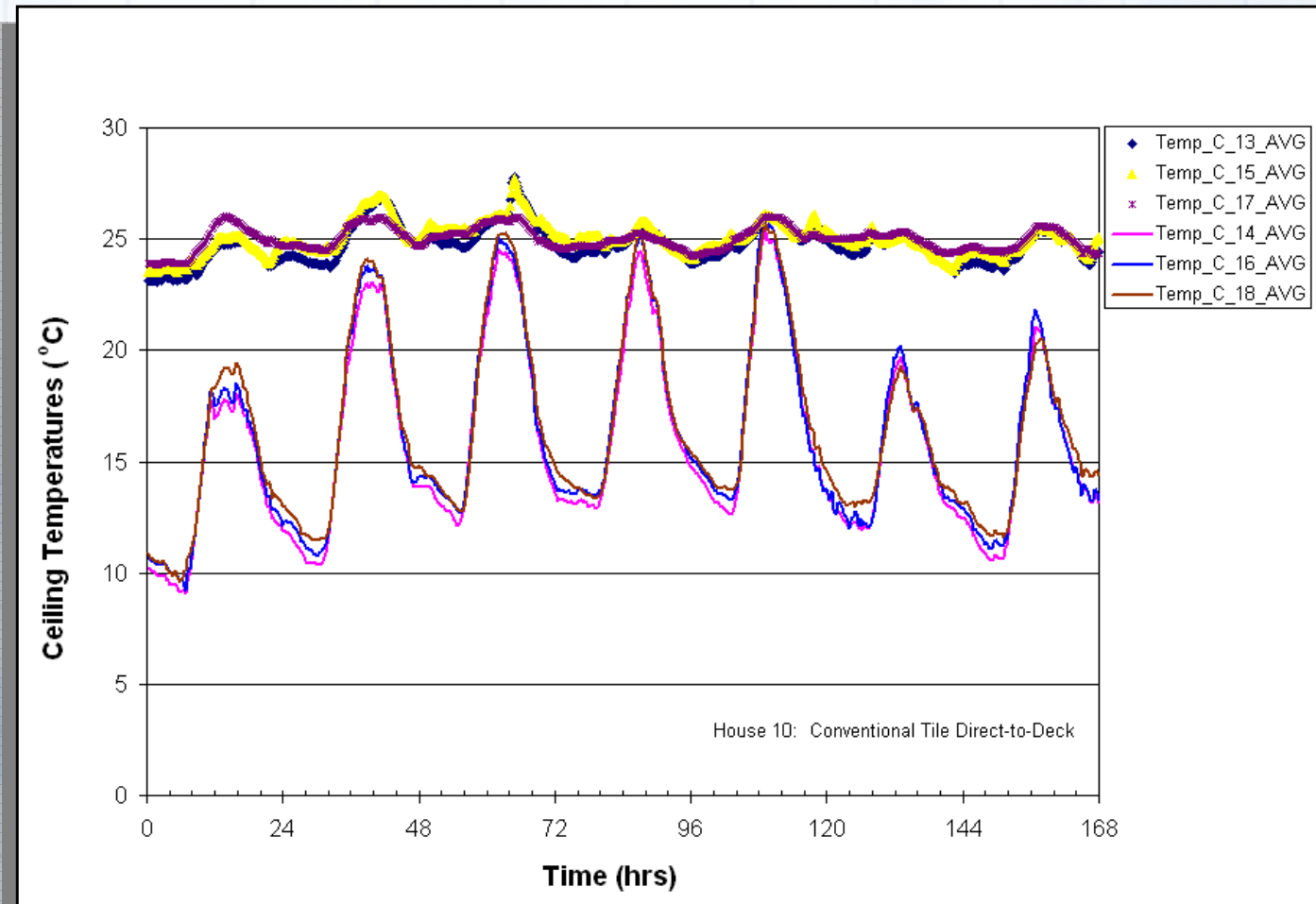
February 22, 2008



Ceiling Temperatures for Heat Flux Calculation

Top of R-38 Batt colder than sheet rock.

House 10: Conventional Tile Direct-to-Deck



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: **85%**

Technology transfer (i)

Published 6 papers in journals, conference proceedings, magazines

- “Surface roughness effects on the solar reflectance of cool asphalt shingles” by Berdahl et al. was published in *Solar Energy Materials and Solar Cells*
- “Global cooling: Effect of urban albedo on global temperature” by Akbari et al. was published at the *PALENC* conference, September 27, 2007; Crete, Greece
- “Status of cool roof standards in the United States” was published at the *PALENC* conference, September 27, 2007; Crete, Greece
- Another cool-roof standards paper by Akbari and Levinson was accepted by *Advances in Building Energy Research*
- “Natural convection heat transfer in roofs with above-sheathing ventilation” by Miller et al. was published in *Thermal Performance of the Exterior Envelopes of Buildings, IX*, proceedings of ASHRAE THERM X, Clearwater, FL, Dec. 2007
- “Procedure for measuring the solar reflectance of flat or curved roofing assemblies” by Akbari et al. was accepted for publication in *Solar Energy*

Technology transfer (ii)

Meeting the public

- On September 20, 2007, Dr. Melvin Pomerantz (member of the Heat Island Group at LBNL) delivered an invited talk about the project's cool colored roofing technology at West Coast Green, the world's largest exhibition for residential builders (San Francisco)
- On September 19, 2007, Akbari conducted a workshop of Heat Island Mitigation and Cool Roof Technologies in Delhi, India
- On September 21, 2007, Akbari gave two presentations (U.S. Cool Roof Standards and Policies; Advances in Cool Roofing Technologies) at the Green Building Congress, in Chennai, India
- On October 19, 2007, Akbari gave a keynote presentation on Cool Urban Surfaces and Global Warming at the GEA conference in Tokyo, Japan
- On November 9, 2007, Akbari and Desjarlais attended the CRRC board meeting
- On December 5, 2007, Akbari gave a keynote presentation on the cool roof standards and technologies at the 38th International Congress on Heating, Refrigeration and Air-conditioning, Beograd, Serbia
- In January 2008, W. Miller presented "Cool Roof Cool Gap Research" at a technical forum of the was guest speaker at the Metal Construction Association Annual
- On February 20, 2007, Akbari and Desjarlais attended the CRRC board meeting in Las Vegas

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>

