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September 16, 2004

To: Chris Scruton (CEC)
From: Steve Wiel
Subject: **Cool Roof Colored Materials**: Monthly Progress Report for August 2004
CC: Hashem Akbari, Paul Berdahl, Andre Desjarlais, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of August 31, 2004 is presented in Attachment 1.

HIGHLIGHTS

- On August 25, 2004, we presented the paper "Cool colored materials for roofs" at the ACEEE conference in Asilomar, CA.
- Preparation for the 5th PAC meeting to be held at ORNL was completed.
- We are testing the mixture model to be used in the coating formulation software.
- We developed a tentative proposal to quantify the effect of solar reflectance on the useful life of roofing.
- We are preparing to install cool shingles on two houses in Redding, CA.

Tasks

1.1 Attend Kick-Off Meeting
This Task is completed.

1.2 Describe Synergistic Projects
This Task is completed.

2.1 Establish the Project Advisory Committee (PAC)
This Task is completed.

2.2 Software Standardization
(No activity.)

2.3 PAC Meetings
The next PAC meeting will be held at ORNL on September 9, 2004. The industry partners and the project team will meet on the afternoon of September 8, 2004 to discuss technical issue and coordination related to planning and progress of project tasks.

The agenda and presentation for the PAC meeting were prepared.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance

We prepared a series of nonwhite paint mixtures to test the mixture model used in our software for design of high-reflectance coatings.

2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings

We tested our volumetric mixture model for estimating the solar spectral reflectance of a paint mixture by comparing the Kubelka-Munk absorption and scattering coefficients of tints (mixture of colors with white) and nonwhite binary mixtures to those of their components. We found that a volumetric model (contributions proportional to volume fraction) typically well-estimates absorption by tints, and occasionally well-estimates absorption by nonwhite mixtures; estimates of scattering by tints and nonwhite mixtures are less effective. We are refining the mixture model with particular attention to prediction of scattering.

We have begun design of the coating formulation software for design of color-matching pigmented coatings with maximum solar reflectance.

2.4.3 Develop a Database of Cool-Colored Pigments

We added descriptions of 146 pigmented coatings to our database, including 32 mixtures of nonwhite paints, 57 1:4 tints (1 part color to 4 parts white), and 57 1:9 tints.

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods

The revised paper will be distributed to the Industry Partners at the September PAC meeting. Assuming that further modification will not be required, we will send the paper for journal publication. With the submission of the report for publication, this task will be completed.

2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials

We continued working with shingle/granule manufacturing partners and Cedar Shake & Shingle Bureau for developing cool roofing materials.

2.5.3 Accelerated Weathering Testing

The currently available data from BASF on the small color shifts on aging are adequate for our purposes (e.g., see the draft paper for the THERM IX conference). We need to seek further comparable data from the pigment companies, and from the roofing materials manufacturers.

2.6 Field-Testing and Product Useful Life Testing

Agreements are in place to work with a builder to demonstrate asphalt shingles with and without cool colored pigments. Work continues on developing a cedar shake with cool colored pigments that appears weathered and highly reflective and that also meets Class B flame resistance for California building codes.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

A home builder in Redding, CA has agreed to work with the "Cool Team" and demonstrate asphalt shingle roofs on two adjacent homes of identical footprint. Shingles with and without cool colored pigments are on-hand from a shingle manufacturer for the builder to install on the two homes. The homes are part of a new residential development, and the builder, Jerry Wagar, is digging the footers for the foundations as of this report. The builder stated, "*I will setup the two homes with the front door of each house facing the same direction.*" Therefore the roofs of both homes have the same azimuth orientation with respect to the sun, which will allow a direct comparison of roof performance, similar to that seen at Cavalli Hills. Instrumented sandwich panels made of oriented strand board (OSB) have been shipped to the builder for placement in the roof decks. The OSB panels from ORNL are 2-ft by 2-ft, and contain thermocouples and heat flux transducers embedded in the panel for measuring the thermal performance of the roofs. Tentatively, ORNL personnel are scheduled to instrument the two homes the first week of October, depending on the progress of the builder.

A pair of existing homes located in Martinez CA is also available for demonstrating cedar shake roofs with and without cool colored pigments. The homeowners donating use of their homes are John Goveia of Technical Roof Services and his neighbor. Goveia sent ORNL and FERRO samples of new and weathered Class B, Western Red Cedar shakes. The weathered shakes from Goveia's roof have 16 years of CA exposure (Fig. 1). Solar reflectance of the weathered shake is about 0.35, while the solar reflectance before weathering is about 0.45 (Fig. 1). The weathered shake has a silvery-gray color, which Goveia states "the residents of CA prefer."

Figure 1. Picture of a 16 year old western cedar shake roof and a sample of a new cedar shake (Goveia residence).

Therefore, Steve Harris of the Cedar Shake Bureau is working with FERRO Corp. to prepare cedar shakes painted with cool colored coatings that mimic the weathered look (Fig. 1). FERRO has painted new shakes with cool colored coatings that are visibly silvery-gray and have solar reflectance measures of 0.59 to 0.65. The cool pigments will be added while applying fire retardants to the shake. The process places the shakes in a vacuum chamber and pressurizes chemicals to about 100 psi, forcing them into the shake. Hopefully, the technique will fully cover the shake with cool colored coatings, which are inorganic non-combustible materials having heat stability at upwards of 1000ºC. Steve Harris will then have the shakes tested by the International Accreditation Service to determine the effects of the cool colored coatings on the fire resistance of the shakes. FERRO proposes to use a binder made from a silicone polymer to minimize the binder's effect on cedar shake's flammability.

All four demonstration homes in Cavalli Hills are on-line. The field data is being automatically downloaded to a dedicated PC at ORNL every other day.

ORNL personnel and Wim Boss of SMUD reviewed the power instrumentation because measurements showed little if any power usage. Part of the problem occurs because the homeowners seldom operate their air-conditioners. At our most recent visit in August, we observed that three of the four homeowners had their windows open and their air-conditioner off even with an outdoor ambient temperature of 100ºF.

Checks showed the watt hour meter for A-style home (House 1 at 4979 Mariah Place) to probably be defective. The revenue meter would not turn while some power was on in the home. Only one of the homes (C-style home at 4987 Mariah Place) had reasonable air-conditioner power readings. ORNL personnel made bench top checks of the same identical transducer as used at Cavalli Hills for measuring air-conditioning power. Results were compared to a Wattnode transducer Model WNA-1P-240-P, which ORNL has successfully applied to Habitat homes under field test in TN. Bench top tests showed the SMUD transducer (Rochester model PM 1000) read within 6% of the Wattnode transducer. Further checks of the PM-1000 transducers made at Cavalli Hills with a voltmeter (August 11) indicated a constant output of about 0.4 Vdc. At ORNL we were able to duplicate and measure the 0.4 volt output characteristic with both a voltmeter and a data logger in bench top testing when the PM-1000 output leads were reversed from that used by the data logger in the field at Cavalli Hills. We also checked the direction of the PM-1000 current transformer (CT) to determine whether an output was received from the transducer. Testing shows that the direction of the CT must be oriented such that the dot on the front of the CT is pointing toward the line (house breaker). Hence ORNL requested that SMUD 1) check the output wiring of the PM-1000 watt-hour transducer to verify that the positive lead from each transducer meter goes to the P3 (compressor) and P4 (whole house), and 2) verify the CT direction; the dot on the front of the CT points toward the line (house breaker).

2.6.2 Materials Testing at Weathering Farms in California
(No activity)

2.6.3 Steep-slope Assembly Testing at ORNL

The fourth lane's soffit vent was opened last reporting period making its attic ventilation similar to the other five test lanes having soffit and ridge vents. The heat flux penetrating the roof deck is shown for the six test lanes in Figure 2. The results show that the S-mission tiles had the lowest heat flux penetrating into the attic (Figure 2) due to their higher solar reflectance and also due to the venting occurring in the air gap made by the tile with the roof deck. The slate tile and the shingle roofs have about the same solar reflectance (0.13 vs. 0.10); however, the heat flux penetrating the slate roof was half that entering the asphalt shingle roof at solar noon because of the thermal buoyancy effects occurring in the air gap. The batten-counter batten arrangement places the tile about 1.5-in (38 mm) off the roof deck, which allows air currents induced by temperature gradients to traverse up the roof from the soffitt to the ridge. These convective currents in the laminar boundary layer are apparently dissipating heat through the gaps formed by overlapping tiles.

It is also interesting to compare the performance of the MCA S-mission clay tile to the Eagle concrete S-mission tile. The MCA clay tile with cool colored pigments has a solar reflectance of 0.54 while the Eagle is from standard production and has solar reflectance of about 0.34. The MCA clay tile was direct nailed to the roof. The Eagle tile was placed on a batten system about 0.75-in (19 mm) above the deck. Yet despite the batten construction the Eagle tile had a higher heat flow penetrating the roof as compared to the MCA clay tile (Fig. 2). Hence the results tend to show that solar reflectance of the tile has a more dominant effect on the thermal performance of the roof; however, the venting does provide benefit as seen by comparing the slate roof on a batten-counter-batten system and the direct nailed shingle roof.

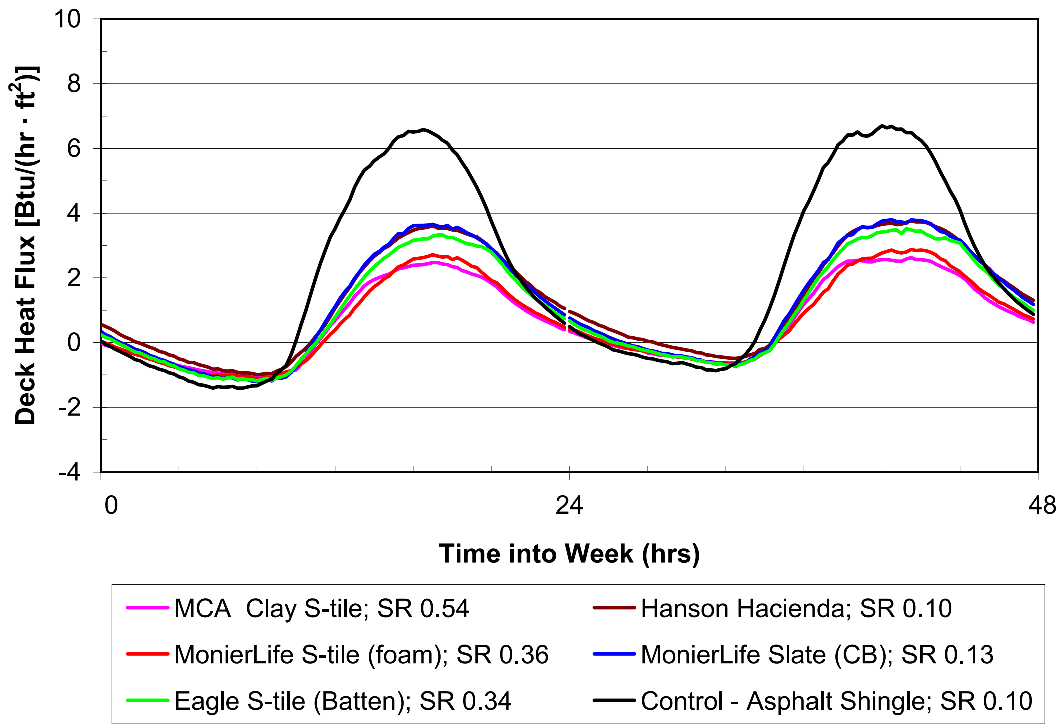

Figure 2. Heat flux penetrating the roof deck of the clay, concrete and asphalt shingle roof systems being field tested on the Envelope Systems Research Apparatus (ESRA).

2.6.4 Product Useful Life Testing

In preparation for our September PAC meeting, we reviewed additional literature on asphalt shingle ageing, and prepared a "straw man" proposal for an experiment to characterize how asphalt shingles become stiffer after prolong exposure to elevated temperatures. Two controversial issues are:

(1) Does industry have sufficient data that can be made public, and therefore make the proposed experiment unnecessary?

(2) Changes in stiffness may be related to brittle failure in some cases, but may not be a major determinant of shingle lifetime.

Further consultation with shingle manufacturers and discussions among the project team will be undertaken to further clarify this task.

2.7 Technology transfer and market plan

2.7.1 Technology Transfer

On August 25, 04, Akbari presented the paper “Cool colored materials for roofs” at the ACEEE conference in Asilomar, CA. A copy of the presentation is attached (See Attachment 2).

2.7.2 Market Plan

(No activity.)

2.7.3 Title 24 Code Revisions
(No activity.)

Management Issues

- None

Attachment 1

Project Tasks and Schedules (*Approved on May 16, 2002*)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 08/31/2004
1	**Preliminary Activities**					
1.1	Attend Kick Off Meeting *Deliverables:* • Written documentation of meeting agreements and all pertinent information (**Completed**) • Initial schedule for the Project Advisory Committee meetings (**Completed**) • Initial schedule for the Critical Project Reviews (**Completed**)	5/16/02	5/16/02	6/1/02	6/10/02	100%
1.2	Describe Synergistic Projects *Deliverables:* • A list of relevant on-going projects at LBNL and ORNL (**Completed**)	5/1/02	2/1/02	5/1/02	5/1/02	100%
1.3	Identify Required Permits	N/A		N/A		
1.4	Obtain Required Permits	N/A		N/A		
1.5	Prepare Production Readiness Plan	N/A		N/A		
2	**Technical Tasks**					
2.1	Establish the project advisory committee *Deliverables:* • Proposed Initial PAC Organization Membership List (**Completed**) • Final Initial PAC Organization Membership List • PAC Meeting Schedule (**Completed)** • Letters of Acceptance	6/1/02	5/17/02	9/1/02		100%
2.2	Software standardization *Deliverables:* • When applicable, all reports will include additional file formats that will be necessary to transfer deliverables to the CEC • When applicable, all reports will include lists of the computer platforms, operating systems and software required to review upcoming software deliverables	N/A		N/A		

Project Tasks and Schedules (contd.)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 08/31/2004
2.3	PAC meetings *Deliverables:* • Draft PAC meeting agenda(s) with back-up materials for agenda items • Final PAC meeting agenda(s) with back-up materials for agenda items • Schedule of Critical Project Reviews Draft PAC Meeting Summaries • Final PAC Meeting Summaries	9/1/02	6/1/02	6/1/05		67% (4/6)
2.4	Development of cool colored coatings					
2.4.1	Identify and Characterize Pigments with High Solar Reflectance *Deliverables:* • Pigment Characterization Data Report	6/1/02	6/1/02	12/1/04		~ 97%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings *Deliverables:* • Computer Program	11/1/03	11/1/03	12/1/04		~ 55%
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database	6/1/03	7/1/03	6/1/05		~ 50%
2.5	Development of prototype cool-colored roofing materials					
2.5.1	Review of Roofing Materials Manufacturing Methods *Deliverables:* • Methods of Fabrication and Coloring Report	6/1/02	6/1/02	6/1/03		~ 99%
2.5.2	Design Innovative Methods for Application of Cool Coatings to Roofing Materials *Deliverables:* • Summary Coating Report • Prototype Performance Report	6/1/02	6/1/02	12/1/04		~ 85%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05		~ 15%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 08/31/2004
2.6	Field-testing and product useful life testing					
2.6.1	Building Energy-Use Measurements at California Demonstration Sites *Deliverables:* • Demonstration Site Test Plan • Test Site Report	6/1/02	9/1/02	10/1/05		79%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05		65%
2.6.3	Steep-slope Assembly Testing at ORNL *Deliverables:* • Whole-Building Energy Model Validation • Presentation at the Pacific Coast Builders Conference • Steep Slope Assembly Test Report	6/1/02	10/1/02	10/1/05		60%
2.6.4	Product Useful Life Testing *Deliverables:* • Solar Reflectance Test Report	5/1/04	5/1/04	6/1/05		12%
2.7	Technology transfer and market plan					
2.7.1	Technology Transfer *Deliverables:* • Publication of results in industry magazines and refereed journal articles • Participation in buildings products exhibition, such as the PCBC Brochure summarizing research results and characterizing the benefits of cool colored roofing materials	6/1/03	6/1/02	6/1/05		~ 50%
2.7.2	Market Plan *Deliverables:* • Market Plan(s)	5/1/05		6/1/05		
2.7.3	Title 24 Code Revisions *Deliverables:* • Document coordination with Cool Roofs Rating Council in monthly progress reports • Title 24 Database	6/1/02	5/16/02	6/1/05		~ 10%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 08/31/2004
VII	Critical Project Review(s) *Deliverables:* • Minutes of the CPR meeting					
XII (C)	Monthly Progress Reports *Deliverables:* • Monthly Progress Reports	6/1/02	6/1/02	6/1/05		69% (25/36)
XII (D)	Final Report *Deliverables:* • Final Report Outline • Final Report	3/1/05		10/1/05		
	Final Meeting *Deliverables:* • Minutes of the CPR meeting	10/15/05		10/31/05		

Attachment 2.

"Cool colored materials for roofs"
a presentation given at the ACEEE conference in Asilomar, CA.
August 25, 2004

COOL COLORED MATERIALS FOR ROOFS

Hashem Akbari
Heat Island Group
Ernest Orlando Lawrence Berkeley National Laboratory

Presented at the
2004 ACEEE Summer Study on Energy Efficiency in Buildings
August 22 - 27, 2004 • Asilomar Conference Center • Pacific Grove, CA

August 25, 2004

Contributing Authors

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  Lawrence Berkeley National Laboratory (LBNL)
- A. Desjarlais, W. Miller
  Oak Ridge National Laboratory (ORNL)
- N. Jenkins, A. Rosenfeld, C. Scruton
  California Energy Commission (CEC)

Cool Roof Technologies

Old

flat, white

pitched, white

New

pitched, cool & colored

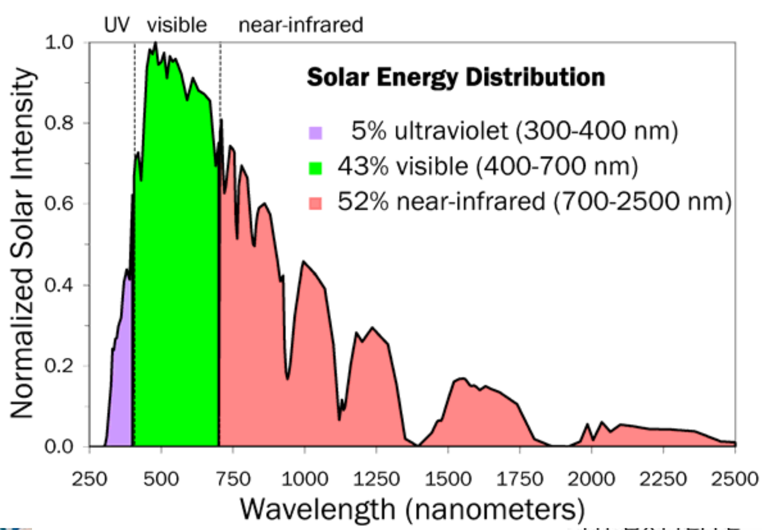
White is 'cool' in Bermuda

and in Santorini (Mykonos, Greece)

Join us at the second International Conference on Passive and Low Energy Cooling for the Built Environment, 19-21 May 2005.

http://palenc2005.conferences.gr

Cool Colors Reflect Invisible Near-Infrared Sunlight



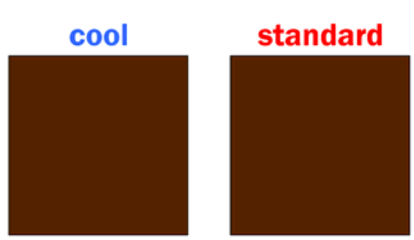
Terminology

- Solar reflectance (= albedo): Fraction of reflected sunlight (0.3-2.5 μm)
- Solar absorptance = 1 – Solar reflectance (opaque surfaces)
- Near infrared radiation (NIR): Invisible solar radiation in the range of 0.7-2.5 μm
- Thermal emittance: Ability to radiate heat at ambient temperature (~10 μm)

Cool and Standard Brown Metal Roofing Panels

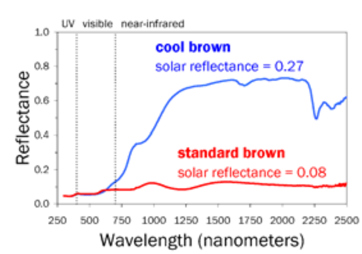
- Solar reflectance ~ 0.2 higher
- Afternoon surface temperature ~ 10ºC lower

Courtesy BASF Coatings

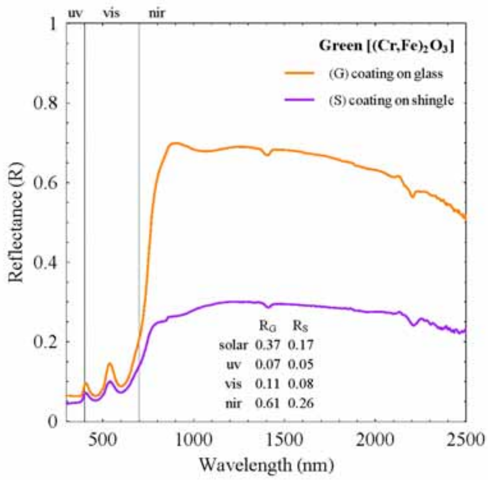


solar reflectance = 0.27
thermal emittance = 0.85
roof temp – air temp = 36ºC (65ºF)

solar reflectance = 0.08
thermal emittance = 0.85
roof temp – air temp = 45ºC (81ºF)



From Cool Pigments to Cool Shingles: a Difficult Problem



R= 37%

(G) coating on glass

R= 17%

(S) coating on shingle

Goals

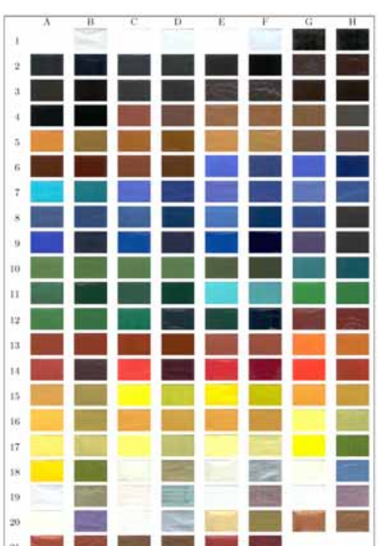
- Develop new cool roofing materials: metal, wood shake, tiles, and shingles
- Measure and document laboratory and *in-situ* performances of cool roofing products
- Measure and document improvements in the durability of roofing expected to arise from lower operating temperatures
- Accelerate market penetration of cool roofing products

National Labs and Industrial Partnership

- Program is sponsored by California Energy Commission's (CEC) Public Interest Energy Research (PIER)
- ORNL and LBNL are teaming with industry
- Broad industrial partnership

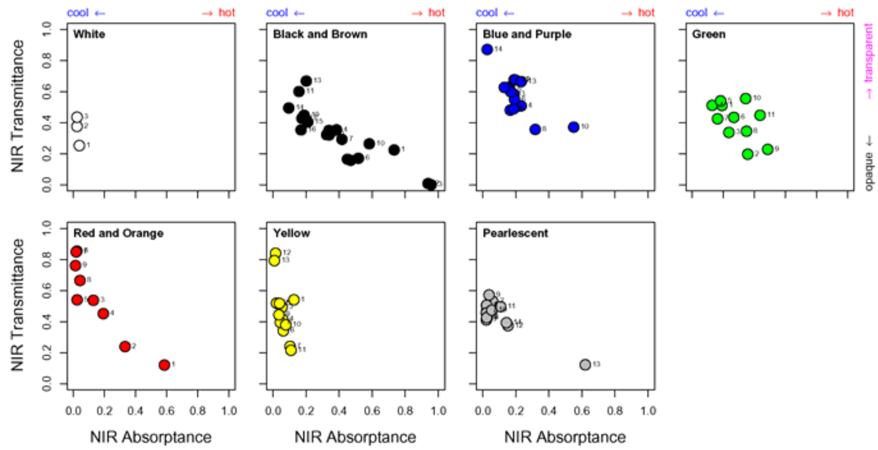
- Industry partners
  - 3M
  - American Roof Tile Coating
  - BASF
  - Custom-Bilt Metals
  - Elk Manufacturing
  - Ferro Corp.
  - GAF Material Corp.
  - Hanson Roof Tile
  - ISP Minerals
  - Maruhachi Ceramics of America (MCA Tile)
  - Monier Lifetile
  - Shepherd Color Company

Paints Over White & Black



- 87 common pigments over black, white backgrounds
- Color distribution:
  - white
  - black/brown
  - blue/purple
  - green
  - red/orange
  - yellow
  - pearlescent

Near Infrared Properties of Thin Paint Films



Examples of Cool Pigments

- **All are weak NIR absorbers**
- Strong NIR scatterers (suitable for any substrate)
  - TiO_2 white
  - Nickel titanate and chrome titanate yellows
  - Mixed-metal oxide blacks – $(Fe,Cr)_2O_3$, many related compounds
  - Co_2TiO_4 teal (bluish green)
  - TiO_2 on mica flakes - various colors
- Weak NIR scatterers (need NIR-reflective substrate)
  - Cobalt chromite, cobalt aluminate, and ultramarine blues
  - Some iron oxide browns (burnt sienna, raw sienna)
  - Many organics (perylene black, phthalo blue, quinacridone red...)

Examples of Hot Pigments

- **All are strong NIR absorbers**
- Carbon black (also lamp black, ivory black)
- Fe_3O_4 black (magnetite)
- Copper chromite black
- Iron blue $KFe_2(CN)_6 \cdot H_20$

Adaptation of Kubelka-Munk Theory

- K-M theory relates *paint film* properties to *pigment* properties

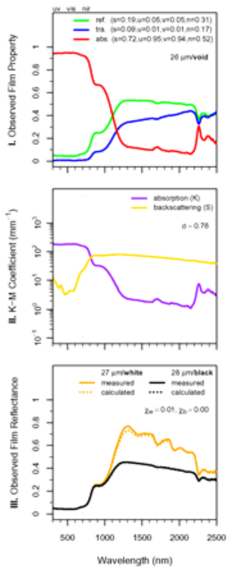
PAINT FILM PROPERTIES
- **reflectance**
- **transmittance**
- **thickness**

⟷

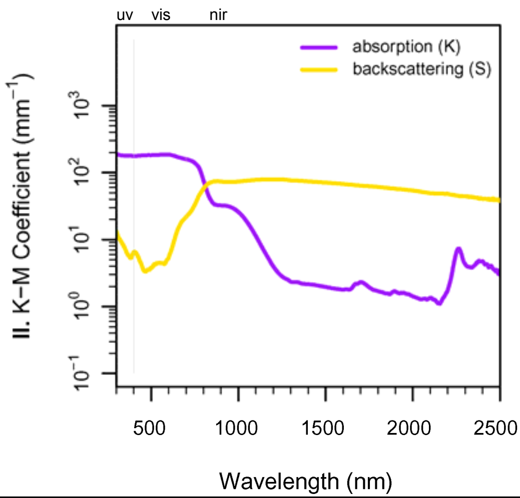
PIGMENT PROPERTIES
- **scattering coefficient**
- **absorption coefficient**

- LBNL adapted to better characterize pigments that weakly scatter light

Calculate K-M Coefficients (Absorption *K*, Backscattering *S*)

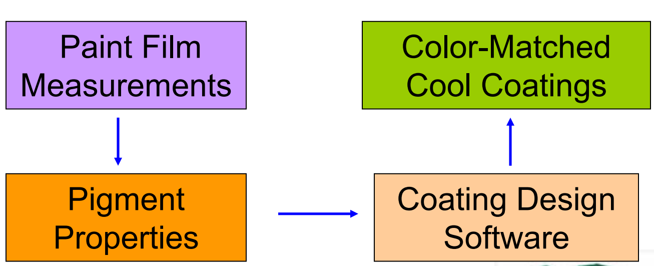


- **Chromium Green-Black Hematite Modified (Cool Black)**
- **25-µm film with 7% pigment volume concentration**



Coating Design Software

- Estimate coating reflectance from pigment properties (absorption, scattering), film geometry (mixing, layering)
- Recommend pigments & geometry to match color, maximize solar reflectance

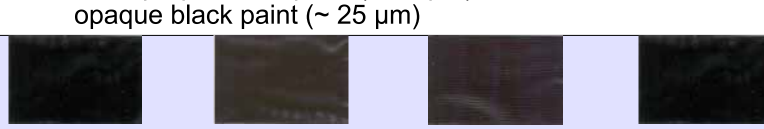


Application of Cool Colors to Roofing Products

- Asphalt shingles (granules)
- Metal roofing
- Clay roof tiles
- Concrete roof tiles
- Wood shakes

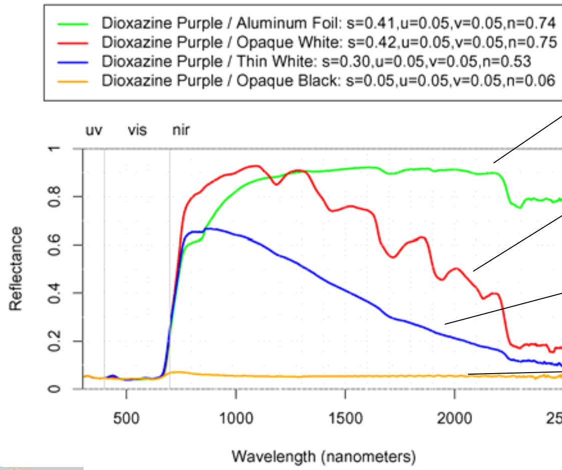
LBNL Innovation: Two-layered technique (NIR-Reflective Undercoating)

- Two-layer system
  - top coat: thin layer of dioxazine purple (14-27 µm)
  - undercoat or substrate:
    - aluminum foil (~ 25 µm)
    - opaque white paint (~1000 µm)
    - non-opaque white paint (~ 25 µm)
    - opaque black paint (~ 25 µm)



purple over aluminum foil	purple over opaque white paint	purple over non-opaque white paint	purple over opaque black paint

Dioxazine Purple Reflectances



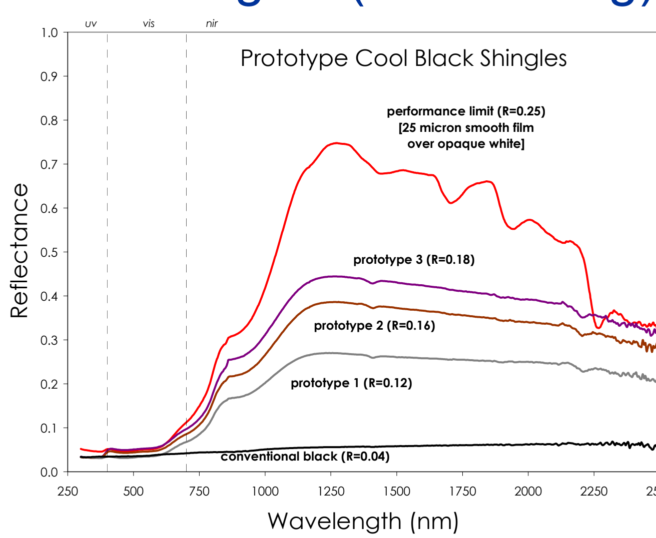
over aluminum R_{solar} = 0.41

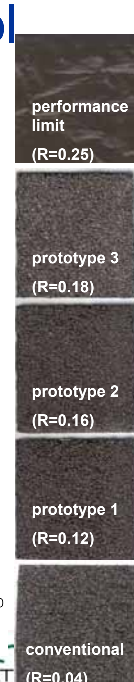
over opaque white R_{solar} = 0.42

over non-opaque white R_{solar} = 0.30

over opaque black R_{solar} = 0.05

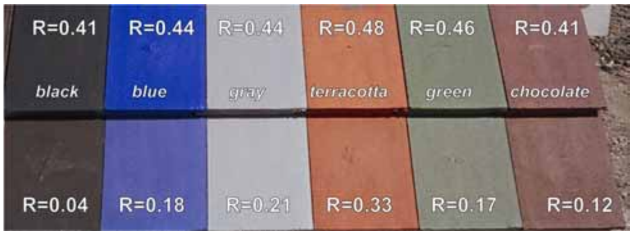
Example: Development of Cool Black Shingles (thin coating)





Example: Cool and Standard Color-Matched Concrete Tiles

Courtesy American Rooftile Coatings



cool

standard

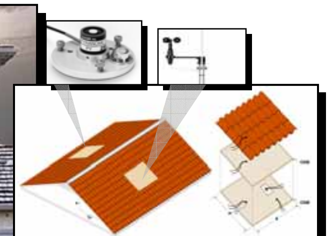
ΔR=0.37 ΔR=0.26 ΔR=0.23 ΔR=0.15 ΔR=0.29 ΔR=0.29

- Can increase solar reflectance by up to 0.5
- Gain greatest for dark colors

Building Energy-Use Measurements at California Demonstration Sites

- Sacramento Municipal Utility District (**SMUD**) and ORNL/LBNL are working together monitoring Cool Roofs

Mike Evans Construction building Cavalli Hills



Samples exposed for 6 months

CA Topographic Map

Sites	Company	City	County	Climate Zone
1	Custom-Bilt	**Sacramento**	Sacramento	12
2	Steelscape	**Richmond**	Contra Costa	3
3	BASF	**Colton**	San Bernadino	10
4	Maruhachi Ceramics of America	**Corona**	Riverside	10
5	ELK Corporation	**Shafter**	Kern	13
6	Department of Water Resources	**McArthur**	Shasta	16
7	Department of Water Resources	**Meloland**	Imperial	15

Field Exposure Sites

Shuttle Radar Topography Mission (SRTM)
Space Shuttle Endeavor
National Imagery and Mapping Agency (NIMA)

Materials are tested at ORNL

Progress and Challenges

- We have made significant progress with
  - Tiles/tile coatings
  - Metal/metal coatings
- We still have to find economical solutions for development of
  - Cool shingles/granules
  - Cool wood shakes
- We need to understand
  - Aging of cool roofing materials
  - Effect of temperature on longevity of roofs