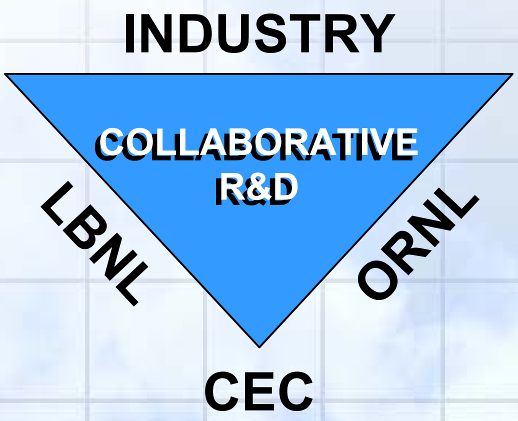
Development of Cool Colored Roofing Materials

Project Advisory Committee (PAC) Meeting



Sponsored by the

California Energy Commission

(Project Manager: Chris Scruton)

September 9, 2004; Oak Ridge, TN

Project Goals

- Bring cool colored roofing materials to market
- Measure and document laboratory and *in-situ* performances of roofing products
- Accelerate market penetration of cool metal, tile, wood shake, and shingle products
- Measure and document improvements in the durability of roofing expected to arise from lower operating temperatures

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Project Advisory Committee (PAC) Members

1. Asphalt Roofing Manufacturers Association
2. Bay Area Air Quality Management District
3. Cedar Shake and Shingle Bureau
4. Cool Metal Roofing Coalition
5. Cool Roof Rating Council
6. DuPont Titanium Technologies
7. Environmental Protection Agency (EPA)
8. EPA San Francisco Office
9. Mike Evans Construction
10. National Roofing Contractors Association
11. Pacific Gas and Electric Company (PG&E)
12. Tile Roof Institute
13. Southern California Edison Company (SCE)

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Industrial Partners

- 3M
- BASF
- CertainTeed
- Custom-Bilt Metals
- Elk Manufacturing
- Ferro
- American Roof Tile Coatings
- GAF
- Hanson Roof Tile
- ISP Minerals
- MCA
- Monier Lifetile
- Steelscape
- Shepherd Color

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Project Team

- **LBNL**
  - Steve Wiel (Project Director) SWiel@LBL.gov
  - Hashem Akbari (Technical Lead) H_Akbari@LBL.gov
  - Paul Berdahl PHBerdahl@LBL.gov
  - Ronnen Levinson RMLevinson@LBL.gov
- **ORNL**
  - André Desjarlais (Technical Lead) yt7@ORNL.gov
  - Bill Miller wml@ornl.gov

Technical Tasks

- 2.4 Development of cool colored coatings
- 2.5 Development of prototype cool-colored roofing materials
- 2.6 Field-testing and product useful life testing
- 2.7 Technology transfer and market plan

2.4 Development of Cool Colored Coatings

- Objectives
  - Maximize solar reflectance of a color-matched pigmented coating
  - Compare performance of a coated roofing product (e.g., a shingle) to that of a simple smooth coating
- Subtasks
  - Identify & characterize pigments with high solar reflectance
  - Develop software for optimal design of cool coatings
  - Develop database of cool-colored pigments

2.4.1 Identify & Characterize Pigments w/High Solar Reflectance

- Objective: Identify and characterize pigments with high solar reflectance that can be used to develop cool-colored roofing materials
- Deliverables:
  - Pigment Characterization Data Report (2 papers submitted to journal)
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 97%

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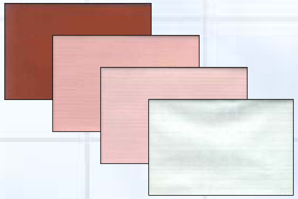
Completed Study of Masstones (Pure Color Paints)

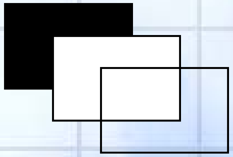
- Levinson, Berdahl, and Akbari submitted two papers to *Solar Energy Materials & Solar Cells*
  - Solar Spectral Optical Properties of Pigments, Part I: Model for Deriving Scattering and Absorption Coefficients from Transmittance and Reflectance Measurements
  - Solar Spectral Optical Properties of Pigments, Part II: Survey of Common Colorants

Completed Characterization of Tints (Mixtures of Colors w/White)

- Prepared, characterized 57 “tint ladders”
  - pure color (masstone)
  - 1 part color: 4 parts white
  - 1 part color: 9 parts white
  - white



- Three backgrounds for each tint ladder
  - black
  - white
  - none



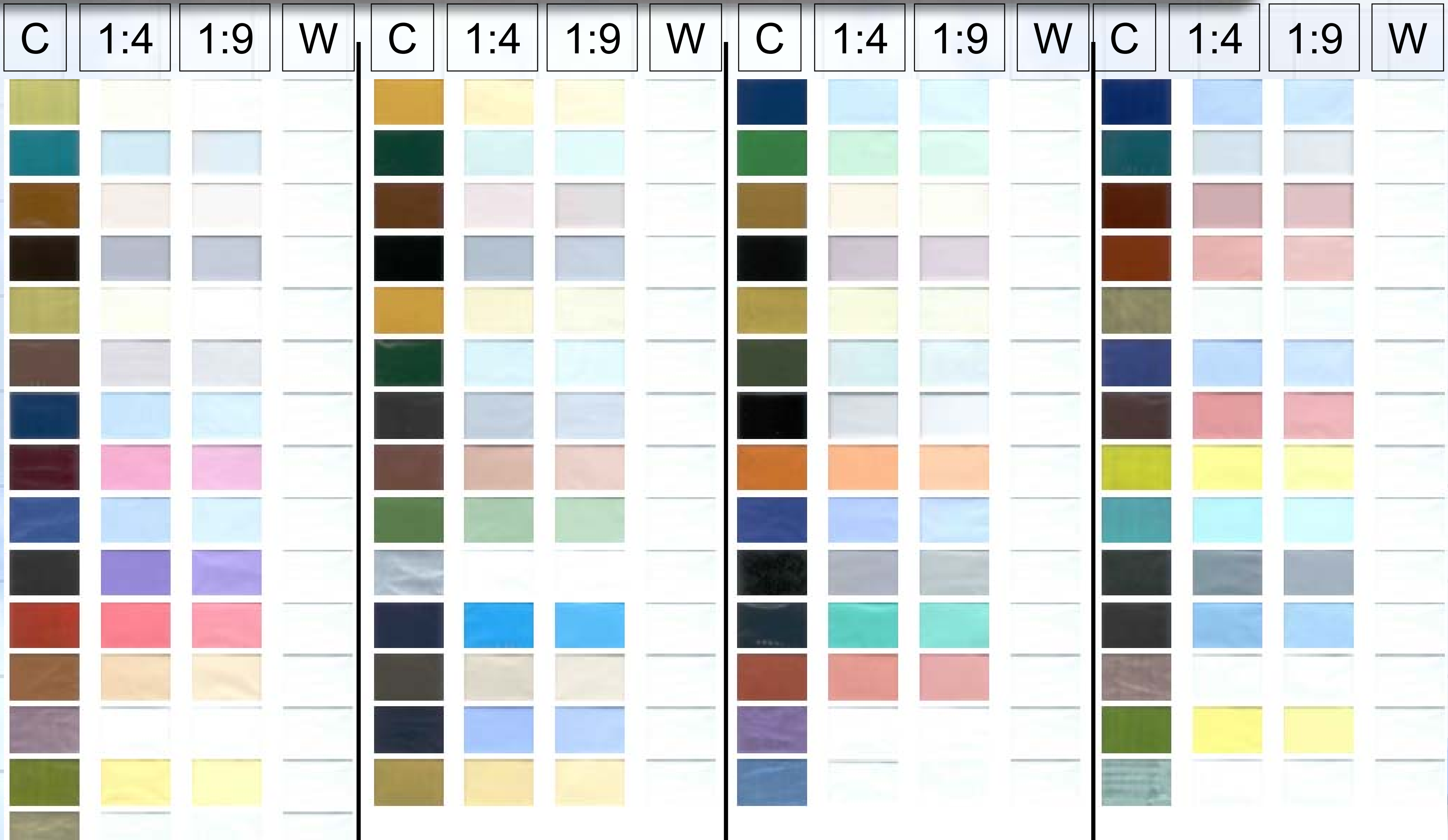
- Computed Kubelka-Munk absorption and scattering coefficients (K, S)
  - used to refine mixture model for coating formulation software

Tint Ladders Over White

C=color
1:4=1C:4W
1:9=1C:9W
W=white

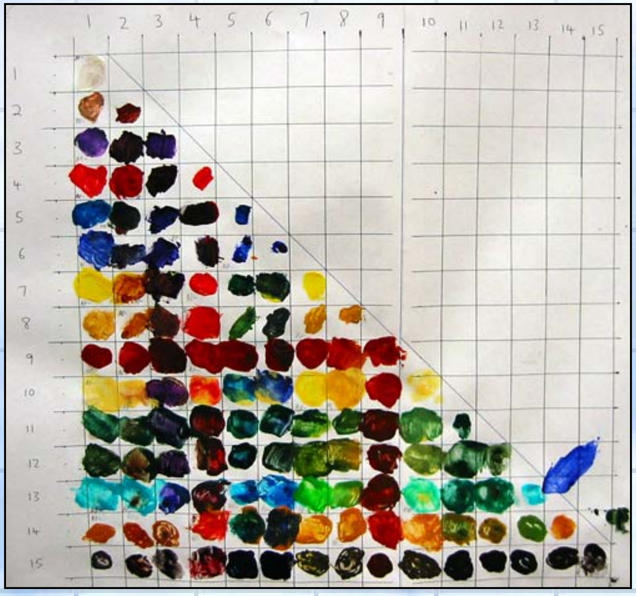
Tint Ladders Over Black

C=color
1:4=1C:4W
1:9=1C:9W
W=white



Characterization of Nonwhite Mixtures: Cool Color Combinations

- Initial focus includes 15 cool colors
- Inspected 105 binary mixtures (1:1)
- Chose 32 appealing cool color combinations

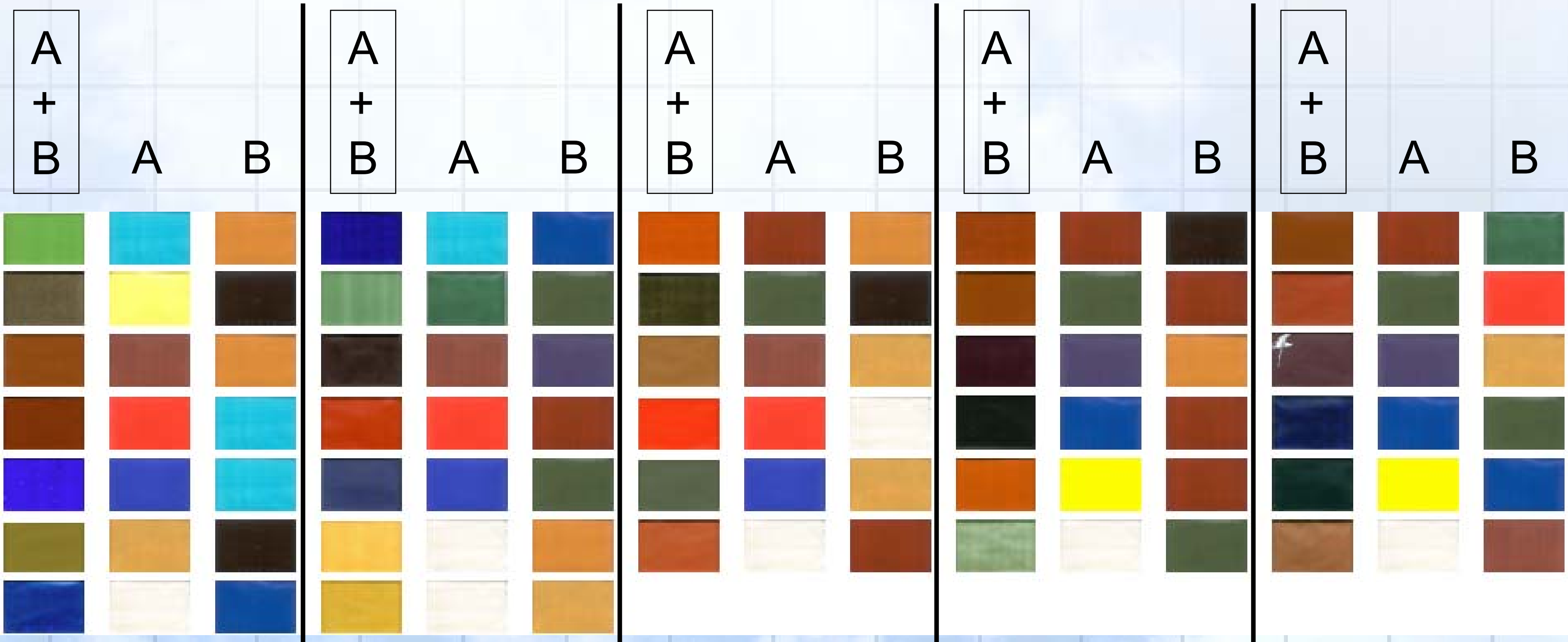


105 equal-volume binary mixtures (15 colors taken two at a time)

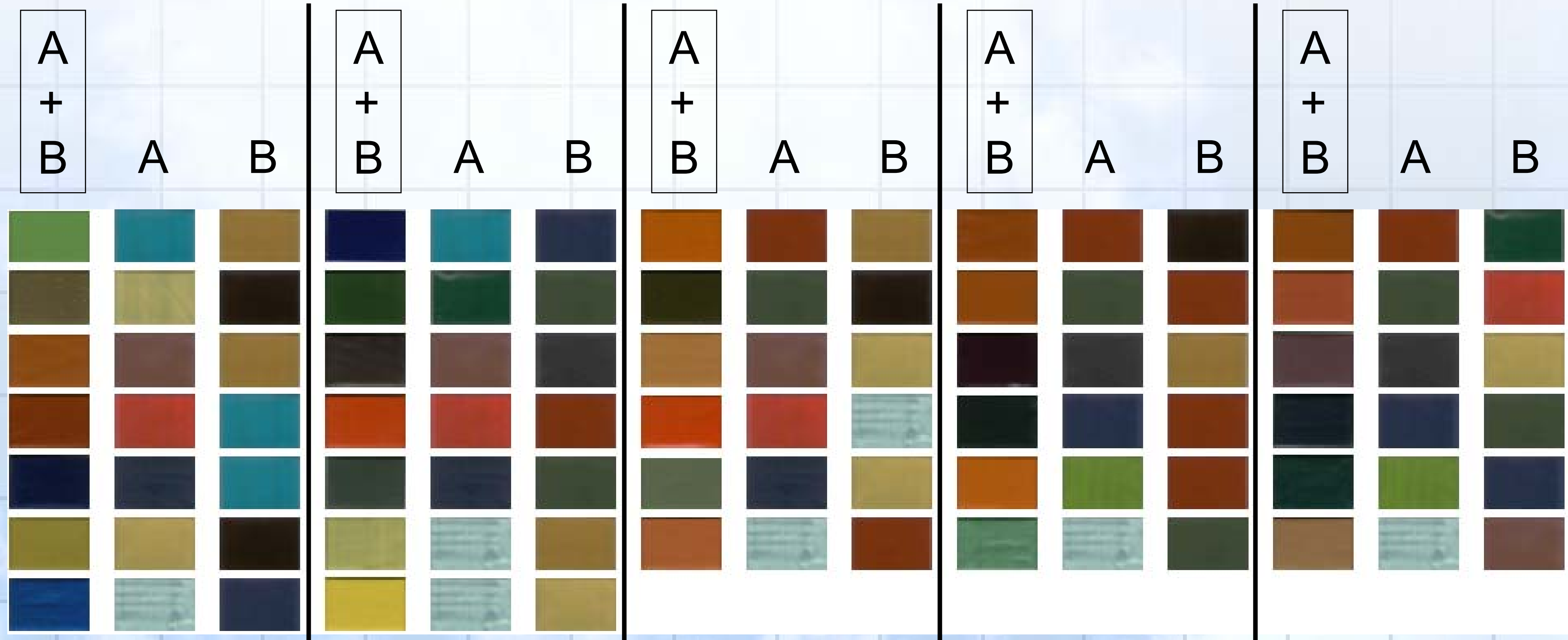
Characterization of Nonwhite Mixtures: Equal Volumes

- Prepared, characterized 32 nonwhite mixtures
  - equal volumes of each color paint
  - same technique previously applied to masstones and tints
- Computed Kubelka-Munk absorption and scattering coefficients (K, S)
  - used to refine mixture model for coating formulation software

Equal-Volume Mixtures Over White



Equal-Volume Mixtures Over Black



Pigment Characterization: Next Steps

- Task is essentially complete

  …though more could be done
- Time permitting, will prepare
  - 1:4 mixtures
  - 4:1 mixtures

  of same 32 cool color combinations to refine mixture model

2.4.2 Develop a Computer Program For Optimal Design of Cool Coating

- Objective: Develop software for optimal design of cool coatings used in colored roofing materials
- Deliverables:
  - Computer Program
- Schedule: 11/1/03 – 12/1/04
- Funds Expended 55%

Step 1: Development of Mixture Model

- Coating design software requires
  - database of pigment properties (ready)
  - optimization algorithm (to be chosen)
  - **model for absorption, scattering of mixture**
- Simple volumetric model: each component contributes volumetrically to absorption K and scattering S of mix, such that

$$K_{mix} = \sum c_i K_i$$

$$S_{mix} = \sum c_i S_i$$

where c_i = volume fraction of component i

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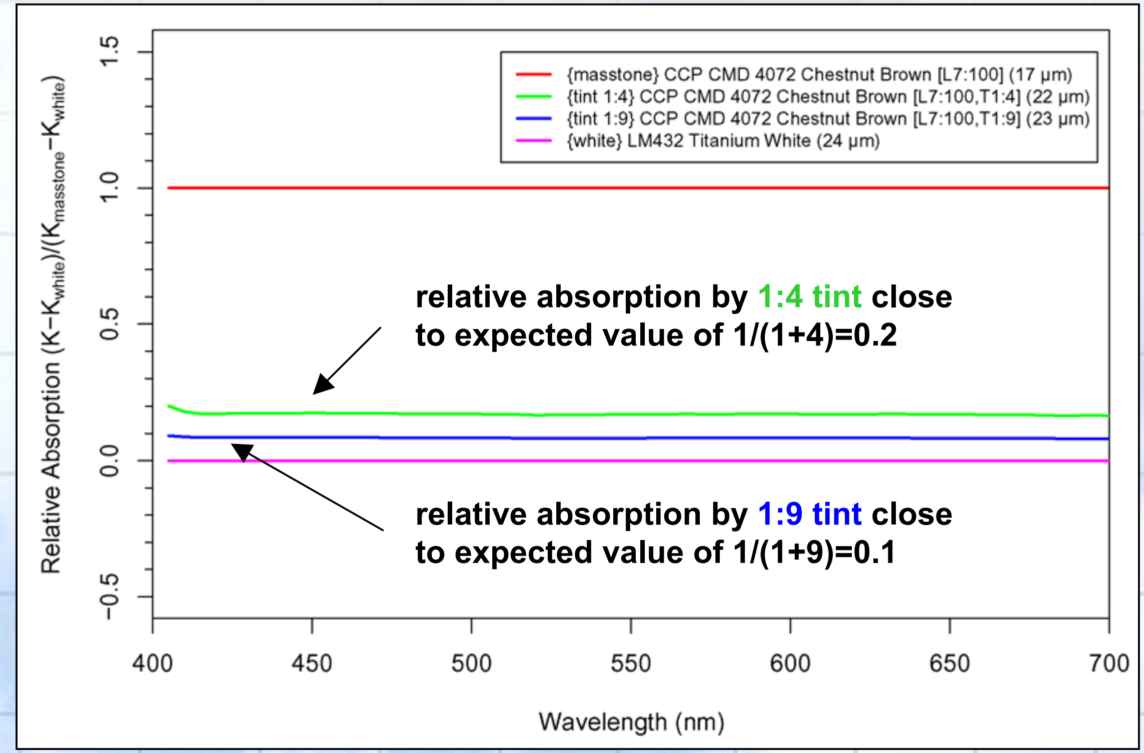
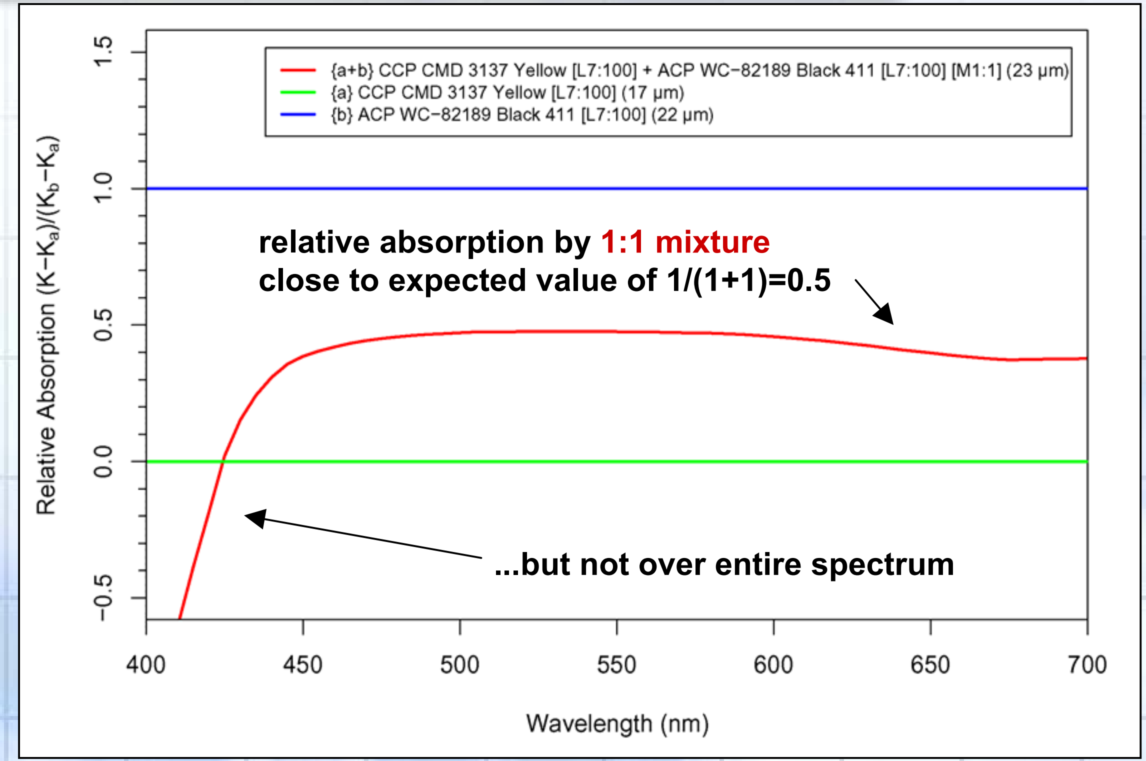
Example 1: Absorption by Tints

- Volumetric model often works for **absorption by tints**
- Relative absorption $K_{relative}=(K-K_{white})/(K_{masstone}-K_{white})$



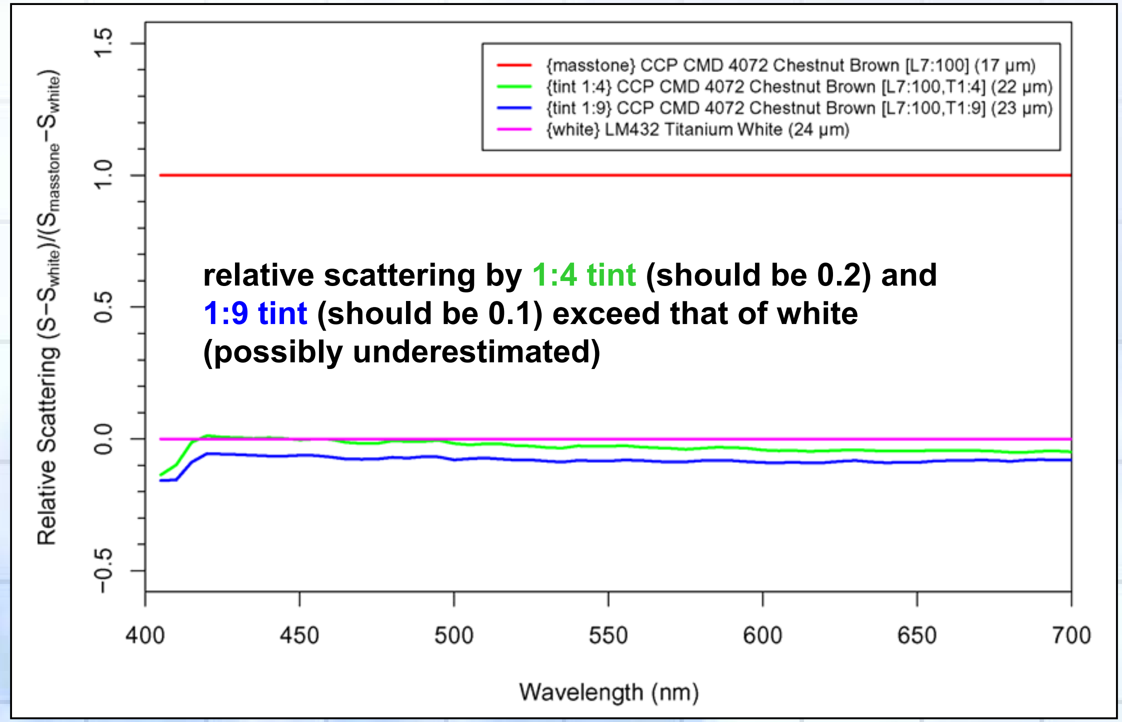
Example 2: Absorption by Mixtures

- Volumetric model occasionally works for **absorption by nonwhite mixtures**
- Relative absorption
  $K_{relative}=(K-K_a)/(K_b-K_a)$
  [a,b are components]



Example 3: Scattering by Tints

- Volumetric model *might* work for **scattering by tints** (analysis is ongoing)
- Relative scattering
  $S_{relative}=(S-S_{white})/(S_{masstone}-S_{white})$



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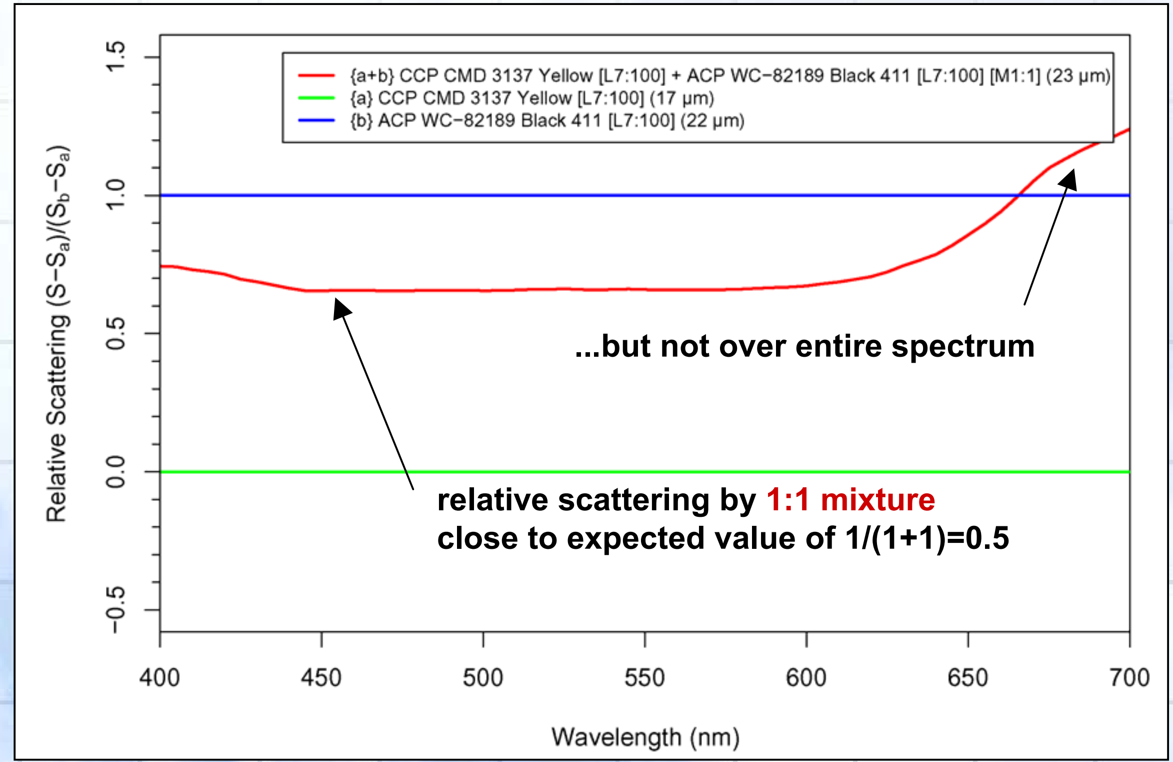
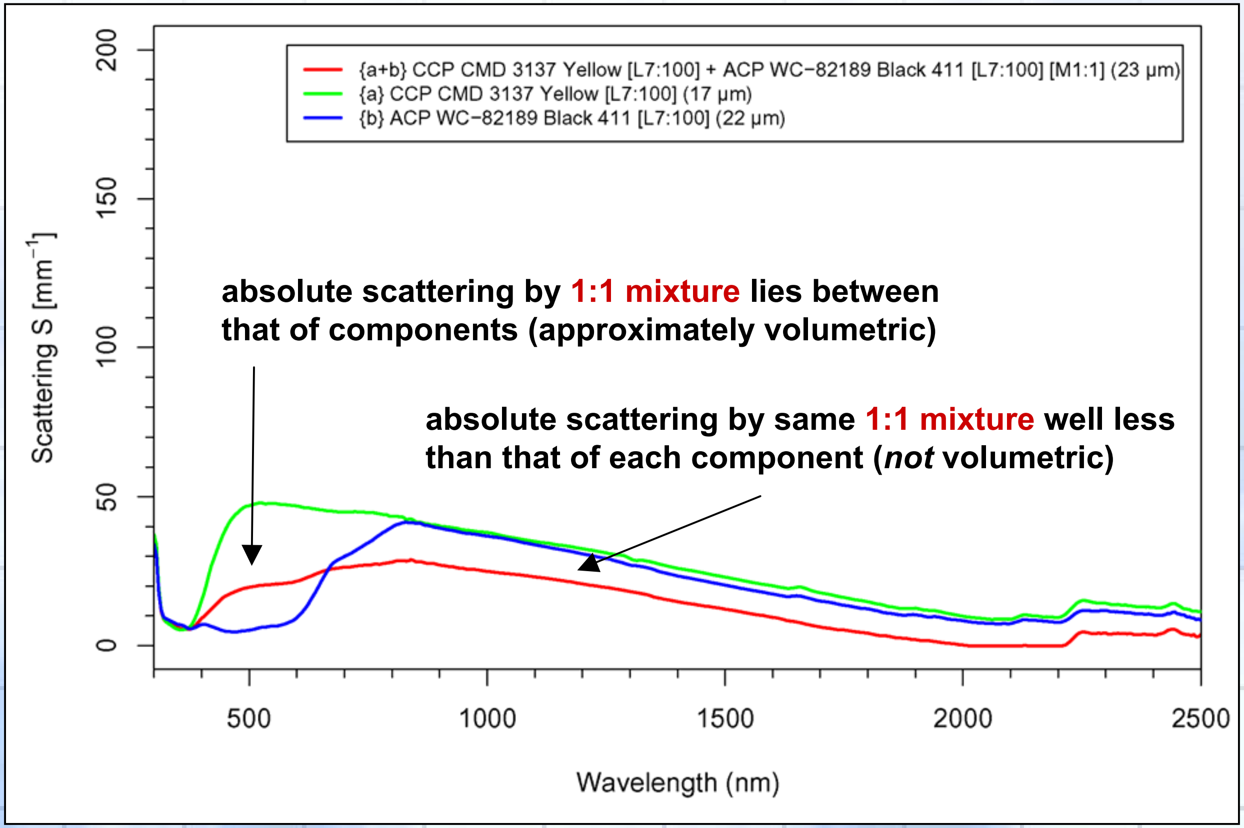
Example 4: Scattering by Mixtures

- Volumetric model occasionally works for **scattering by nonwhite mixtures**
- Relative scattering
  $S_{relative}=(S-S_a)/(S_b-S_a)$
  [a,b are components]



Simplest (Volumetric) Model Often Fails For Scattering by Mixtures



Refining the Mixture Model

- Analyze scattering by tints
  - $S_{tint} > S_{white}$ seems wrong
  - have we underestimated S_{white} or overestimated S_{tint}?
- Develop better physical model
  - Why are K_{mix} and S_{mix} not volumetric?
- Develop better empirical model
  - Are K_{mix} and S_{mix} each influenced by <u>both</u> K_i and S_i?

Overview of Coating Formulation Software

- Purpose: suggest formulas for color-matched nonwhite coatings with high solar reflectance
- Inputs
  - Absorption, scattering coefficients of pure colors (pigment database)
  - Desired visible reflectance spectrum or color of coating (latter is less well defined)
  - Constraints (e.g., pigment palette, film thickness)
- Outputs
  - Coating formulations (volume fractions of pure colors)
  - Predicted solar reflectance
  - Predicted color & solar spectral reflectance

Operational Details (to be discussed with partners)

- Minimalist interface
  - Input = text file detailing target appearance, pigment palette, and constraints
  - Output = text file detailing formulas, predicted reflectances, predicted colors
- Code
  - maximizes solar reflectance while constraining color
  - mixture model + optimization algorithm
  - platform: “R” (Windows, Mac, Linux, Unix; **free**)

Software Development: Next Steps

- Finalize mixing model
- Choose optimization algorithm
- Share code w/partners

2.4.3 Develop Database of Cool-Colored Pigments

- Objective
  - Develop a database that can be readily used by the industry to obtain characteristic pigment information for the design of cool-colored coatings
- Deliverables
  - Electronic-format Pigment Database
- Schedule: 6/1/03 – 6/1/05
- Funds Expended 50%

Cool Colored Pigment Database: Updates

- Database online at http://CoolColors.LBL.gov
  - partners may contact Ronnen for password
- Now describes **233** pigmented coatings
  - 87 masstones (pure colors)
  - 57 ratio 1:4 tints (new!)
  - 57 ratio 1:9 tints (new!)
  - 32 ratio 1:1 nonwhite mixtures (new!)
- Possible future additions (time permitting)
  - ratio 1:4, 4:1 nonwhite mixtures

2.5 Develop Prototype Cool-Colored Roofing Materials

- Objective: Work with manufacturers to design innovative methods for application of cool coatings on roofing materials
- Subtasks:
  - Review of roofing materials manufacturing methods
  - Design innovative engineering methods for application of cool coatings to roofing materials
  - Accelerated weathering testing

2.5.1 Review Roofing Materials Manufacturing Methods

- Objective: Compile information on roofing materials manufacturing methods
- Deliverables:
  - Methods of Fabrication and Coloring Report (prepared on July 1, 2003)
- Schedule: 6/1/02 – 6/1/03
- Funds Expended 99%

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Updated and Finalized the Roofing "Manufacturing" Report

- Akbari, Levinson, and Berdahl. 2004. "A Review of Methods for the Manufacture of Residential Roofing Materials," to be submitted for journal publication

2.5.2 Design Innovative Engineering Methods for Application of Cool Coatings To Roofing Materials

- Objective: Work with manufacturers to design innovative methods for application of cool coatings on roofing materials
- Deliverables:
  - Summary Coating Report
  - Prototype Performance Report
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 85%

Engineering Methods Overview

- Collaborating with 12 companies
  - shingles/granules
  - tiles/tile coatings
  - metal/metal coatings
  - pigments
- Prototypes developed and characterized include (~)
  - 120 shingles
  - 30 tiles or tile coatings
  - 20 metal panels

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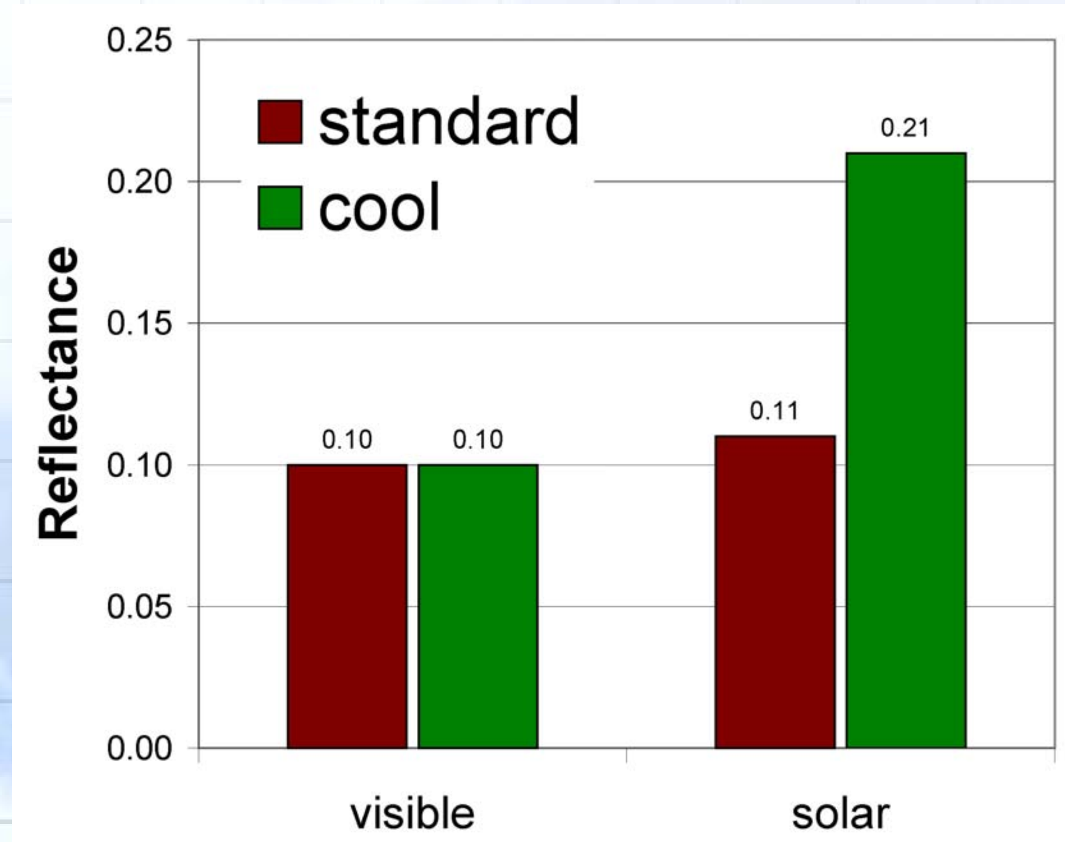
Recent Activities

- Development of cool granules using
  - reflective undercoats (e.g., TiO_2 white)
  - topcoats with cool nonwhite pigments (identified in Pigment Characterization Task 2.4.1)
- Development of cool shingles
  - collaboration with industrial partners
  - characterized about 70 prototypes
  - several dark to medium color prototypes have solar reflectances of 0.20 - 0.36

Example 1: Cool Dark Brown Shingle (representive image)



- Matches standard dark brown shingle
- Solar reflectance R > 0.2
- Next version may achieve R > 0.25 (Energy Star)

Example 2: Cool Light Brown Tile (photographed in sunlight)

standard: R=0.23

cool: R=0.28

R = solar reflectance

Example 3: Cool Gray Shingle (photographed in sunlight)

standard: R=0.27

cool: R=0.36

R = solar reflectance

Example 4: Cool Reddish Shingle (photographed in sunlight)

standard: R=0.28

cool: R=0.37

R = solar reflectance

Engineering Methods: Next Steps

- Improve shingles
  - increase use of cool pigments
  - increase reflectance of undercoating
- Time permitting, work on
  - concrete tile
  - clay tile

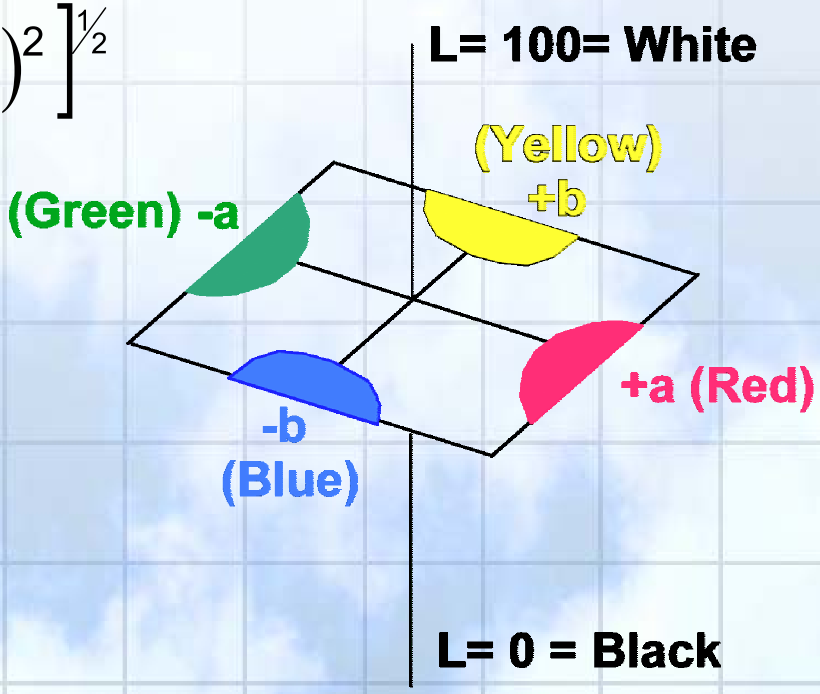
2.5.3 Accelerated Weathering Testing

- Objective: Identify latent materials defects early by accelerated weathering tests
- Deliverables:
  - Accelerated Weathering Testing Report
- Schedule: 11/1/02 – 6/1/05
- Funds Expended 15%

PIGMENT FADE RESISTANCE

- Total Color Difference measure ΔE

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2}$$

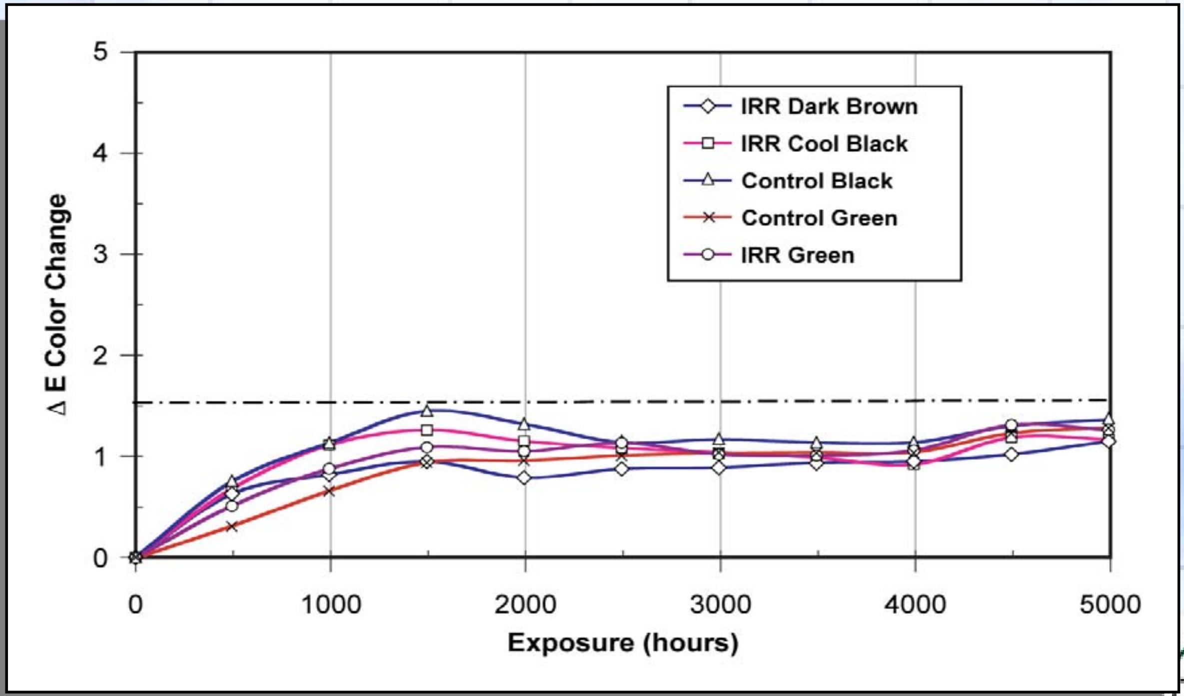


Proven Fade Resistance for Painted Metal Roofs with CRCMs

- Xenon-arc exposure for 5000 hours

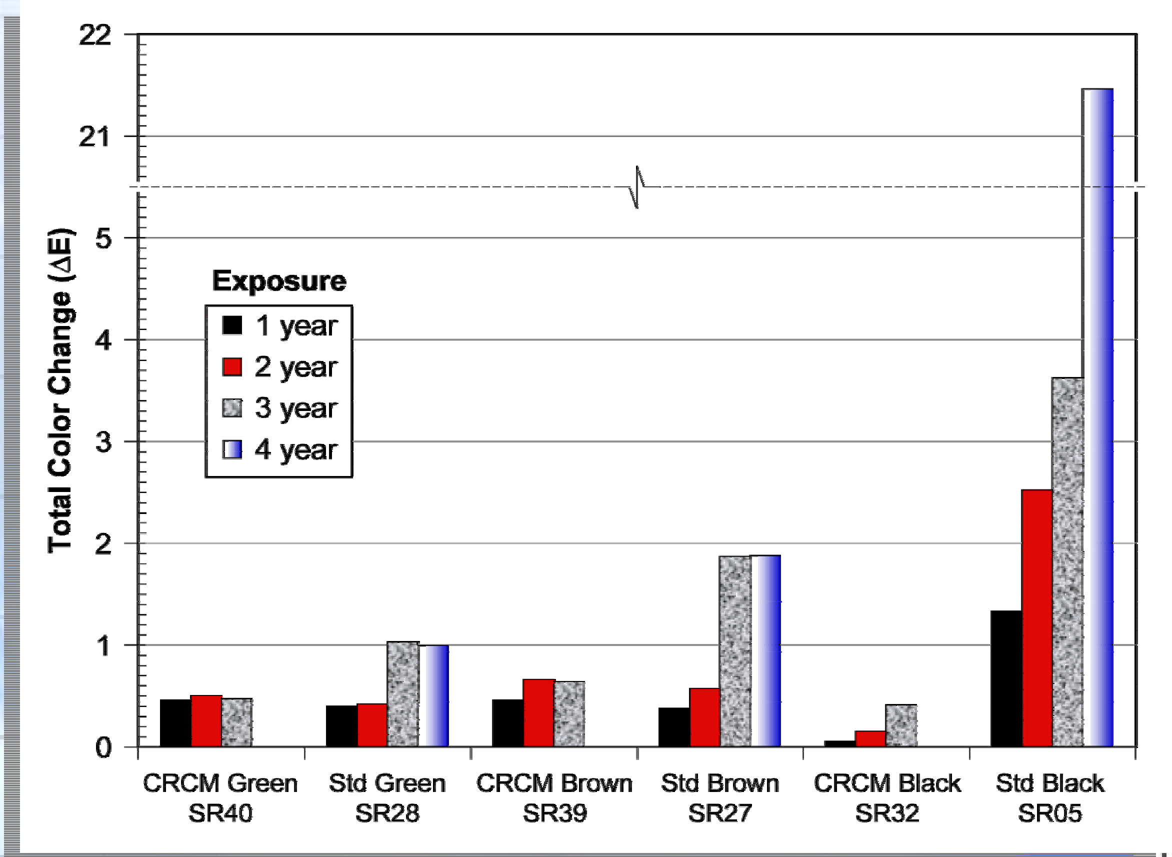
  Coil-coated metal roofing warranted for 20 yrs

  - require $\Delta E \leq 5$



Three years of field exposure in Florida shows improved fade resistance

Painted PVDF metals



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Next Steps

- Collect additional industry data on accelerated weathering tests
- Integrate with weather farm data
- Prepare a report summarizing performance of cool pigments

2.6 Field-testing and Product Useful Life Testing

- **Objective:** Demonstrate, measure and document the building energy savings, improved durability and sustainability of Cool Roof Color Materials (CRCMs)

- Subtasks:
  - Building energy-use measurements at California demonstration sites
  - Materials testing at weathering sites in California
  - Steep-slope assembly testing at ORNL
  - Product useful life testing

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2.6.1 Building Energy-Use Measures at California Demonstration Sites

- **Objective:** Setup residential demonstration sites; measure and document the energy savings of CRCMs
- Deliverables:
  - √ Site Selection: Cavalli Hills, Fair Oaks,CA
    Shingle & Cedar Shake Demonstrations
  - √ Site Test Plan
  - – Test Site Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 77 %

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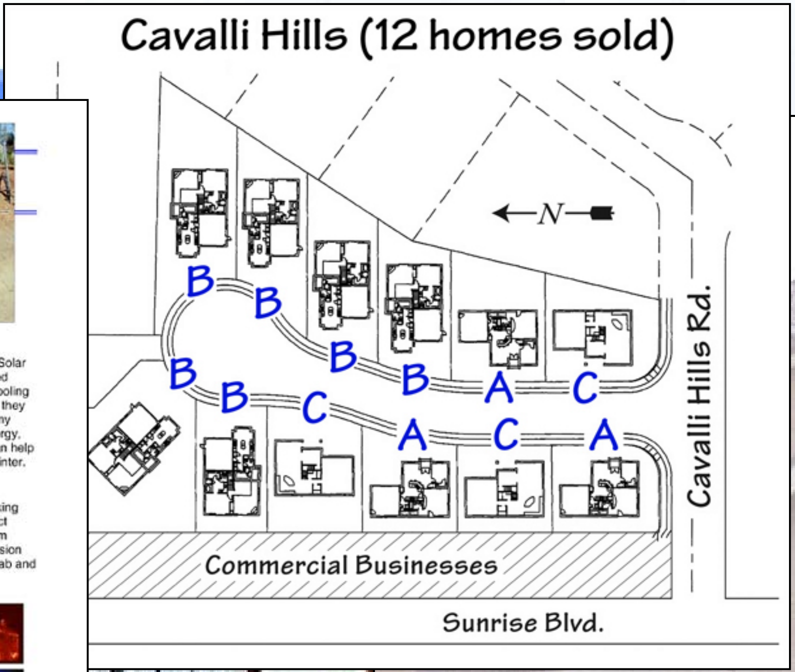
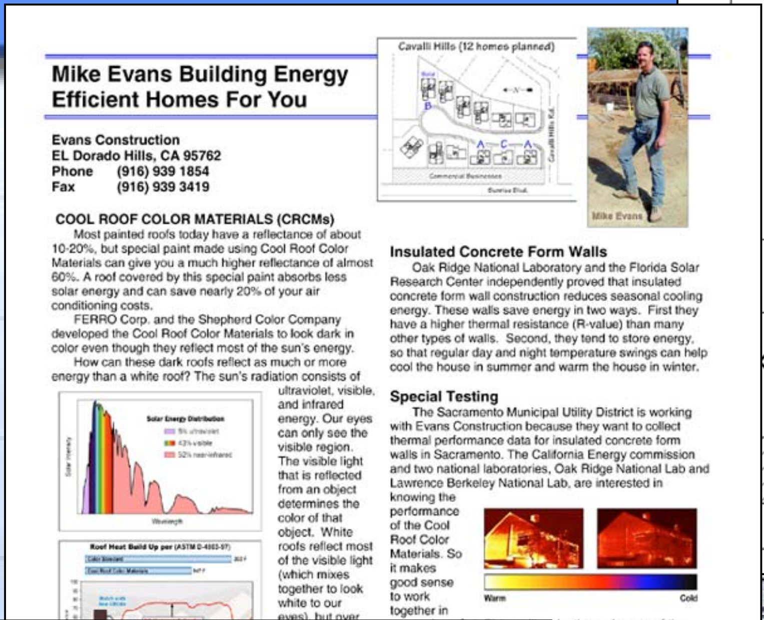
Cavalli Hills Subdivision
Fair Oaks, CA





Mike Evans Building Energy Efficient Homes For You

Evans Construction
EL Dorado Hills, CA 95762
Phone (916) 939 1854
Fax (916) 939 3419

COOL ROOF COLOR MATERIALS (CRCMs)

Most painted roofs today have a reflectance of about 10-20%, but special paint made using Cool Roof Color Materials can give you a much higher reflectance of almost 60%. A roof covered by this special paint absorbs less solar energy and can save nearly 20% of your air conditioning costs.

FERRO Corp. and the Shepherd Color Company developed the Cool Roof Color Materials to look dark in color even though they reflect most of the sun's energy.

How can these dark roofs reflect as much or more energy than a white roof? The sun's radiation consists of ultraviolet, visible, and infrared energy. Our eyes can only see the visible region. The visible light that is reflected from an object determines the color of that object. White roofs reflect most of the visible light (which mixes together to look white to our eyes), but over

Solar Energy Distribution

Roof Heat Build Up per (ASTM D-4803-97)

Insulated Concrete Form Walls

Oak Ridge National Laboratory and the Florida Solar Research Center independently proved that insulated concrete form wall construction reduces seasonal cooling energy. These walls save energy in two ways. First they have a higher thermal resistance (R-value) than many other types of walls. Second, they tend to store energy, so that regular day and night temperature swings can help cool the house in summer and warm the house in winter.

Special Testing

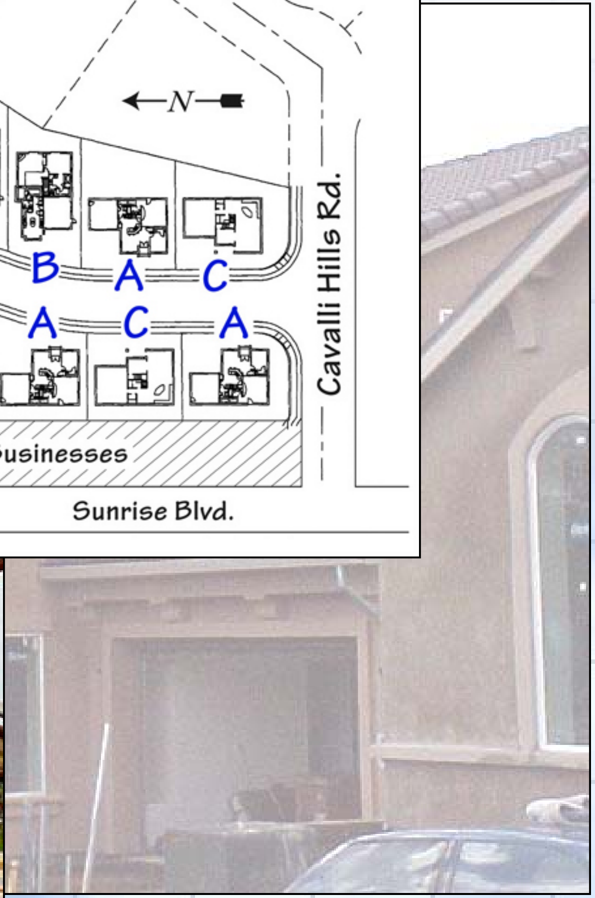
The Sacramento Municipal Utility District is working with Evans Construction because they want to collect thermal performance data for insulated concrete form walls in Sacramento. The California Energy commission and two national laboratories, Oak Ridge National Lab and Lawrence Berkeley National Lab, are interested in knowing the performance of the Cool Roof Color Materials. So it makes good sense to work together in

Warm Cold

ake thermal scans of the
s, cold surfaces show as
s are orange, red or white in
ls on the right show lower
me construction house on
er heat losses.

Cavalli Hills (12 homes planned)

Mike Evans

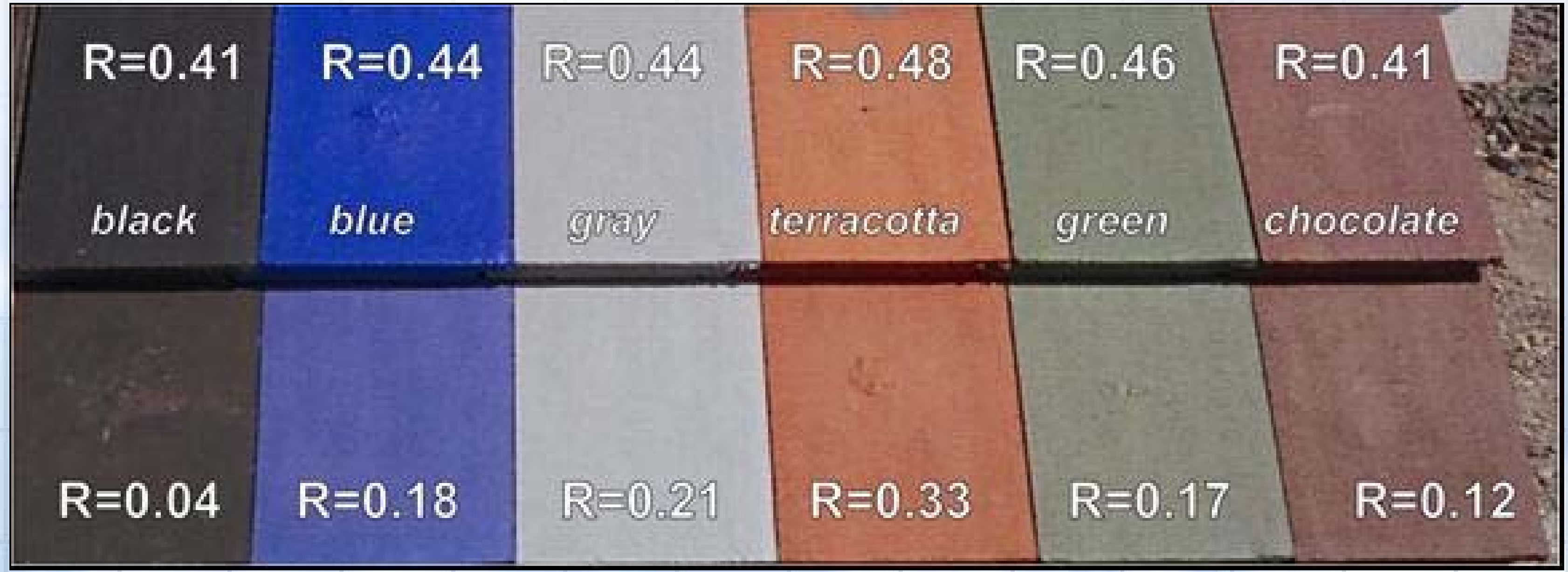


A-Style Homes Finished with Hanson Roof Tile and Stucco

House-1 4979 Mariah Place

House-3 4987 Mariah Place

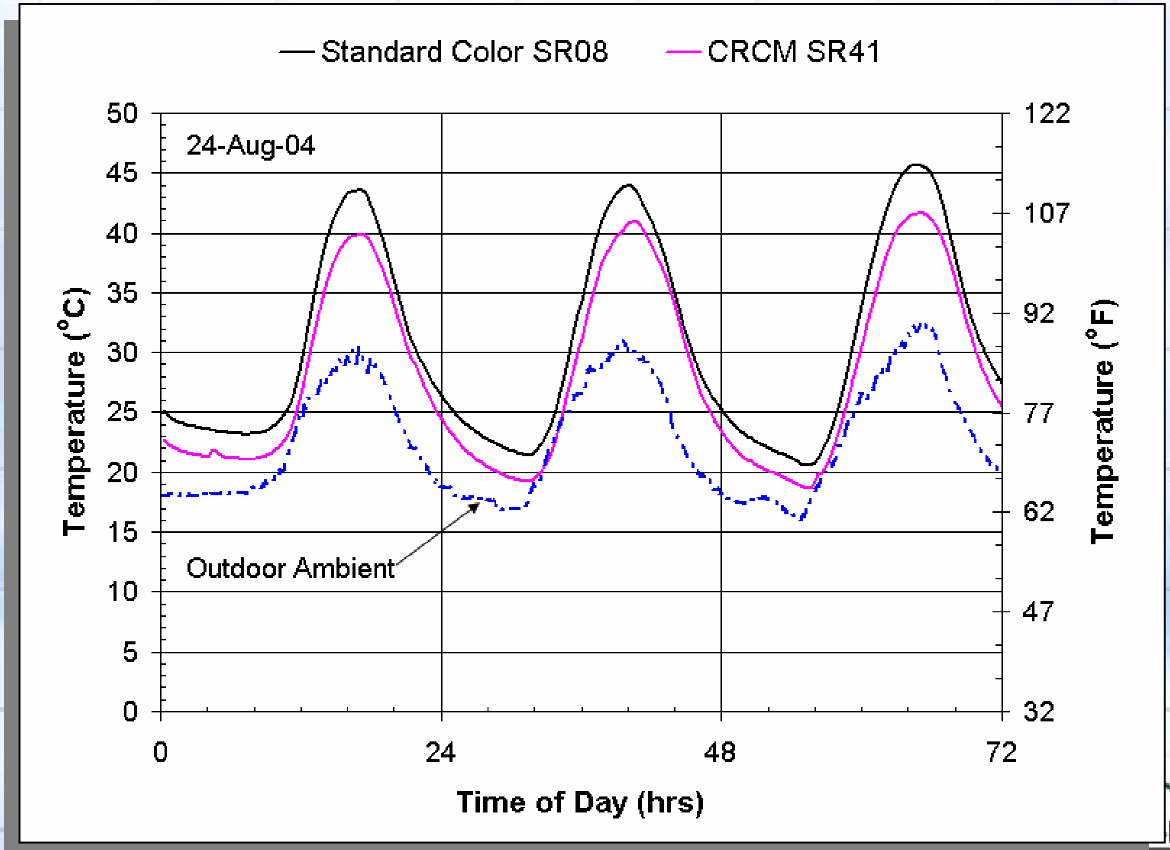
COOL TILE IR COATING™ Applied to Hanson Tile on 2nd A-Style Home



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

Cool Coating Drops Attic Temperature about 4°C (7°F) around Solar Noon

Hanson Tile Roofs



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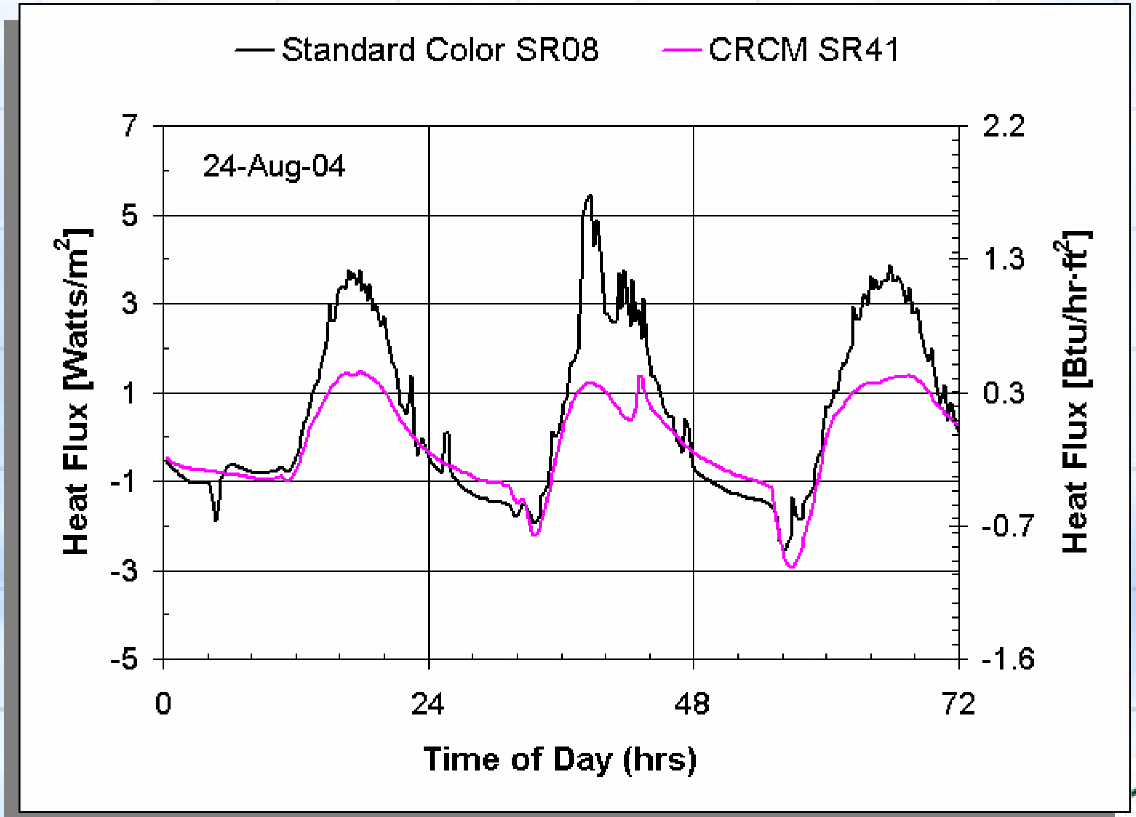
Cool Coating Reduces Heat Flux Through Ceiling

Hanson Tile Roofs



C-Style Homes Finished with Painted Metal Shingles and Stucco

Custom-Bilt Metals

House-2 4983 Mariah Place

House-4 4991 Mariah Place

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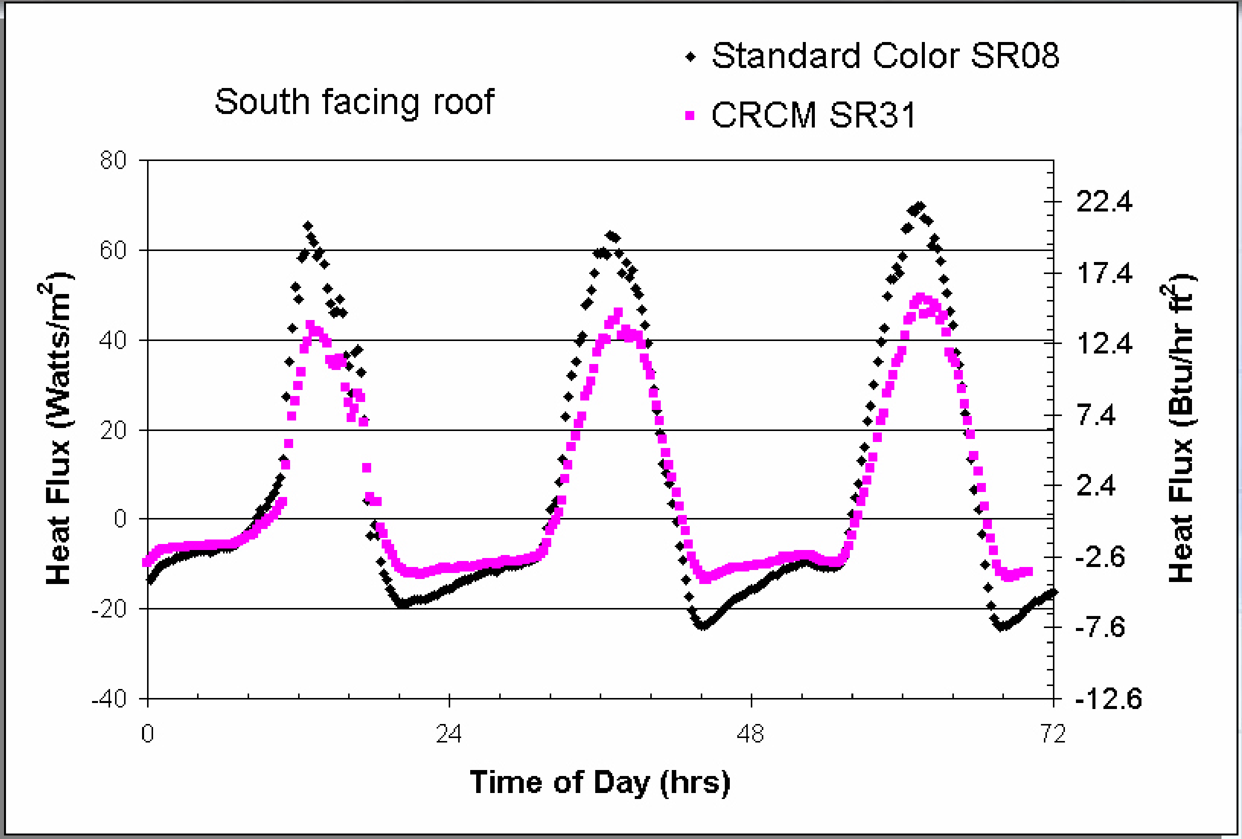
Cool Coating Reduces Heat Flux Through South Facing Roof Deck

Painted Metal Roofs



2.6.1 Next Steps

- **Establish Demonstration Sites**

  One Pair of Composition shingles **Redding, CA**

  - Scheduled for September 28, 2004

  One Pair of Cedar Shakes **Martinez, CA**

  - CRCM effect on fire resistance (Class B reqd)
  - FERRO working with Cedar Shake Bureau

- **Report writing for Demonstration Sites**

2.6.2 Materials Testing at Weathering Sites in California

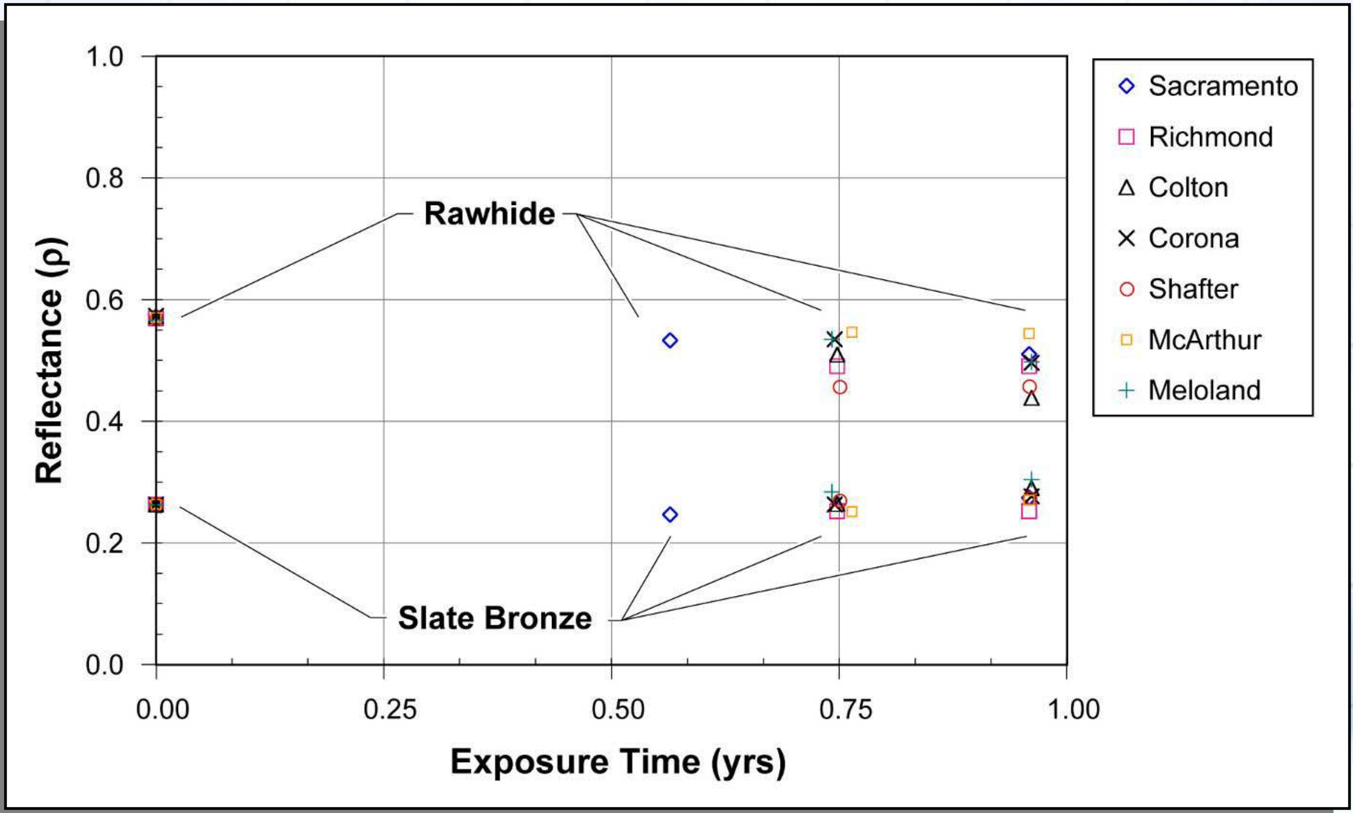
- **Objective:** Document the change in reflectance and emittance for roof products having Cool Roof Color Materials
- Deliverables:
  – Weathering Studies Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 60 %

Concrete and Clay tile, Painted Metals and Shingles under exposure

Clay and Painted Metal exposed for 1 year

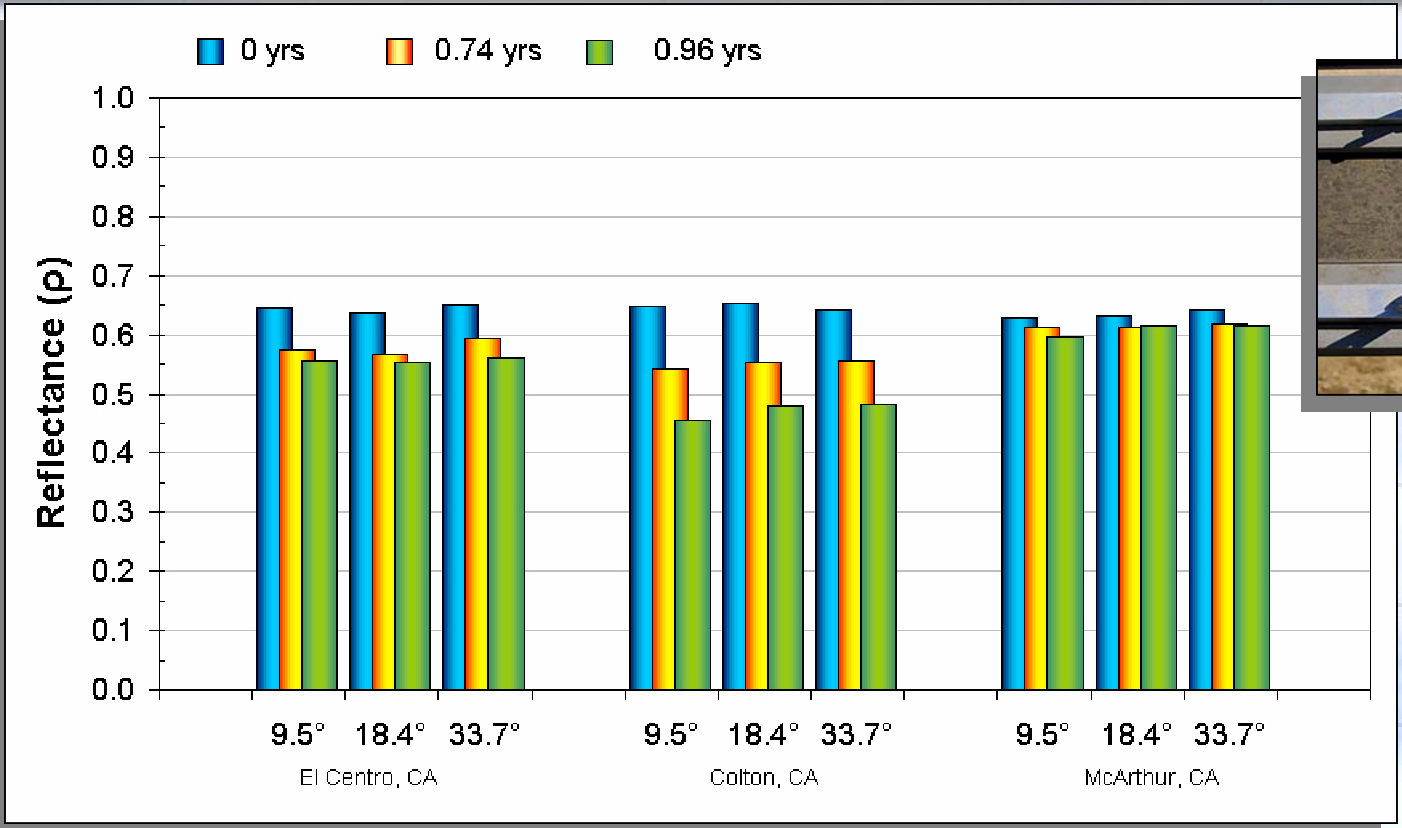
Rawhide and Slate Bronze Painted Metal Solar Reflectance

Climatic zone affects loss of reflectance



Airborne Pollutants Appear to have a strong effect on the Loss of Reflectance

Slope affects loss of reflectance



2.6.3 Steep-slope Assembly Testing at ORNL

- **Objective:** Field test Cool Roof Color Materials on the Envelope Systems Research Apparatus (ESRA) to document the effect of reflectance and emittance weathering on thermal performance
- Deliverables:
  – Attic Model Validation
  – Steep Slope Assembly Test Report
  – Presentation at the Pacific Coast Builders Conference
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 60 %

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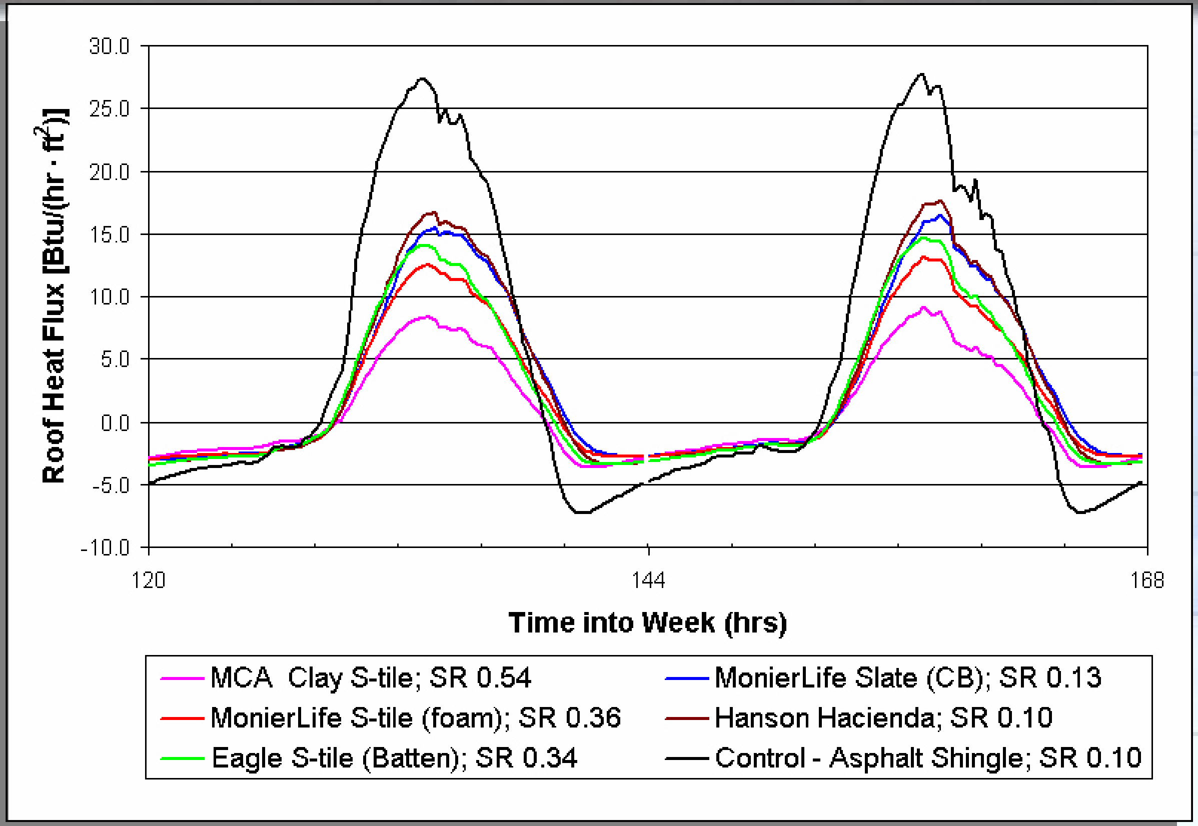
Tile Roofs Being Field Tested For the Tile Roof Institute

Mission Tiles Yield the Lowest Roof Heat Flux and Attic Air Temperature

Reflectance predominates over batten – counter batten system



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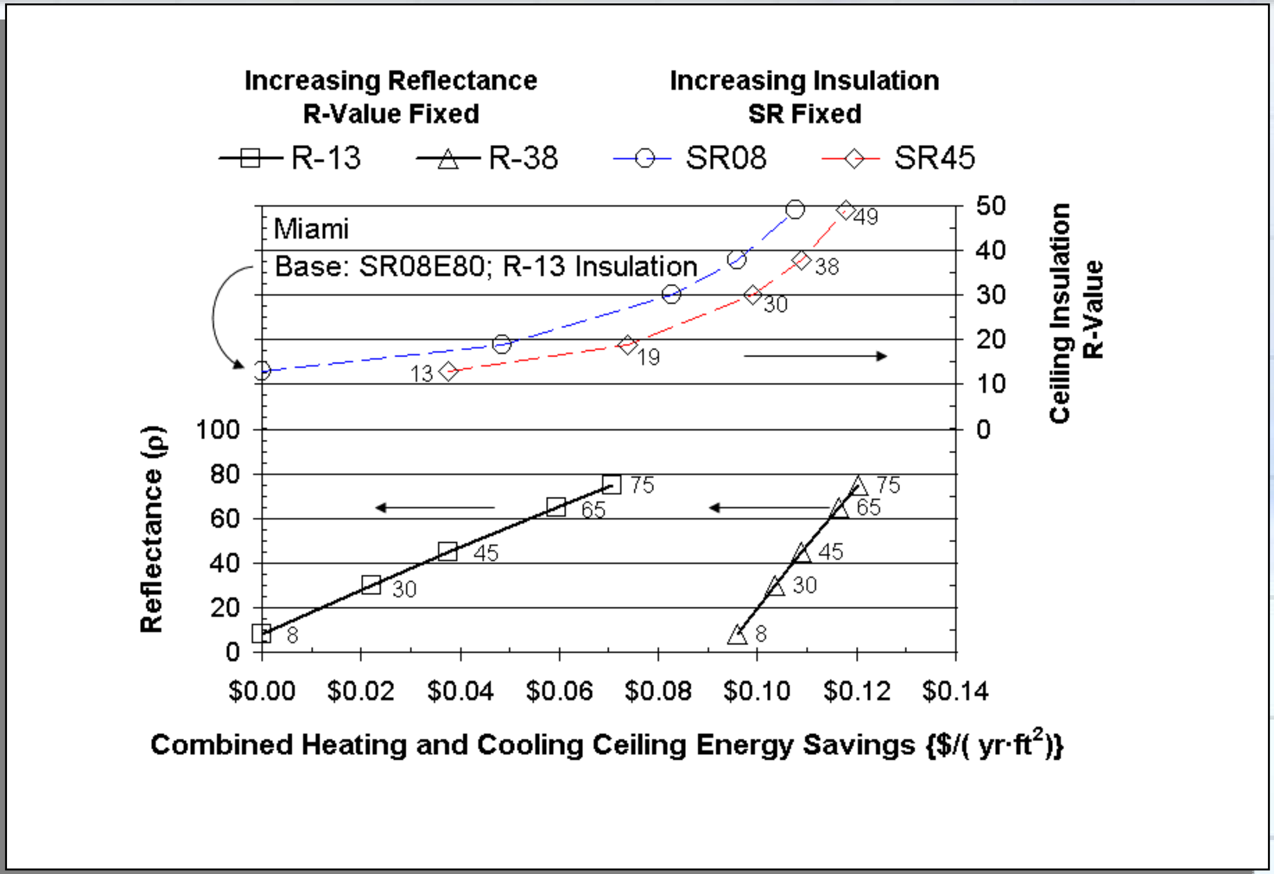
Potential Energy Savings of CRCMs

AtticSim Computer Predictions



2.6.3 Next Steps

- **Flow Visualization Studies**
  - Lafarge Roofing Technical Center
  - Nigel Cherry visit set for Oct 15, 2004
- **Validation of AtticSim code**
  - Direct nailed shingle steep-slope assembly
  - Concrete Tile with venting between deck and roof tile
- **Initiate writing for the CEC and Tile Roof Institute (TRI)**

2.6.4 Product Useful Life Testing

- Objective: Investigate the effect of reflectance on the useful life of roofing products and measure the pertinent mechanical and rheological properties to assess the sustainability of the different roofing products
- Deliverables:
  - Solar Reflectance Test Report
- Schedule: 5/1/04 – 6/1/05
- Funds Expended 12 %

Focus on Asphalt Shingle Aging: Literature Review

- Exemplary publication by CertainTeed

  4th Int. Symp. Roofing. Tech. (1997)
  (www.nrca.net/technical/files/5817.pdf)
- UV damage mitigated by UV-absorbing granules
- Shingles gradually become stiff, brittle
  - Oxidation
  - Out-diffusion of oils
  - Increase of asphaltene content; decrease of naphthene aromatics
- Eventually wind/thermal stress $\Rightarrow$ cracking

Proposed Experiment: Do Cooler Asphalt Shingles Stay Flexible (i.e., Last) Longer?

- Choose 3 shingle products
- Accelerated aging (UV, H_2O) and oven aging at 50, 65, and 80 °C
- 6 month period
- Characterization:
  - Bending stiffness at 0 °C
  - Weight loss
  - Other?

Next Steps: Implementing Asphalt Shingle Aging Experiment with Industry Help

- Need to select specific shingles
- This month: identify equipment
  - Accelerated exposure, ovens
  - Mechanical characterization tests
- October to March timeframe for experiment
- 72 identical samples/shingle (each 1" x 3")
  - temperatures (x3)
  - aging methods (x2)
  - biweekly removal (x12)

2.7 Tech Transfer

- Miller, W. A., Desjarlais, A.O., Akbari, H., Levinson, R., Berdahl, P. and Scichili, R.G. 2004. “Special IR Reflective Pigments Make a Dark Roof Reflect Almost Like a White Roof,” in Thermal Performance of the Exterior Envelopes of Buildings, IX, in progress for proceedings of ASHRAE THERM IX, Clearwater, FL., Dec. 2004.
- Akbari, H., P. Berdahl, A. Desjarlais, N. Jenkins, R. Levinson, W. Miller, A. Rosenfeld, C. Scruton, and S. Wiel.“Cool Colors:A Roofing Study is Developing Cool Products for Residential Roofs,” ECO Structure, September 2004.
- Akbari, H., P. Berdahl, A. Desjarlais, N. Jenkins, R. Levinson, W. Miller, A. Rosenfeld, C. Scruton, and S. Wiel. “Cool Colored Materials for Roofs,” in ACEEE Summer Study on Energy Efficiency in Buildings, proceedings of American Council for an Energy Efficient Economy, Asilomar Conference Center in Pacific Grove, CA., Aug. 2004.

March 2005 Meeting

- March 3, 2005
- At an Industrial Partner Facility?

Cool Colors Project Website

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

http://CoolColors.LBL.gov

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