DEVELOPMENT OF COOL COLORED ROOFING MATERIALS

Project Advisory Committee

(PAC) Meeting

A Collaborative R&D Between Industry

LBNL and **ORNL**

Sponsored by the California Energy Commission

(Project Manager: Chris Scruton)

September 11, 2003; LBNL, Berkeley, CA

UT-BATTELLE

OAK RIDGE NATIONAL LABORATORY

BERKELEY LAB

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, clay & concrete tile, wood shake, and shingle products
- Measure and document improvements in the durability of roofing expected to arise from lower operating temperatures

Project Advisory Committee (PAC) Members

1. Asphalt Roofing Manufacturers Association
2. Bay Area Air Quality Management District
3. California Institute for Energy Efficiency
4. Cedar Shake and Shingle Bureau
5. Cool Roof Rating Council
6. Environmental Protection Agency (EPA)
7. EPA San Francisco Office
8. Mike Evans Construction (replacing Habitat for Humanity)
9. National Roofing Contractors Association
10. Roof Tile Institute
11. DuPont Titanium Technologies
12. Cool Metal Roofing Coalition

Industrial Partners

- **3M**
- **American Roof Tile Coating**
- **BASF**
- **Custom-Bilt Metals**
- **Elk Manufacturing**
- **Ferro**
- **GAF**
- **Hanson Roof Tile**
- **ISP Minerals**
- **MCA Tile**
- **Monier Lifetile**
- **Shepherd Color Company**
- **Certainteed**

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
  - Andre 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 and 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 (a draft paper is completed)
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 50 %

Pigment Characterization Activities

- Paint preparation
- Paint film deposition
- Film property measurement
- Adaptation of Kubelka-Munk (K-M) theory
- Software development
- Pigment classification

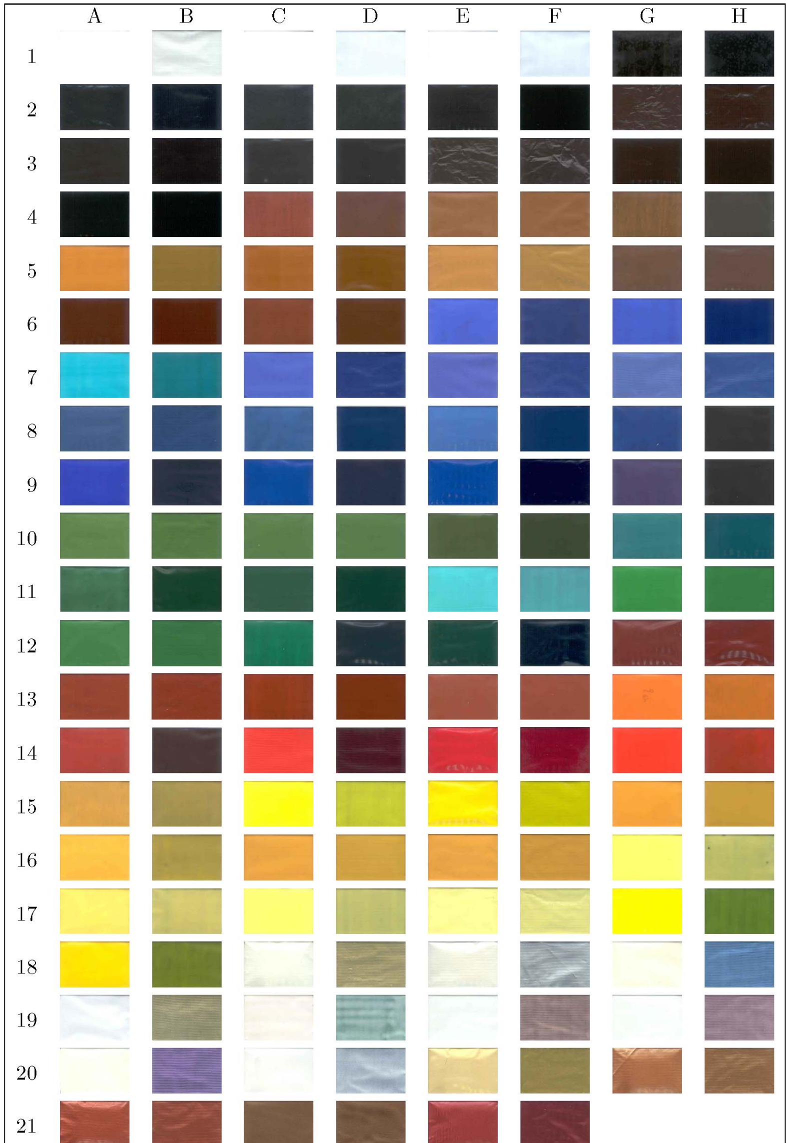
Recent Film Preparation and Measurements

- Prepared 26 paints from cool-pigment dispersions provided by Ferro, Shepherd
- Created 1:4 and 1:9 tints of 58 paints
- Measured 26 masstones and 116 tints
- Cumulative total: 83 masstones, 116 tints

ultramarine blue

masstone 1:4 tint 1:9 tint

Paints Over White & Black



- 83 masstones over black, white
- Color distribution:
  - 3 white
  - 19 black/brown
  - 14 blue/purple
  - 11 green
  - 9 red/orange
  - 13 yellow
  - 14 pearlescent

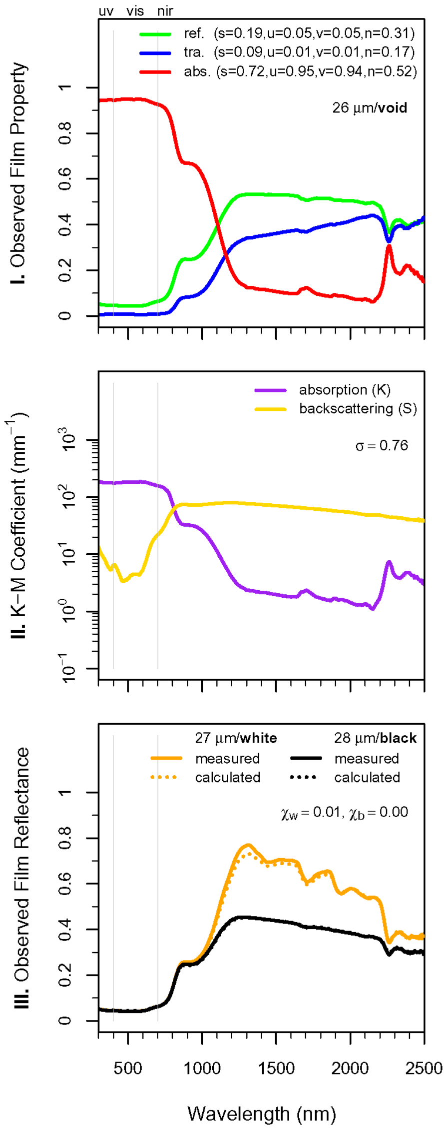
Adaptation of Kubelka-Munk Theory

- Kubelka-Munk (K-M) theory relates *paint film* properties to *pigment* properties

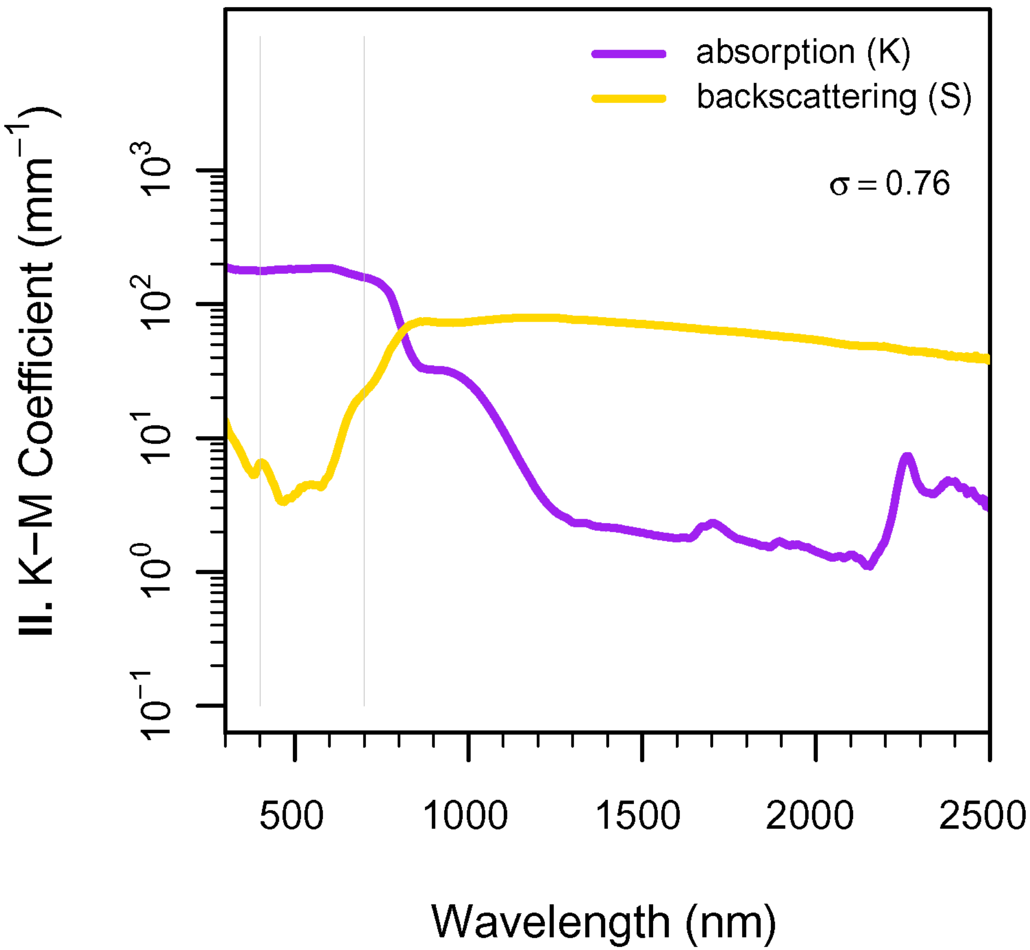
PAINT FILM PROPERTIES		PIGMENT PROPERTIES
• reflectance	⟷	• scattering coefficient
• transmittance		• absorption coefficient
• thickness		

- K-M theory adapted by LBNL to better characterize pigments that weakly scatter light, especially in near-infrared spectrum
- **LBNL model has been completed**

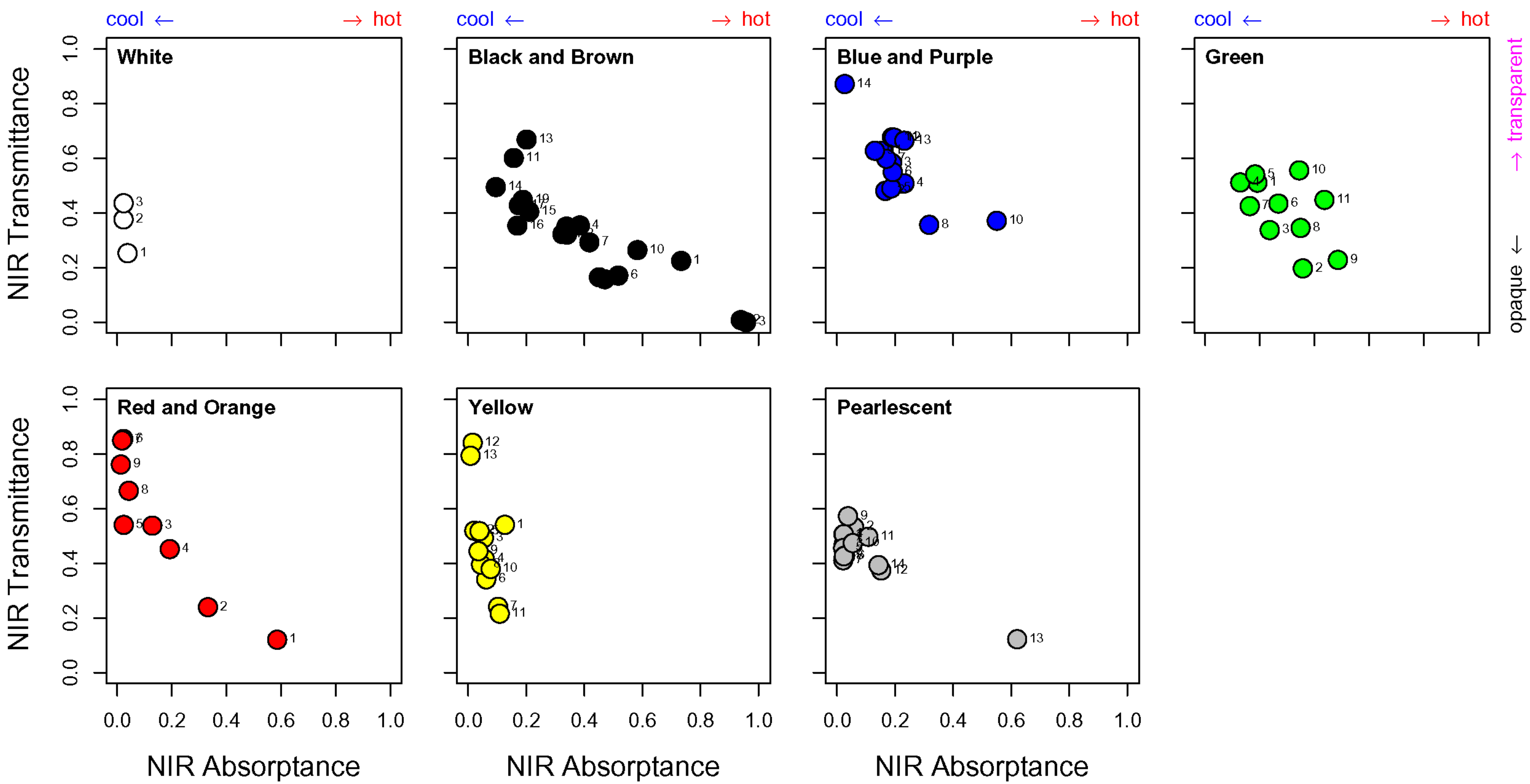
Sample Pigment Characterization: Chromium Iron Oxide IR Black



- **Chromium Green-Black Hematite Modified**
- **7% pigment volume concentation**



NIR Properties of Thin Paint Films



NIR Reflectances of Coolest Pigments With Opaque White Background

- mica coated w/titanium dioxide (0.88-0.90)
- titanium dioxide white (0.88)
- cadmium yellow, orange (0.87)
- Hansa yellow (0.87)
- diarylide yellow (0.87)
- organic red (0.82-0.87)
- dioxazine purple (0.81)
- chrome titanate yellow (0.80-0.86)
- nickel titanate yellow (0.77-0.85)
- iron oxide yellow (0.70)
- cobalt aluminum blue (0.61-0.70)
- cobalt chromite blue (0.54-0.70)
- phthalo blue (0.54-0.63)
- cobalt chromite green (0.58-0.64)
- ultramarine blue (0.52)
- chromium oxide green (0.50-0.57)
- other brown (0.50-0.74)

NIR Reflectances of Coolest Pigments Over Black Background

- titanium dioxide white (0.43-0.64)
- nickel titanate yellow (0.42-0.64)
- mica coated w/titanium dioxide (0.31-0.54)
- chromium oxide green (0.33-0.40).

Next Steps

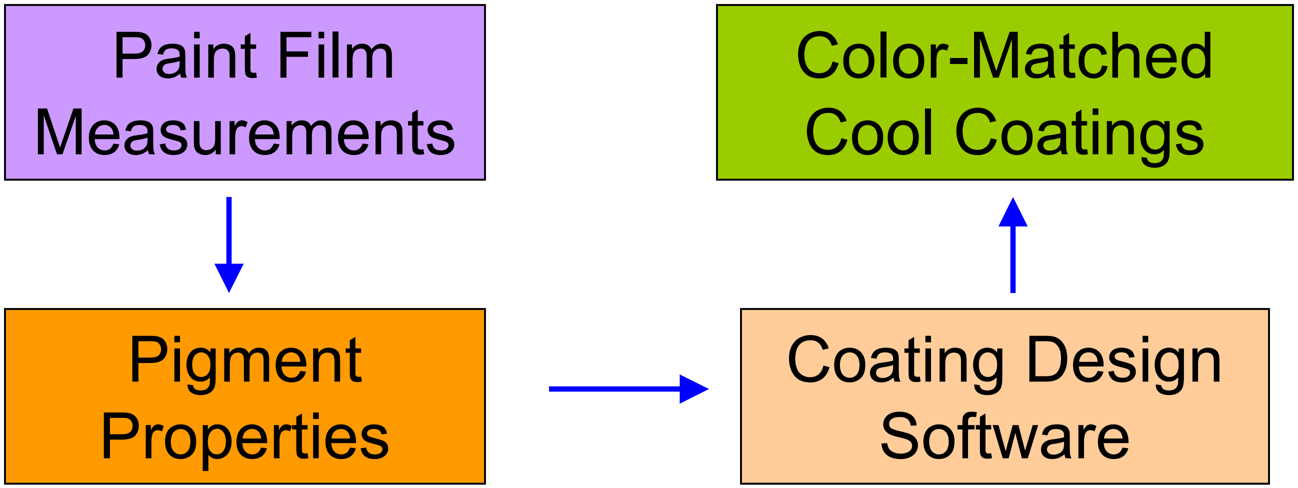
- Develop theory of mixtures
  – analyze tint measurements
  – prepare and measure nonwhite mixtures
- Share detailed pigment characterizations with industrial partners
- Establish measurement protocols
- Characterization task feeds into the coating design task

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 8 %

Coating Design Software

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



2.4.4 Cool Colored Material Database (Preliminary)

- Describes 83 single-pigment paints
- Fields include
  - spectral solar transmittance and reflectances (300 - 2500 nm @ 5 nm)
  - pigment chemistry, pigment name, film thickness
  - computed absorption and backscattering coefficients
  - many ancillary values
- Format
  - one tab-delimited text file per paint (easy to read/write)
  - files packed in ZIP archive

Excerpt From Paint Data File

lambda (nm)	R.tilde.fv	T.tilde.fv	R.tilde.fw	R.tilde.fb	R.tilde.ow	K (1/mm)	S (1/mm)
330	0.0534	2.43E-01	0.0484	0.0468	0.0636	5.58E+01	1.31
335	0.0566	2.71E-01	0.0494	0.0474	0.0628	5.05E+01	1.9
340	0.0596	2.95E-01	0.0503	0.048	0.0625	4.65E+01	2.48
345	0.0623	3.18E-01	0.0511	0.0485	0.0632	4.30E+01	2.92
350	0.0648	3.41E-01	0.0522	0.0486	0.0653	3.97E+01	3.26
355	0.0676	3.64E-01	0.054	0.0485	0.0691	3.68E+01	3.68
360	0.0706	3.85E-01	0.056	0.0487	0.0744	3.41E+01	4.12
365	0.0736	4.06E-01	0.0587	0.0489	0.0817	3.16E+01	4.56
370	0.0761	4.25E-01	0.0622	0.0491	0.0912	2.96E+01	4.84
375	0.0783	4.41E-01	0.0673	0.0491	0.105	2.78E+01	5.08
380	0.08	4.58E-01	0.0748	0.0489	0.125	2.61E+01	4.97
385	0.0818	4.73E-01	0.086	0.0488	0.157	2.44E+01	4.72
390	0.0837	4.88E-01	0.104	0.0489	0.212	2.30E+01	4.6

2.5 Development of 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 of 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 95 %

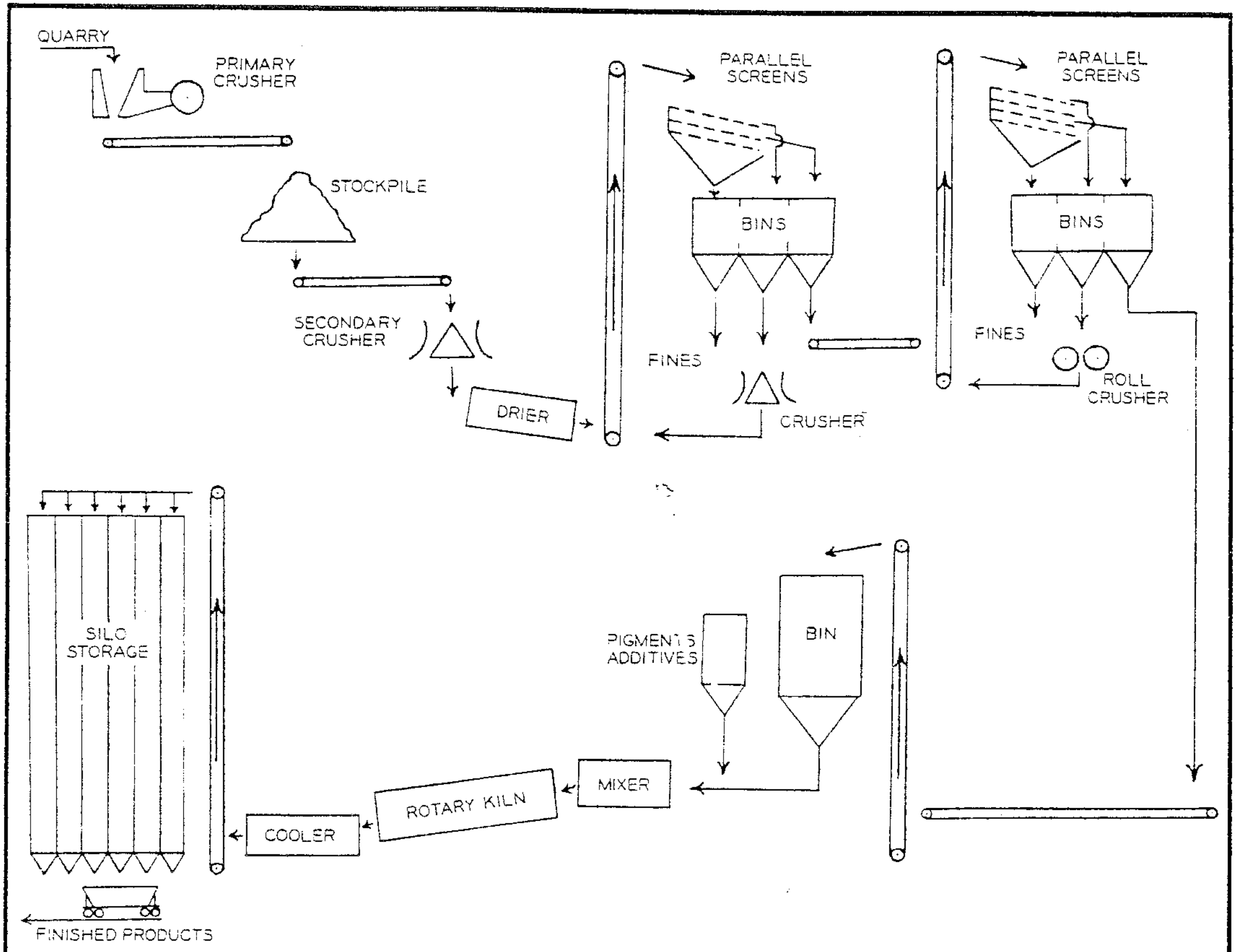
Focus: Application of Cool Colors to Roofing Products

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

Manufacturing Shingles:
ISP Mineral Products in Ione, CA

- On March 12, we visited the ISP Mineral Products roofing granule plant in Ione, CA

Schematic of a Granule Production Plant



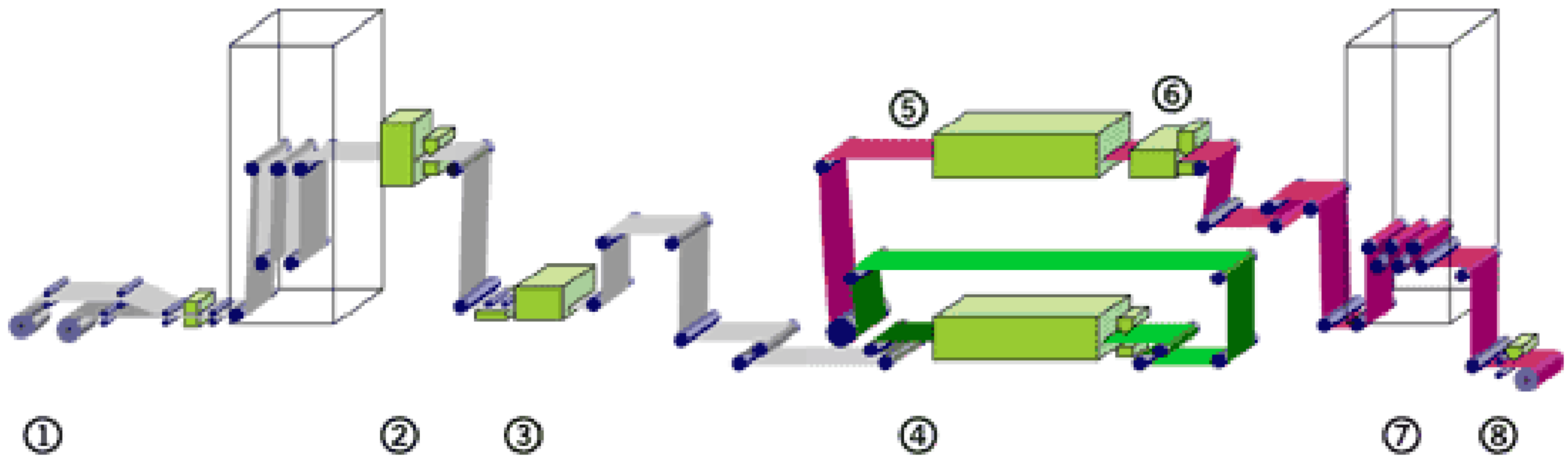
Production of Cool Shingles

- Cool granules = cool shingles
- Two principal methods
  - manufacturing granules from reflective rocks (limited by local availability of suitable inert rocks)
  - coating the granules with reflective pigments
- Two-layered approach
  - the granule is pre-coated with a relatively inexpensive NIR-reflective pigment
  - the cool color pigment is applied to the pre-coated granules
- The industry has designed its quality-control laboratories to test the visible color of products; additional instruments is needed to test the solar reflectance and NIR optical properties of products

Manufacturing Metal Roofs:
Steelscape, Inc., Rancho Cucamonga, CA

- On April 30, we visited the Steelscape metal coil coating plant in Rancho Cucamonga, CA
- Four manufacturing lines
  - pickle line
  - cold mill line
  - metal coating line
  - paint line

Schematic of a Metal Coil Coating Plant

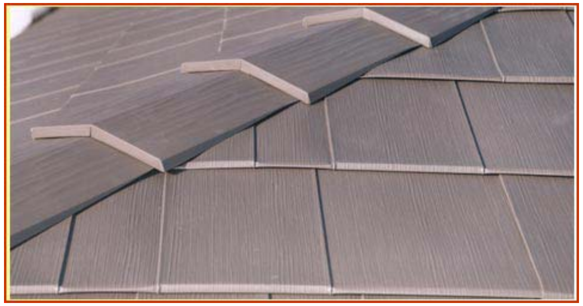


1. Entry reels
2. Cleaning unit
3. Chemical coater, applies an initial coating on the steel
4. Finish coater, coats the steel with the finish paint
5. Water quench, painted steel is cooled down to room temperature
6. Excess water remover
7. Exit accumulator
8. Exit reel

Metal Forming








Production of Cool Metal Roofs

- Of all the colored roofing materials, metal roofs are most suitable for the application of cool colored coatings
- The substrate (bare metal) has high initial reflectance, and is typically coated with two layers (primer + finish)
- If the substrate does not have high initial reflectance, use of a high-reflectance primer could reduce the cool-pigment loading required in the finish

Manufacturing Clay Roof Tiles:
Maruhachi Ceramics of America, Inc., Corona, CA

- On April 30, we visited the MCA clay roofing tile plant in Corona, CA

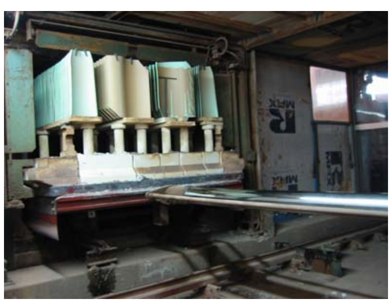
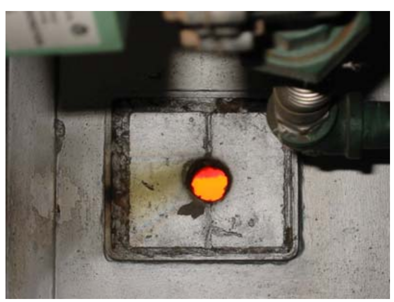
Manufacturing Clay Roof Tiles









Production of Cool Clay Roof Tiles

- Three ways to improve solar reflectance of colored tiles
  - use raw clay with a low concentration of light-absorbing iron and iron oxides.
  - use cool color pigments in the glaze to provide choice of high-reflectance color
  - use cool pigments over a highly reflective undercoat

Next Steps

- Visit a concrete tile manufacturing plant
- Update the manufacturing report
- Help needed to arrange plant visits

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 7 %

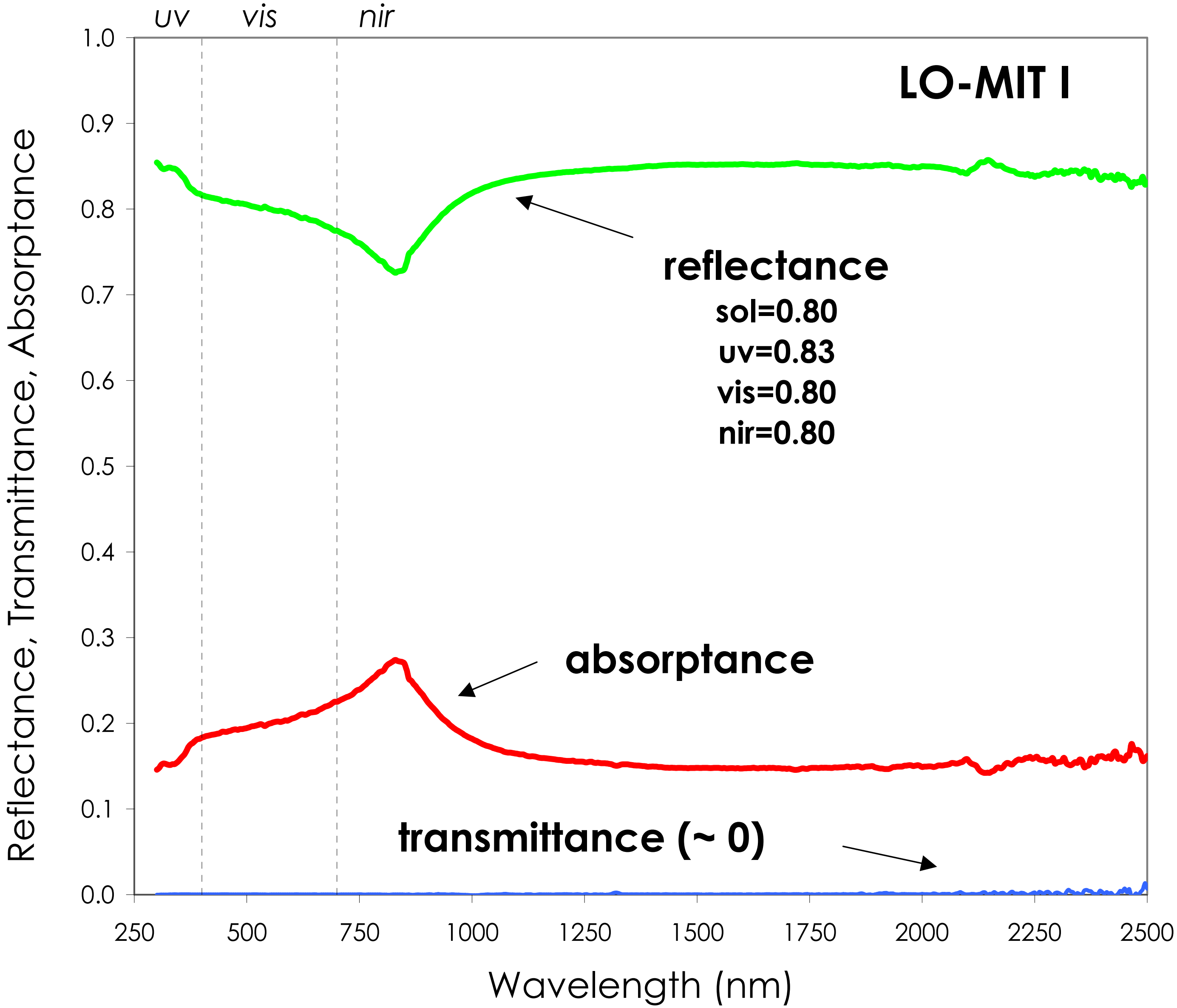
Engineering Methods: NIR-Reflective Undercoating

- All cool pigments must have low NIR absorption
- NIR-reflective undercoats (e.g., white, aluminum) improve performance of cool pigments, especially those with high NIR transparency

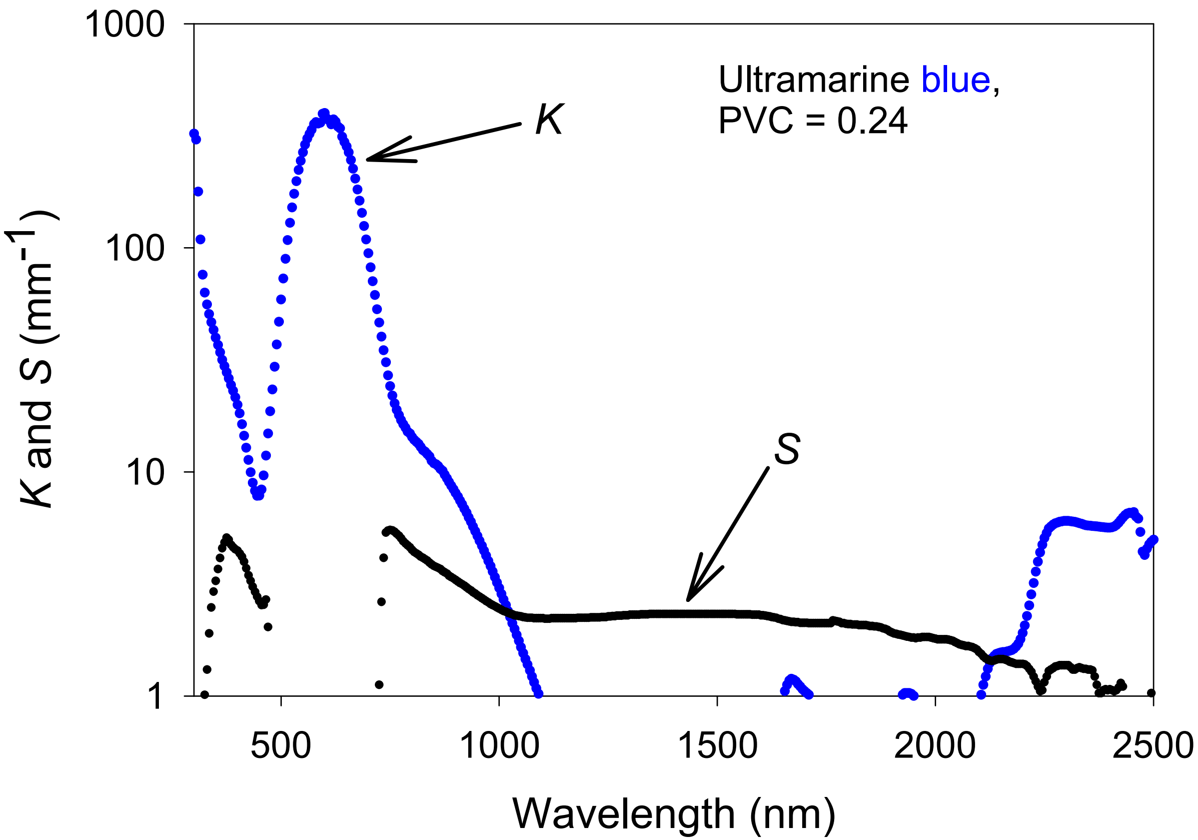
Achieving NIR Reflectance > 0.8

- Best NIR reflectance in a 1 mil (25 μm) film with ~10% TiO_2 is about 0.6
- Roughly 3 mils (75 μm) required for NIR reflectance > 0.8
- A thin layer of TiO_2-coated mica flakes, $(Fe,Cr)_2O_3$, certain titanates are nearly as good as a thick layer of TiO_2
- Pigments with better NIR scattering power?
- Very thin (e.g., 10 nm) continuous metal films/foils/flakes can have NIR reflectance > 0.8 (corrosion an issue, though)

Flake Al Film with NIR Reflectance = 0.8

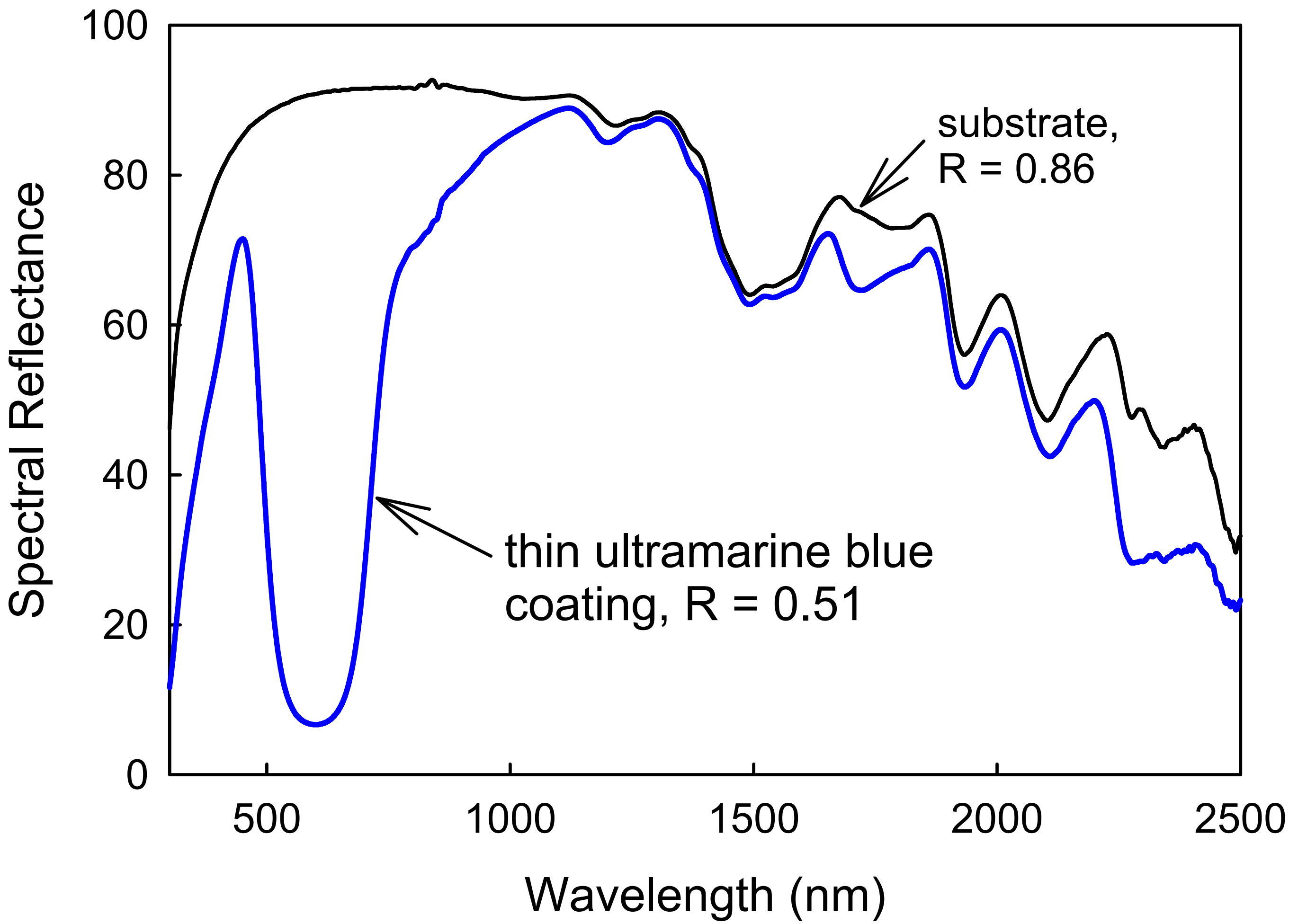


Absorption *K* and Scattering *S* For Ultramarine Blue

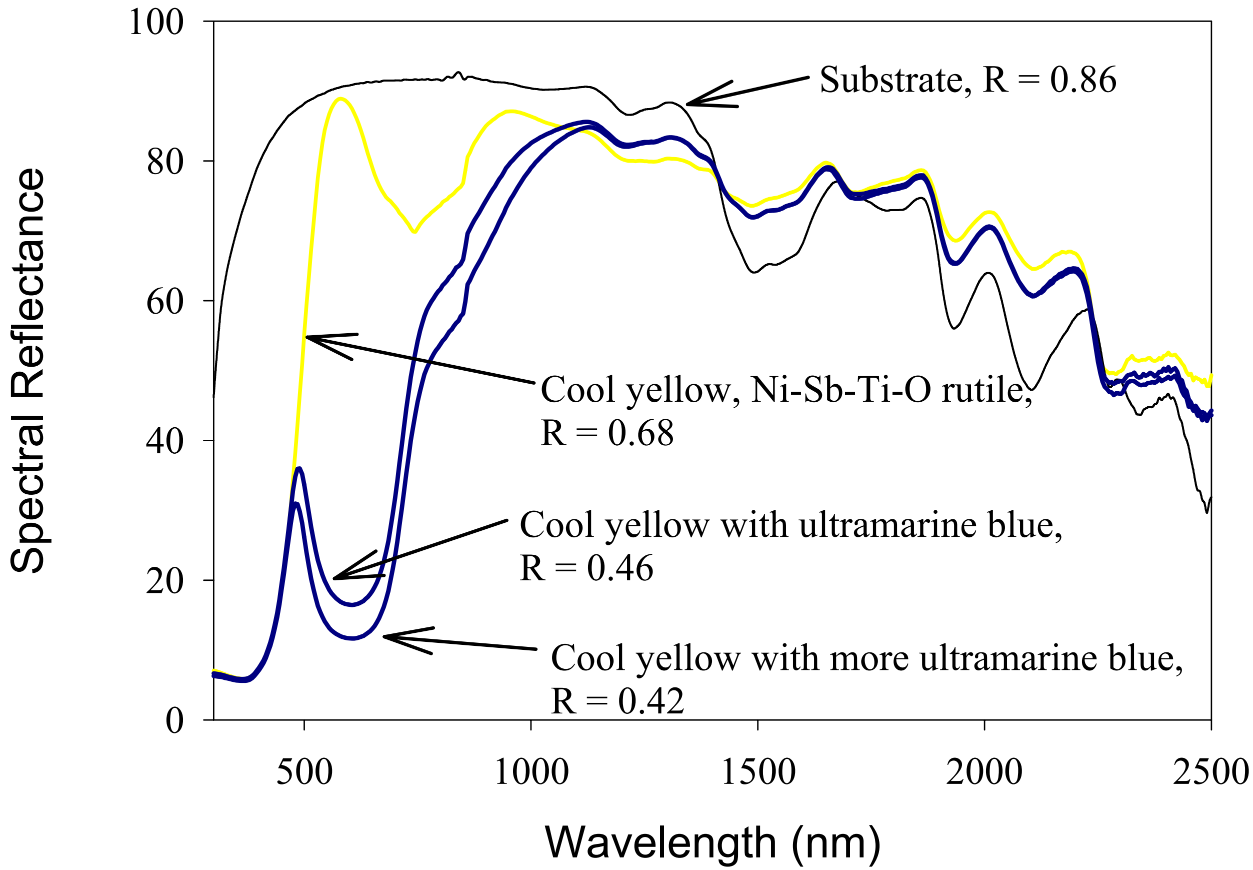


- Strong visible absorption
- Weak IR absorption

Ultramarine blue over white



Bluish Gray Color: Ni-Sb-Ti-O Plus Ultramarine Blue



Other mixtures of ultramarine blue with yellow and orange pigments can produce dark green and brown shades

Next Steps

- Collaboration with industrial partners
  - pigments: identify/develop suitable undercoats with high NIR reflectance
  - review IR-reflective window technology for ideas
  - propose further recipes for high NIR-reflectance colors
  - investigate methods for factory measurement of shingle NIR reflectance

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

- 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

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

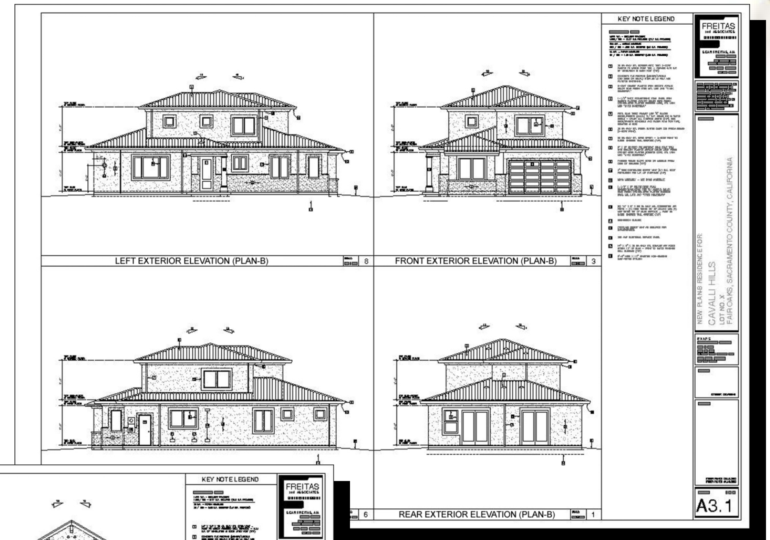
- Objective: Setup residential demonstration sites, measure and document the energy savings of Cool Roof Color Materials

- Deliverables:
  - √ Site Selection : Cavalli Hills, Sacramento, CA
  - √ Site Test Plan
  - – Test Site Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 26 %

Cavalli Hills Subdivision Sacramento, CA

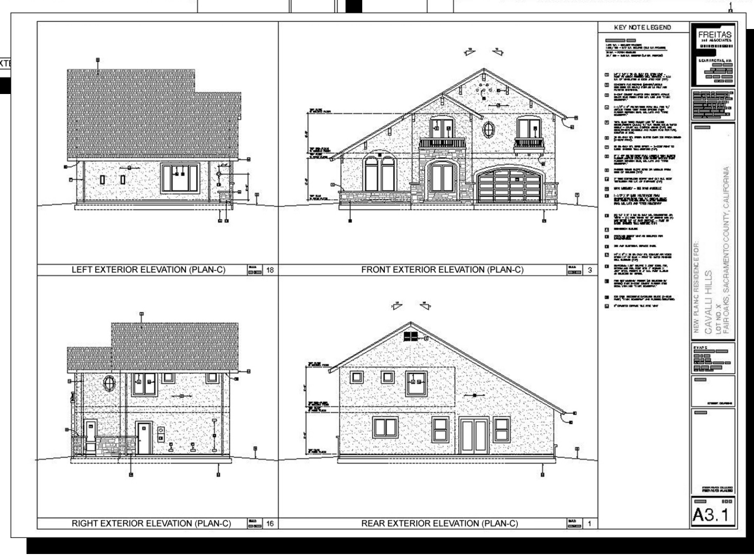
- Sacramento Municipal Utility District (**SMUD**) and ORNL will monitoring homes
  - Signed **Memorandum of Understanding**
  - Cool Roof Color Materials (CRCM)
  - Insulated Concrete Form (ICF) walls

Architectural Plans for Cavalli Hills



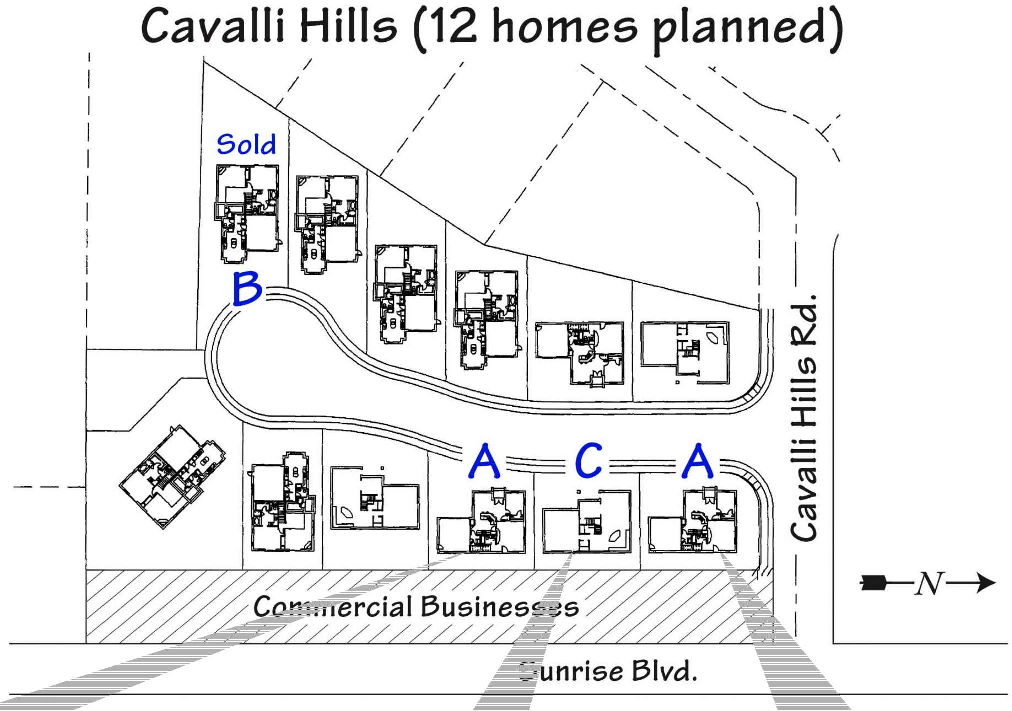
Plan A

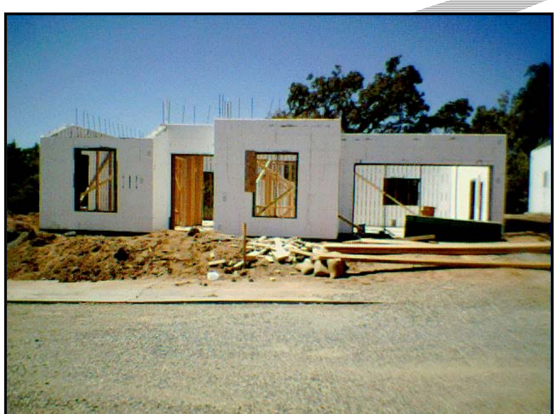
Plan B



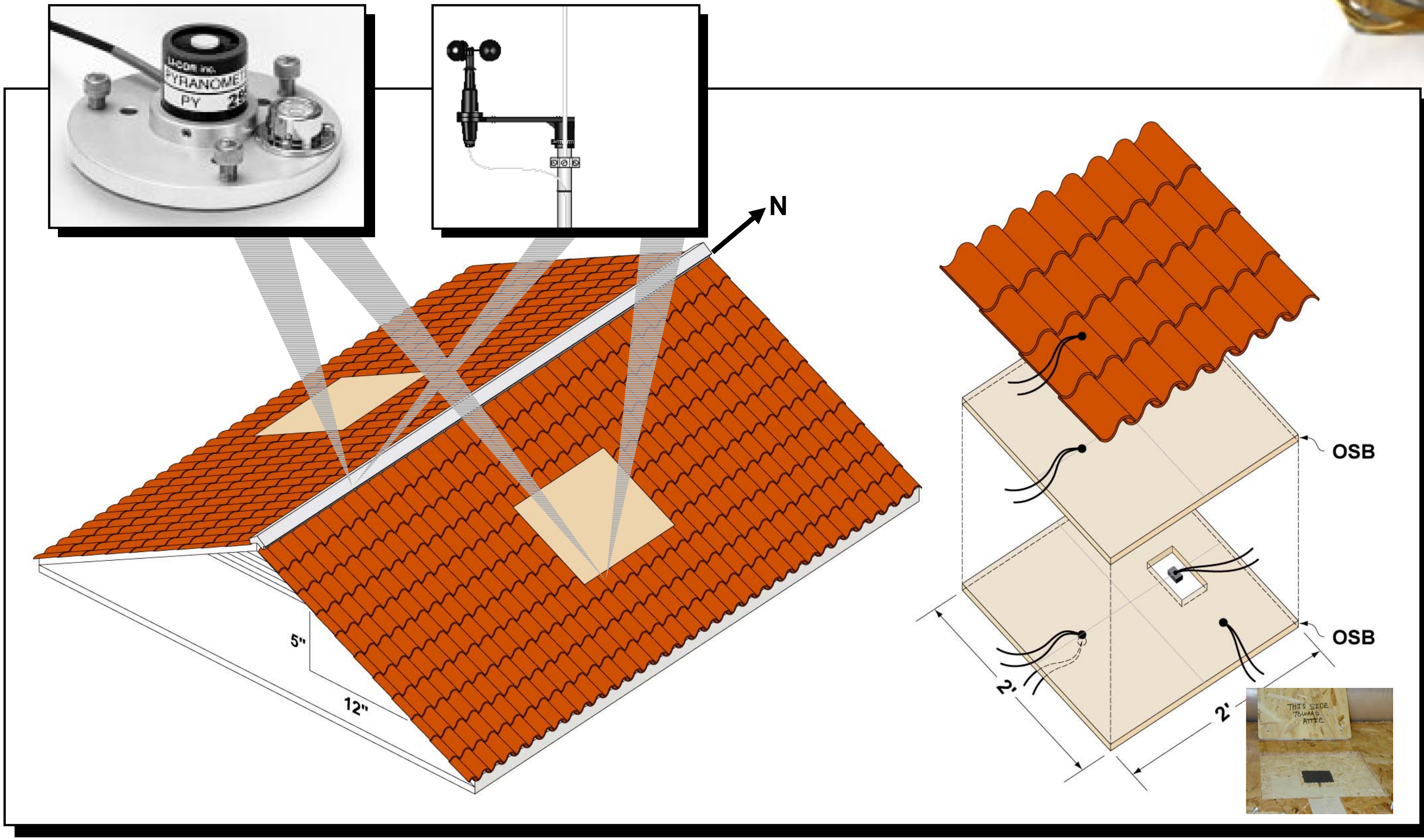
Plan C

Mike Evans Construction is building Cavalli Hills





Roof Instrumentation



OSB Sandwich test panels received by Evans Construction

Implementation Stage for 2.6.1 OUR Next Steps

- **Hanson Roof Tile of *Roof Tile Institute***

  Supplying “Hacienda” Concrete Tile

- **FERRO Corporation**

  Blending cool roof color materials into Hanson’s concrete mix

- **Custom-Bilt Metals**

  Classic Products

  Cool Metal Roofing Coalition

  Supplying *Country Manor Shake*

- **ORNL Contracts Evans Construction**

  ORNL and SMUD commission

  Data Acquisition Systems October 2003

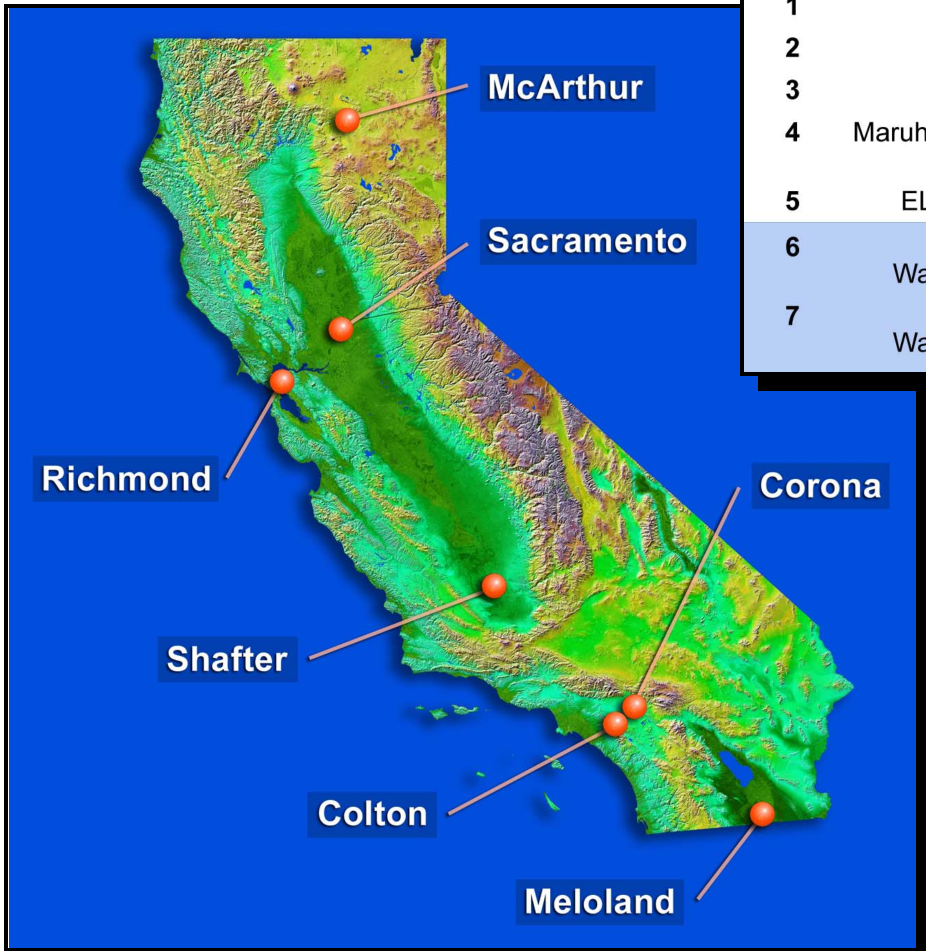
2.6.2 Materials Testing at Weathering Sites in California

- 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 27 %

Exposure Racks were installed August 03

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)

Sites at McArthur Farms, Elk Corp, Custom-Bilt Metals and Steelscape

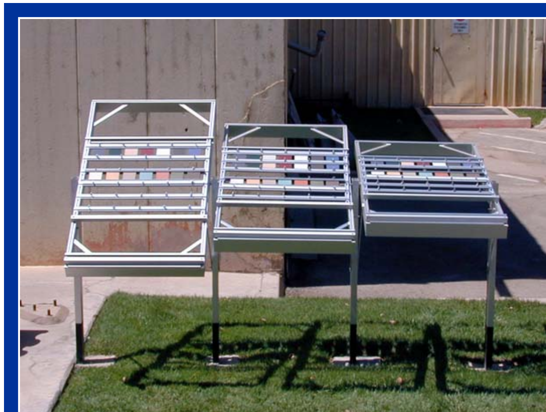
McArthur

Sacramento

Richmond

Shafter

Sites at MCA, BASF and Meloland



Corona

Colton

Meloland

CIMIS and EPA's Aeormetric Information Retrieval System data

CALIFORNIA THE GOLDEN STATE — CALIFORNIA HOMEPAGE — GOVERNOR'S HOMEPAGE

California Irrigation Management Information System
Department of Water Resources

August 20, 2003 - August 26, 2003
Printed on August 27, 2003

Meloland - Imperial/Coachella Valley - Station 87

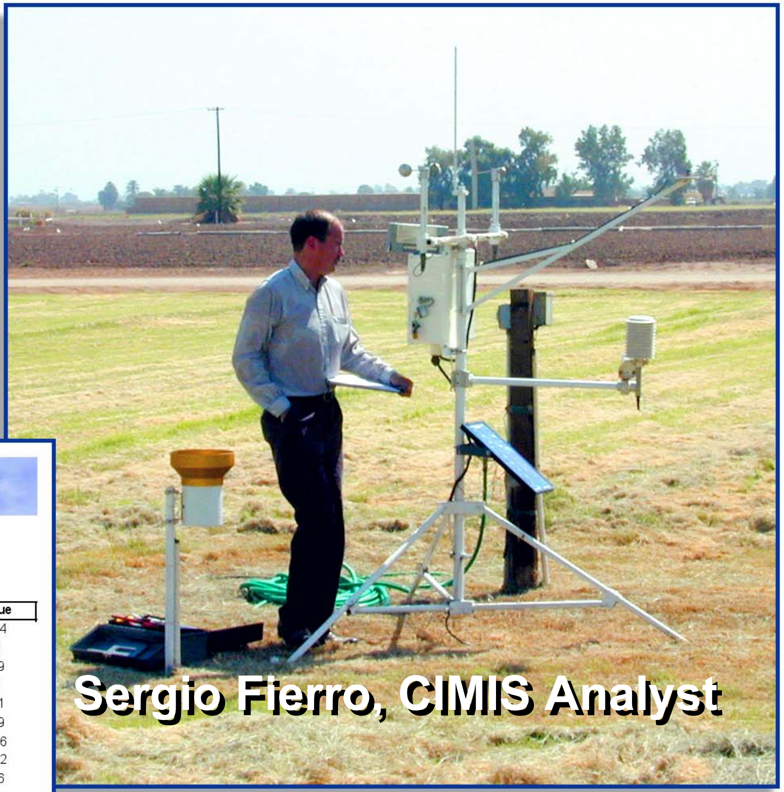
Date	CIMIS ETo (in)	Precip (in)	Sol Rad (Ly/day)	Avg Vap (mBars)	Max Air Temp (°F)	Min Air Temp (°F)	Avg Air Temp (°F)	Max Rel Hum (%)	Min Rel Hum (%)	Avg Rel Hum (%)	Dew Pt (°F)	Avg wSpd (MPH)	Wnd Run (miles)	Avg Soil Temp (°F)
08/20/2003	0.19 R	0.00	449	33.1	98.6	75.6	85.4	93	56	80	78.3	8.0	193.2	83.9
08/21/2003	0.24	0.00	585	29.0	102.3	74.6	88.7	94	41	63	74.3	3.6	86.1	83.8
08/22/2003	0.23	0.00	538	25.0	104.2	79.3	91.2	74	33	50	69.9	3.1	75.5	84.7
08/23/2003	0.26	0.00	564	25.1	107.2	79.0	93.7	69	28	46	70.0	4.1	98.2	85.0
08/24/2003	0.19	1.89	505	35.3 Y	98.3	75.9	88.2	100	58	78 Y	80.3 Y	5.5	133.4	84.8
08/25/2003											80.3			
08/26/2003														
Total/Avg														

California Irrig

California Air Resources Board

The U.S. EPA's Aerometric Information Retrieval System (AIRS) Parameter, Method, Unit, and Null Codes for Selected Particulate Matter-10 Micorns (PM10) Metal Components.

State	County	Site Code	Pollutant	POC	Unit	Method	Date	Value
06	025	0004	Aluminum	5	?g/m^3	303	1/3/1995	0.94
06	025	0004	Aluminum	5	?g/m^3	303	1/9/1995	3
06	025	0004	Aluminum	5	?g/m^3	303	1/15/1995	1.9
06	025	0004	Aluminum	5	?g/m^3	303	1/21/1995	1
06	025	0004	Aluminum	5	?g/m^3	303	1/27/1995	1.1
06	025	0004	Aluminum	5	?g/m^3	303	2/2/1995	2.9
06	025	0004	Aluminum	5	?g/m^3	303	2/8/1995	0.46
06	025	0004	Aluminum	5	?g/m^3	303	2/14/1995	0.82
06	025	0004	Aluminum	5	?g/m^3	303	2/20/1995	2.6
06	025	0004	Aluminum	5	?g/m^3	303	2/26/1995	3.7
06	025	0004	Aluminum	5	?g/m^3	303	3/4/1995	0.53
06	025	0004	Aluminum	5	?g/m^3	303	3/10/1995	6.4
06	025	0004	Aluminum	5	?g/m^3	303	3/16/1995	1.6
06	025	0004	Aluminum	5	?g/m^3	303	3/22/1995	1
06	025	0004	Aluminum	5	?g/m^3	303	3/28/1995	1.2
06	025	0004	Aluminum	5	?g/m^3	303	4/3/1995	1.2
06	025	0004	Aluminum	5	?g/m^3	303	4/9/1995	2.1
06	025	0004	Aluminum	5	?g/m^3	303	4/15/1995	1.6
06	025	0004	Aluminum	5	?g/m^3	303	4/21/1995	3.2
06	025	0004	Aluminum	5	?g/m^3	303	4/27/1995	4.6



Sergio Fierro, CIMIS Analyst

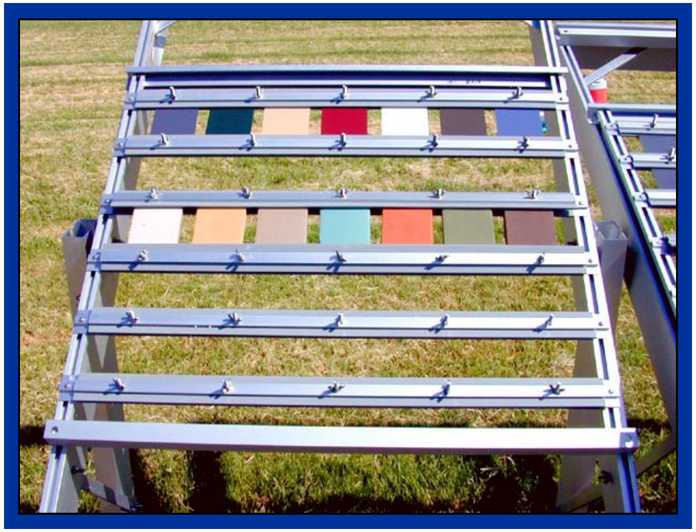
Implementation Stage for 2.6.2
OUR Next Steps

- **Monier Lifetile making concrete tile samples**

  Shepherd Color Co. blending "cool" colors into Monier's concrete mix

- **Space available for additional roof samples**

- **Reflectance and emittance measurements collected biannually**

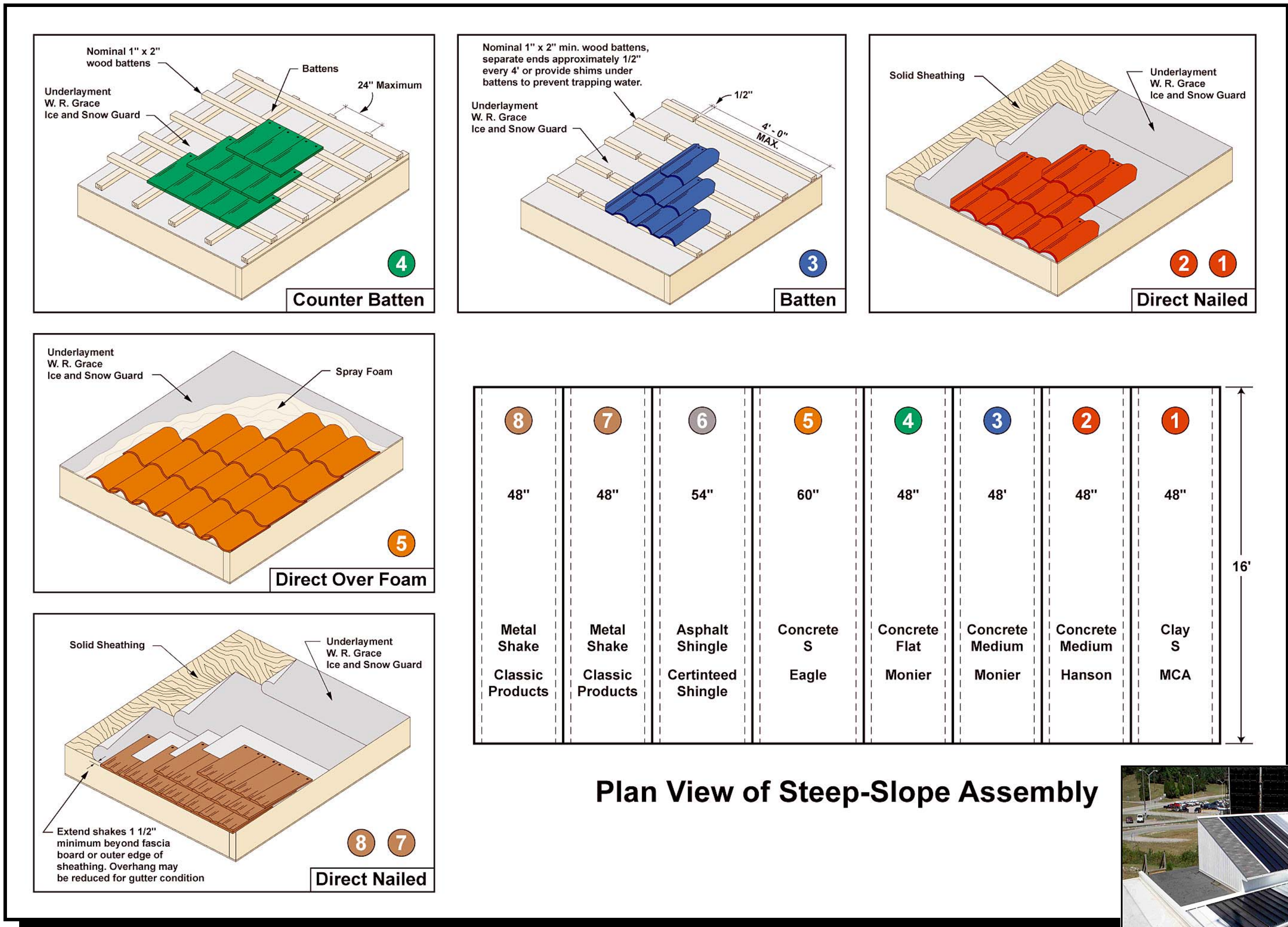


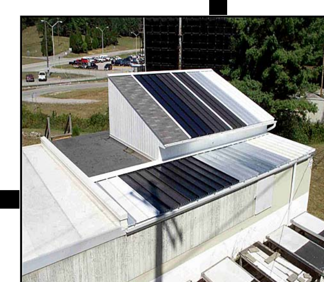
2.6.3 Steep-slope Assembly Testing at ORNL

- 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

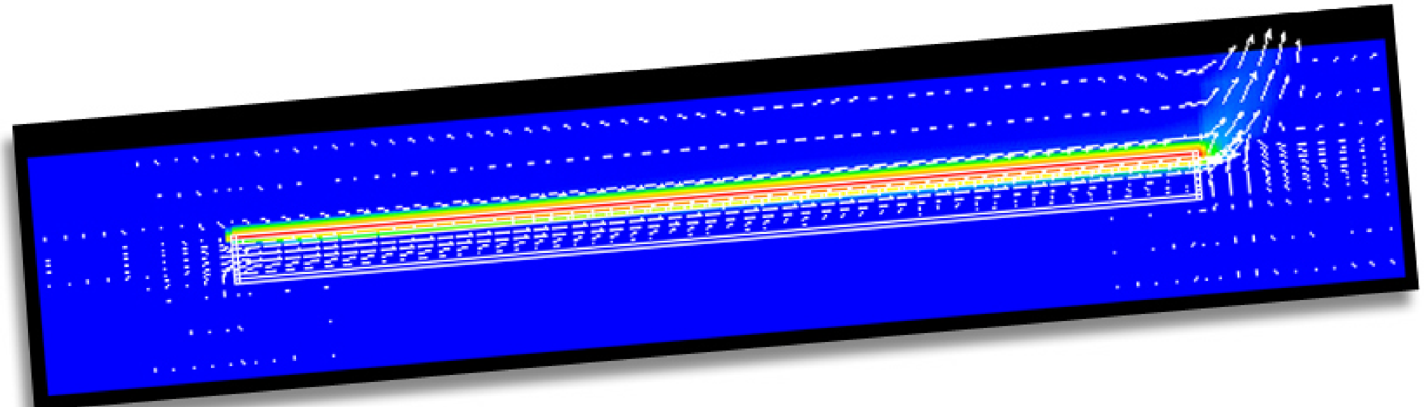
- Deliverables:
  - Whole-Building Energy Model Validation
  - Presentation at the Pacific Coast Builders Conference
  - Steep Slope Assembly Test Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 10 %

Roof Tile Institute to install five different tile assemblies on ESRA

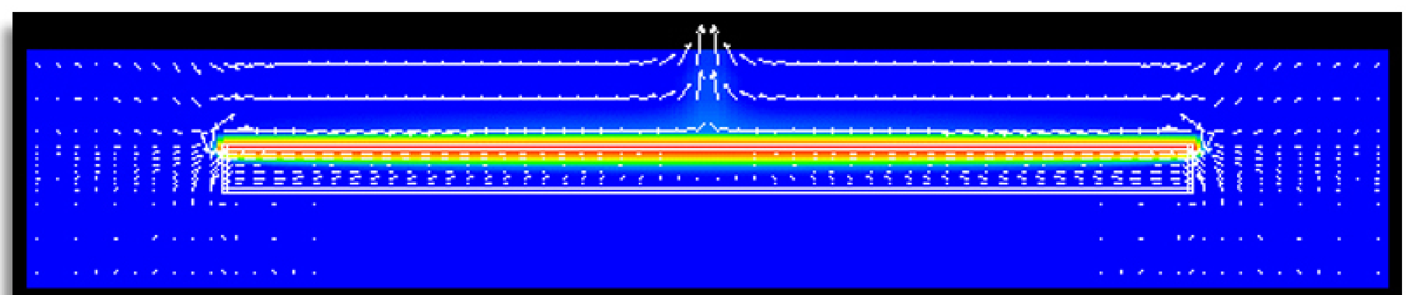




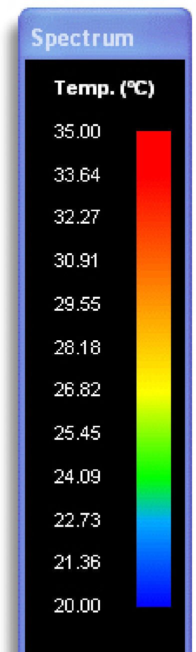
Naturally induced flow observed at low roof slopes and low ΔTs



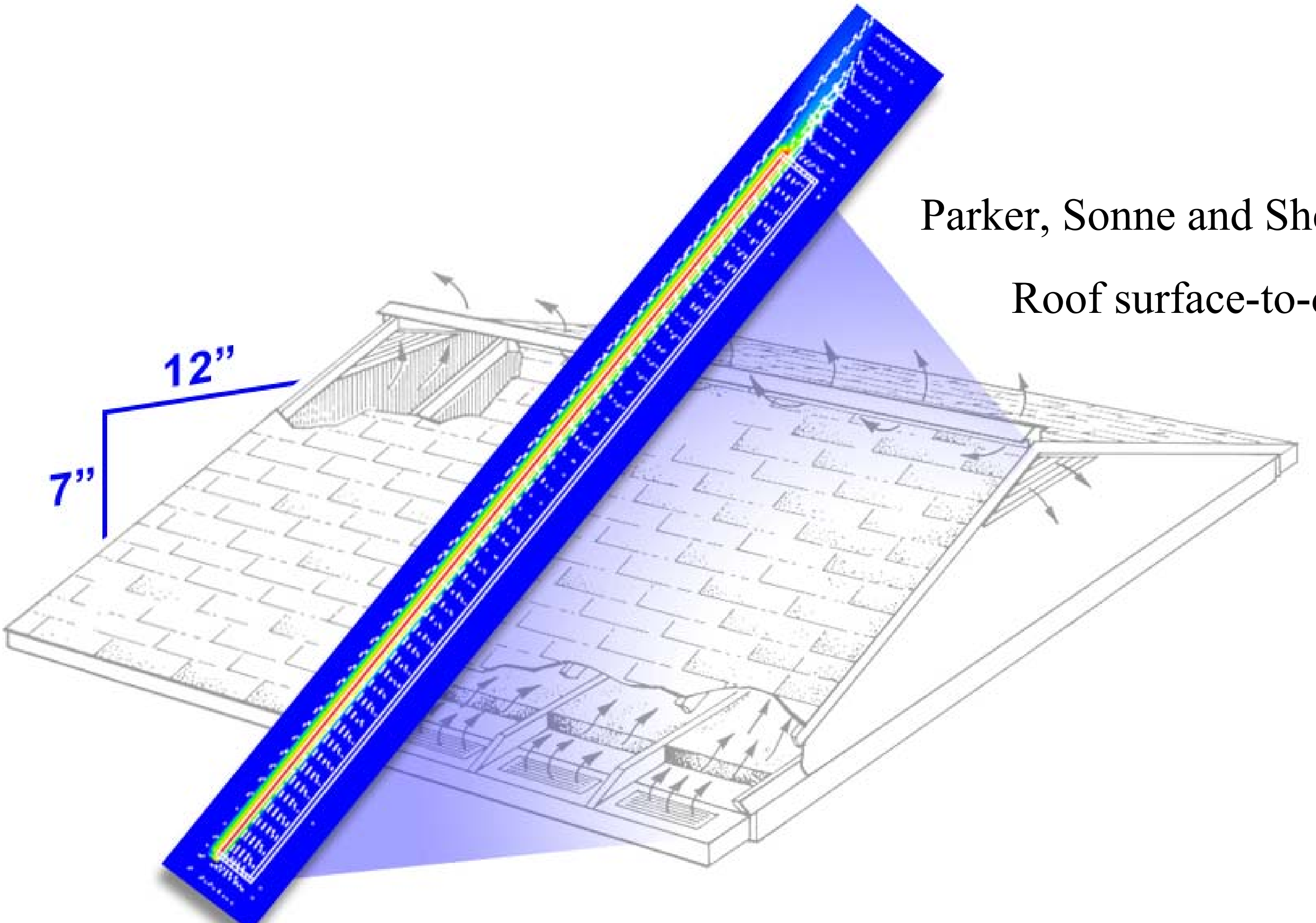
(B) 5° inclination 1°C ΔT



(A) 0° inclination 15°C ΔT



Natural convection effects prevalent in counter-batten roof systems

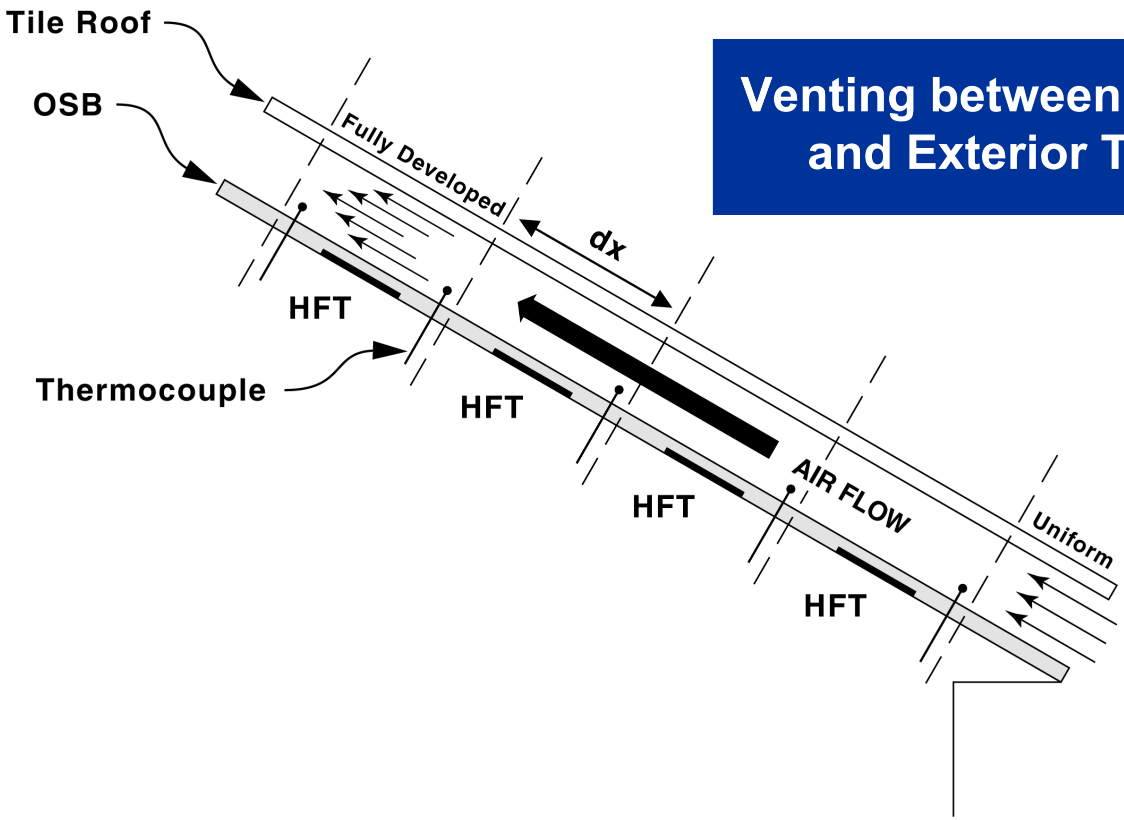


Parker, Sonne and Sherwin (ACEEE 2002)

Roof surface-to-deck ΔT’s ≈ 14°F (8°C)

Airflow patterns between roof deck and concrete tile

$$\frac{dT_B}{dx} = \frac{h_R\left(T_{Roof} - T_B\right)}{\dot{m}C_P} + \frac{h_D\left(T_{Deck} - T_B\right)}{\dot{m}C_P} - \frac{kA}{\dot{m}C_P}\left(\frac{d^2T_B}{dx^2}\right)$$



Venting between Roof Deck and Exterior Tile Roof

Implementation Stage for 2.6.3: Next Steps

- **Tennessee Roofing**
  - Remove existing steep-slope metal roofs from ESRA
  - Remove existing thermoplastic membranes
- **Roof Tile Institute installs concrete tile systems**

1. MCA “S-Mission” Clay tile (Terra Cotta Glaze “cool” color)
2. Hanson “Regal” Concrete Medium “cool” color same as at Cavalli Hills
3. Monier Lifetile “Villa 2000” Concrete Medium (Slurry Terra Cotta color)
4. Monier Lifetile “Sentry Slate” Concrete Flat (Brown)
5. Eagle “Capistrano” Low Profile Concrete (Slurry Terra Cotta color)

- **Custom-Bilt Metals/Classic Products of Cool Metal Roofing Coalition**

7. Painted metal shake “cool” color same as at Cavalli Hills
8. Painted metal shake “standard” color same as at Cavalli Hills

March 2004 Meeting

- March 4, 2004
- At CEC, Sacramento

Cool Colors Project Website

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

http://CoolColors.LBL.gov