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)

March 4, 2004; Sacramento, 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, 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 Metal Roofing Coalition
6. Cool Roof Rating Council
7. DuPont Titanium Technologies
8. Environmental Protection Agency (EPA)
9. EPA San Francisco Office
10. Mike Evans Construction
11. National Roofing Contractors Association
12. Pacific Gas and Electric Company (PG&E)
13. Roof Tile Institute
14. Southern California Edison Company (SCE)

Industrial Partners

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

Project Team

- LBNL
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  - Hashem Akbari (Technical Lead) H_Akbari@LBL.gov
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- ORNL
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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

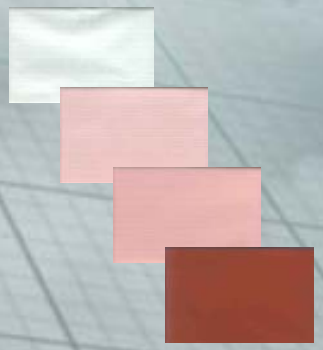
- Objectives
  - Maximize solar reflectance of a color-matched pigmented coating
  - Compare performance of a coated roofing product (e.g., a shingle) to that of a simple smooth coating
- Subtasks
  - Identify and characterize pigments with high solar reflectance
  - Develop software for optimal design 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 (paper to be submitted to journal)
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 80%

Recent Pigment Characterizations

- Diluted strongly absorbing paints (iron oxide black, titanium white)
- Pigmented paint tint ladders (colors + varying amounts of white)
- Pigmented tile glaze ladders (colors in varying concentrations)



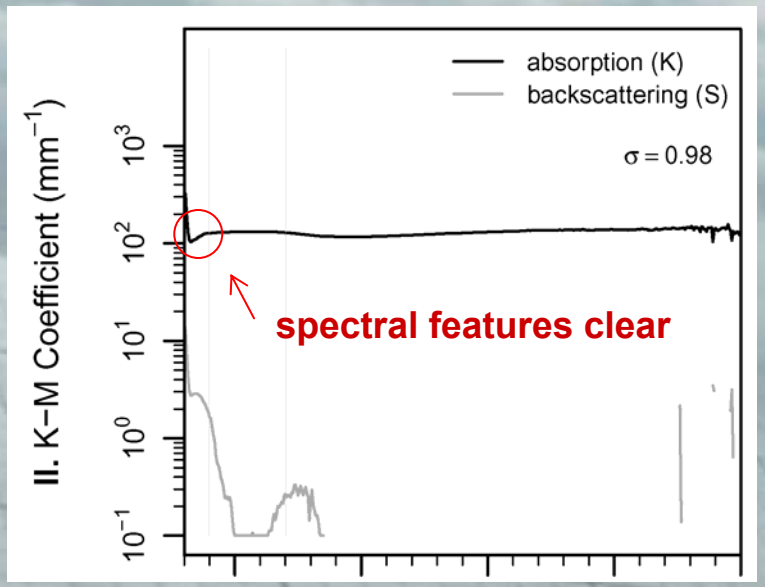
paint tint ladder

tile glaze concentration ladders

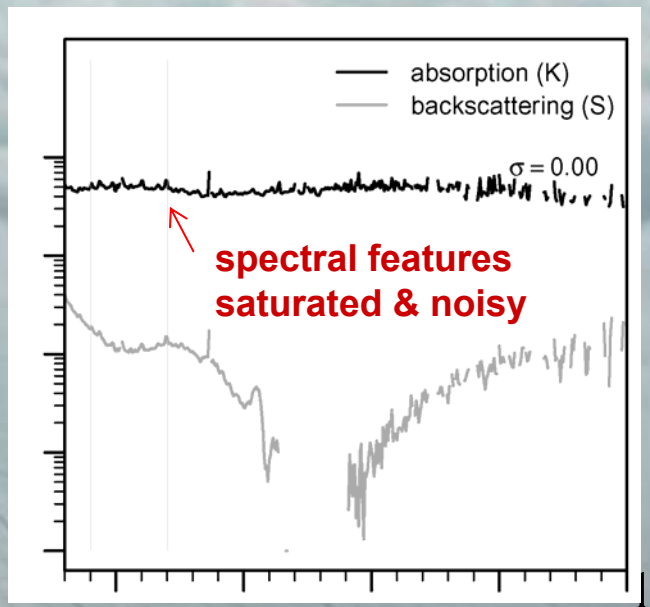
Resolving Spectral Features of Strongly Absorbing Pigments

- We diluted strongly absorbing paints such as **iron oxide black** to reveal spectral reflectance features

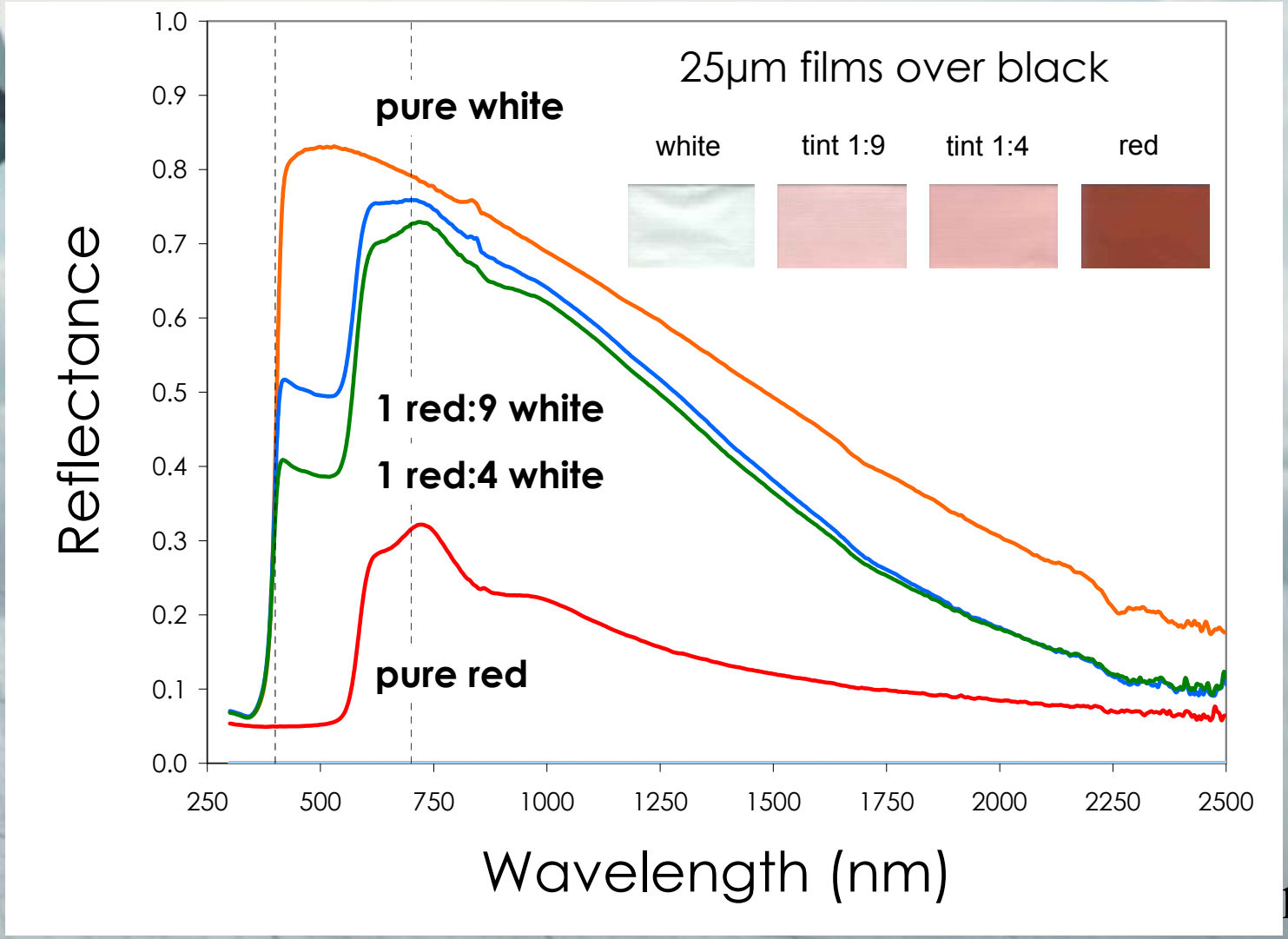
Diluted (4% PVC)



Original (17% PVC)



Sample Paint Tint Ladder: Mixing Red Oxide with White



Characterizing Tile Glazes Using Concentration Ladders

- Problem:
  - Firing changes color of tile glaze
  - Transparent substrates such as quartz difficult to fire with glaze (different thermal expansion rates)
- Solution:
  - Measure spectral reflectances of white tiles coated with color glazes of varying pigment concentration

Tile Glaze Concentration Ladders

Next Steps

- Prepare and characterize mixtures
  - analyze paint tint and tile glaze ladders
  - prepare and measure nonwhite mixtures
- Share pigment characterizations with partners (ongoing)
- Establish measurement protocols
- Apply characterizations to coating design

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 10%

Recent Developments in Coating Design Software

- Design software combines
  - pigment property database
  - theory of mixtures

  to
  - predict spectral reflectance of paint mixtures and layers
  - optimize solar reflectance of a given color
- Tint, mixture, and concentration-ladder data being used to refine mixture theory

Coating Design Software Overview

- Objective
  - optimize total solar reflectance given color, pigment constraints
- Algorithm
  - LBNL-adapted Kubelka-Munk theory
- Validation
  - compare computed, measured spectral reflectances of complex coatings
- Platform: “R” programming language
  - free
  - available for PC, Mac, Unix
  - http://www.r-project.org

Next Steps

- Validate mixture theory
- Develop optimization algorithm
- Validate code in-house
- Share software prototype with partners for further testing

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 25%

Cool Colored Pigment Database: Updates

- Shared database with partners
  - Feedback requested
- Next step: add new data
  - Diluted black and white masstones
  - Tints
  - Pigmented glazes

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 98%

Focus: Application of Cool Colors to Roofing Products

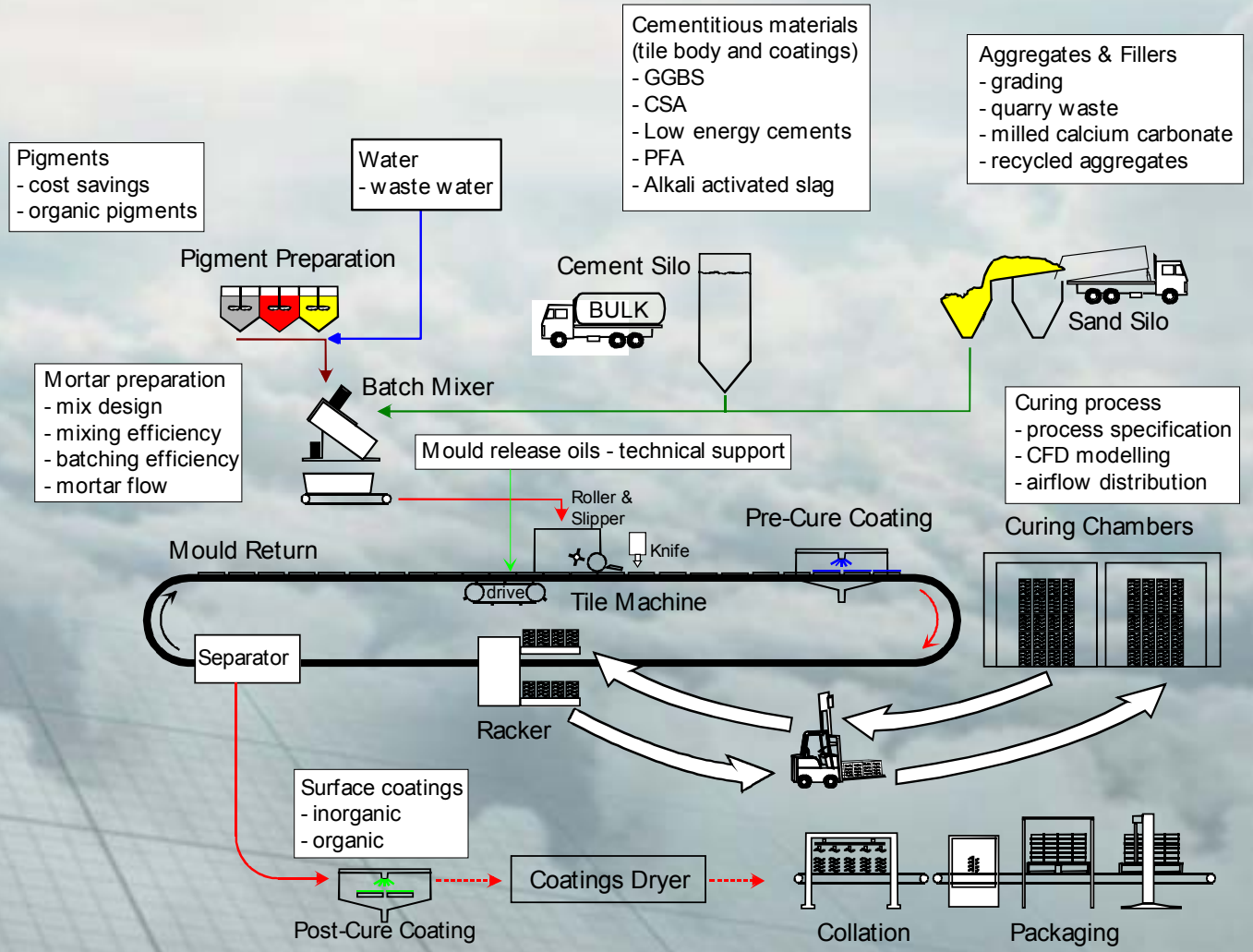
- Metal roofing
- Clay roof tiles
- Concrete roof tiles
- Wood shakes
- Asphalt shingles (granules)

Manufacturing Concrete Roof Tiles

- On October 1, we visited the MonierLifetile concrete roofing tile plant in Lathrop, CA

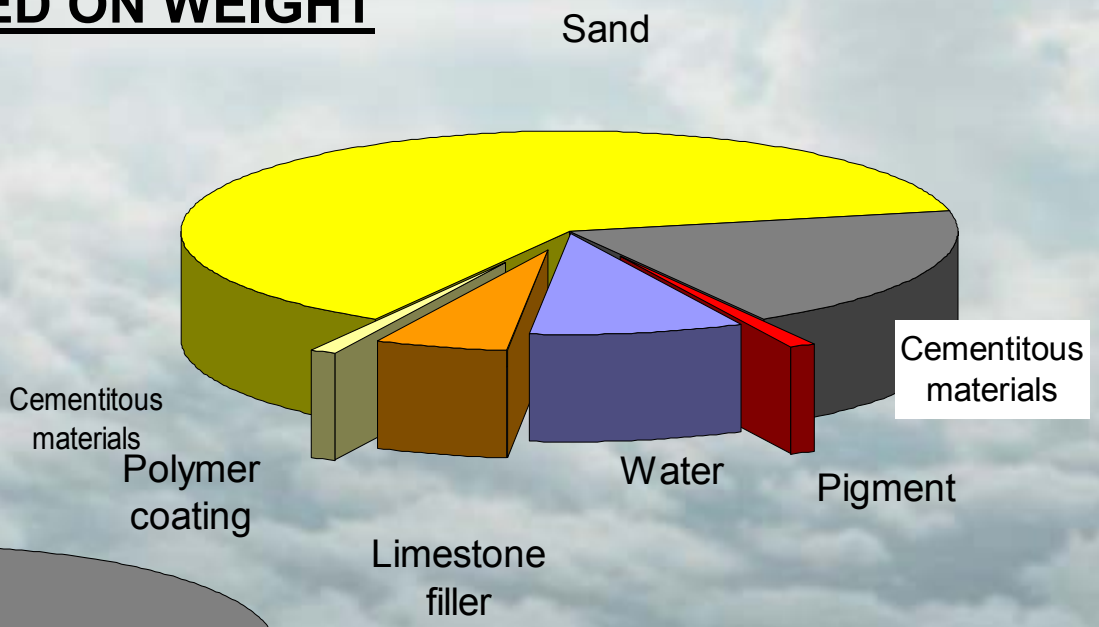
MonierLifetile
Changing the way people think about roofs.

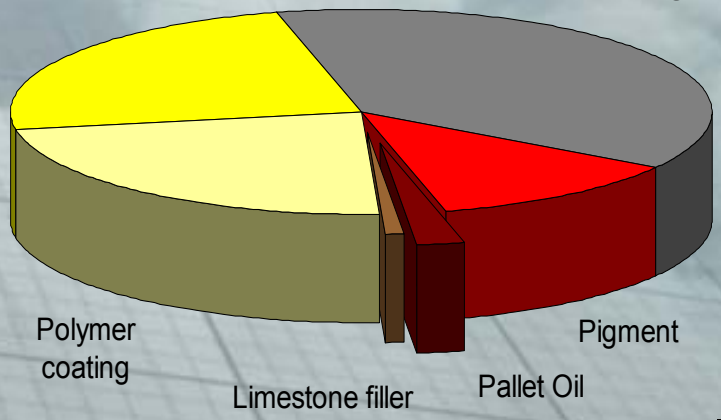
Schematic of a Concrete Roof Tile Plant



Relative Proportions Of Raw Materials in a Tile

BASED ON WEIGHT





BASED ON COST

Production of Cool Colored Concrete Roof Tiles

- Ways to improve solar reflectance
  - whiten tile by
    - using white cement in concrete mix;
    - using white cementitious surface coating; or
    - using white polymeric surface coating
  - use infrared-scattering colored pigments over light or dark tile
    - example: mixed-metal complex inorganics
  - use infrared-transmitting colored pigments over a light tile
    - example: phthalocyanines

Next Steps

- Visit a wood shake manufacturing plant
- Finalize the manufacturing report

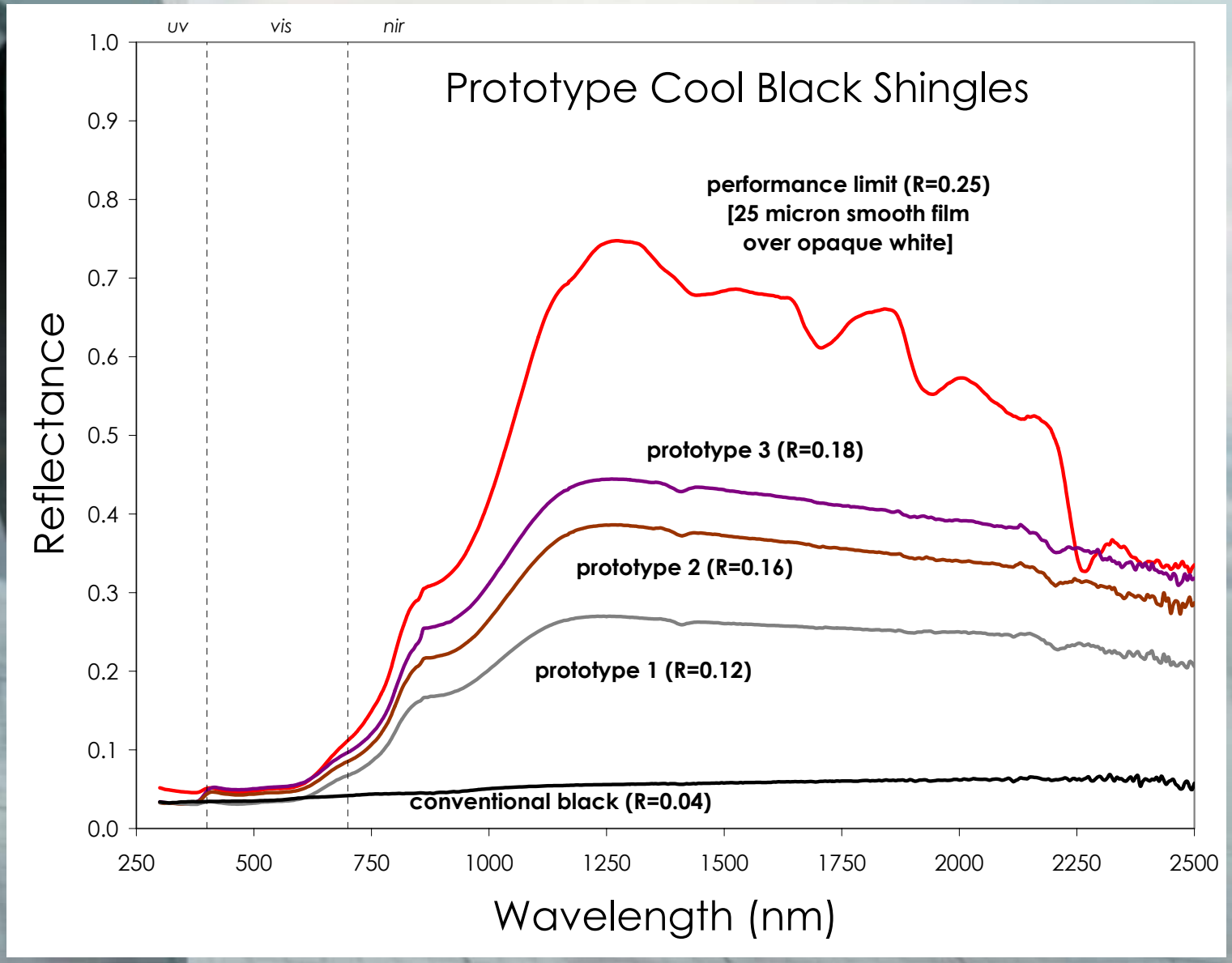
2.5.2 Design Innovative Engineering Methods for Application of Cool Coatings To Roofing Materials

- 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 40%

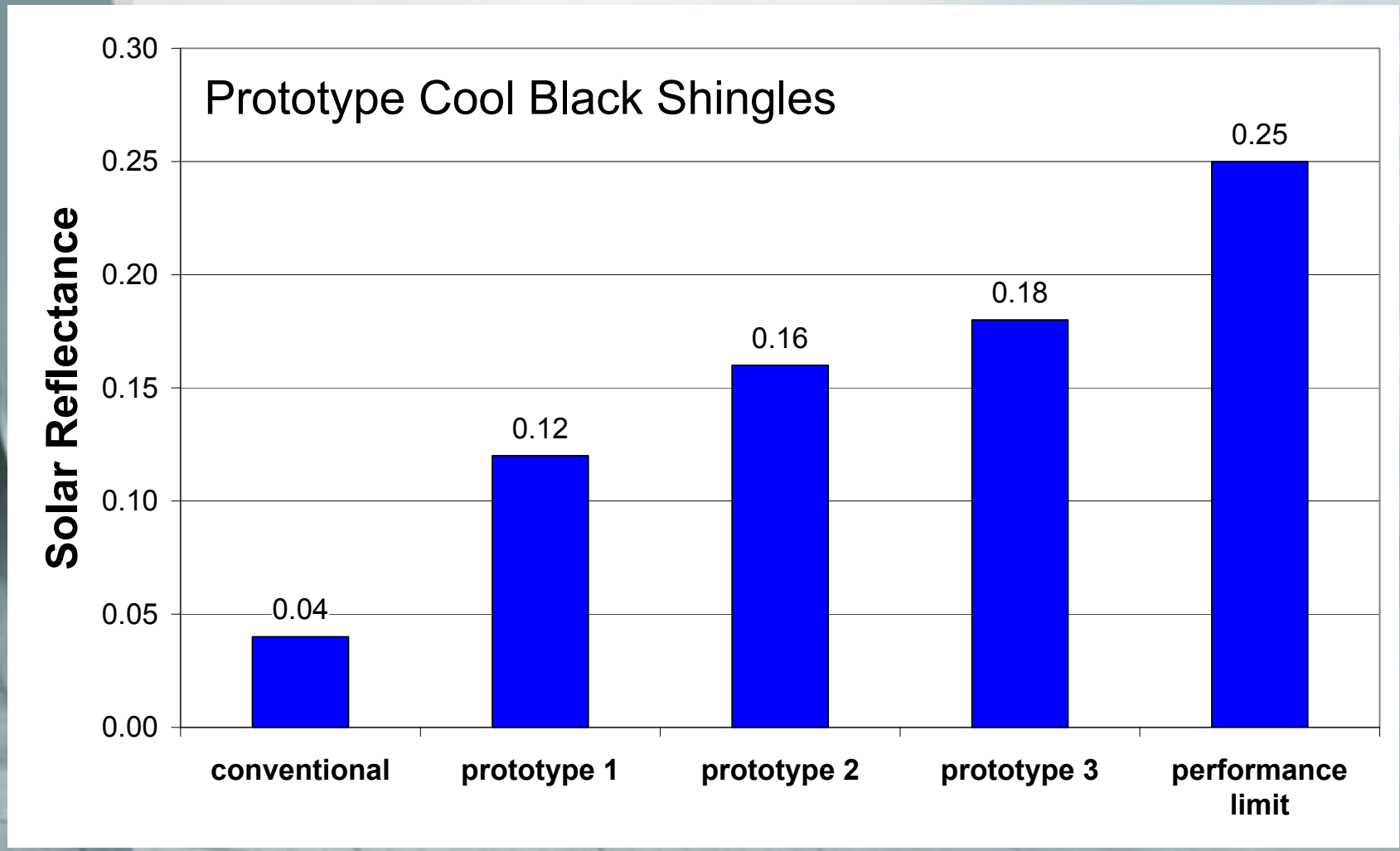
Recent Activities

- Collaborating with 12 companies
  - shingles/granules
  - tiles/tile coatings
  - metal/metal coatings
  - pigments
- Prototypes developed and characterized include (~)
  - 50 shingles
  - 30 tiles or tile coatings
  - 20 metal panels
- Iterative prototype development
  - pigment selection
  - choice of base coats
  - components to avoid

Example: Development of Cool Black Shingles

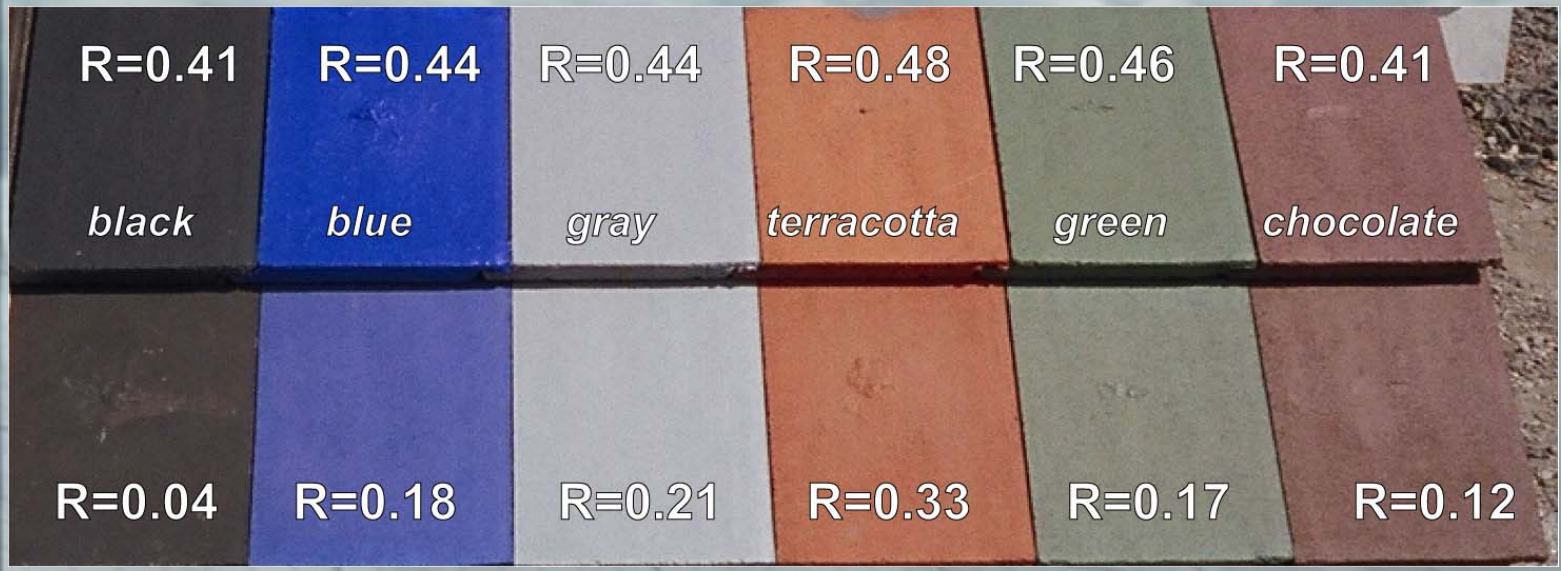


Progressively Improving Reflectance



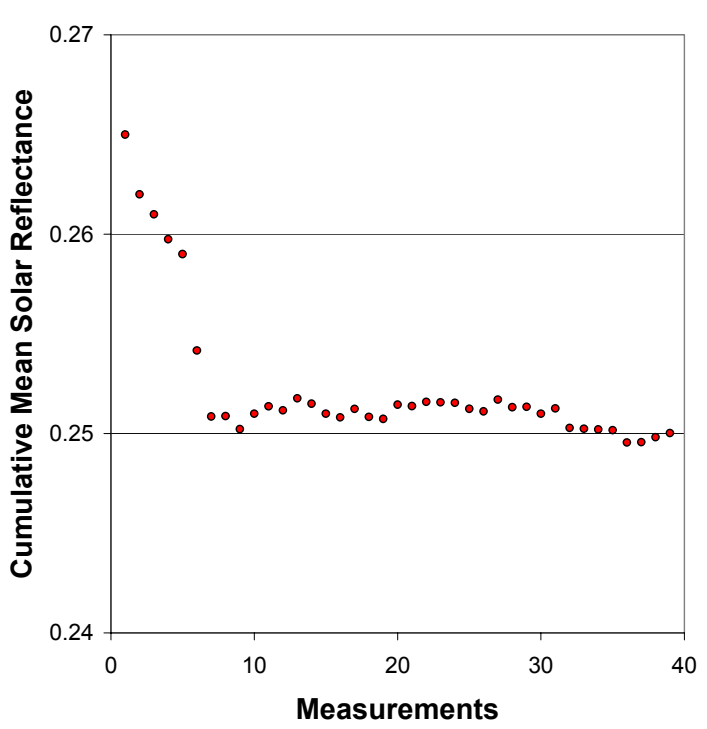
Example: Development of Cool Roof Tile Coatings

- Acrylic roof tile coatings suitable for new tiles, retrofits
- Color palette meets California's Title-24 requirements for tile (reflectance $\geq$ 0.40)



Measuring Reflectance of Non-Uniform Surfaces (e.g., Shingles)

- Monte-Carlo technique
  - measure reflectance in series of random locations until cumulative average stabilizes



Next Steps (Technical)

- 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

Manufacturing Constraints

- Cost of colorants
- Longevity of colorants
- Ability to apply multilayered coatings
- Pilot plant capacity for production of demonstration-home samples

Key Research Direction Issues: 2 Ways to Increase Solar Reflectance

1. Technical
   - Use infrared-reflecting undercoat
   - Use infrared-reflecting or infrared-transmitting topcoat

2. Marketing
   - Changing the consumer preference to accept lighter colors

old color

new color

Criteria for Selecting Roofing Shingles for Demonstration Houses

- Currently, we have budget for testing shingle products on two houses (one for standard color and one for cool color)
- The project currently requires testing of roofing materials with similar color
- We need to expand the demonstration sites to showcase all cool roofs in Northern and Southern CA

Next Steps (Demonstration)

- Develop selection criteria for testing shingle-roofed houses
- Continue working with partners to produce shingles for demonstration
- Continue working with partners to improve the reflectance of other roofing products
- Prepare samples for weathering farms in CA

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 Measures 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, Fair Oaks,CA
    Second Demonstration Reqd
  - √ Site Test Plan
  - – Test Site Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 55 %

Cavalli Hills Subdivision Fair Oaks, CA

- Sacramento Municipal Utility District (**SMUD**) and ORNL/LBNL will monitor homes
  - Cool Roof Color Materials (CRCM)
  - Insulated Concrete Form (ICF) walls

Cavalli Hills Success Story

Mike Evans Building Energy Efficient Homes For You

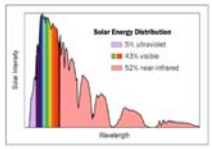
Evans Construction
EL Dorado Hills, CA 95762
Phone (916) 939 1854
Fax (916) 939 3419

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 half of the sun's energy is contained in the infrared region, which isn't visible to our eyes. Because we can't see this energy, we can reflect it away from the roof without changing the roof's color.



Advantages of Cool Roof Color Materials

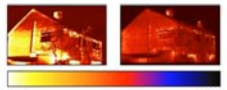
- Better fade resistance than standard colors
- Reflect more sunlight and stay cooler
- Lower utility bill for cooling the house
- Architectural appeal

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 one project. Oak Ridge will make thermal scans of the roofs and walls. In these scans, cold surfaces show as black while the hottest surfaces are orange, red or white in color. The house with ICF walls on the right show lower wall temperatures than the frame construction house on the left, and therefore has lower heat losses.



Air leakage affects the thermal performance of a home, and can account for 30% or more of your home's utility bill. Oak Ridge will conduct blower door and duct testing to determine the natural infiltration rate of the house and duct system. Uncontrolled air leakage can result in high fuel bills and moisture damage.

SMUD • Dave Blebea, Adv. Tech. • (916) 732-6499 ORNL • Dr. William Miller • (865) 574-2013 LBNL • Dr. Hashem Akbari • (510) 486-4287

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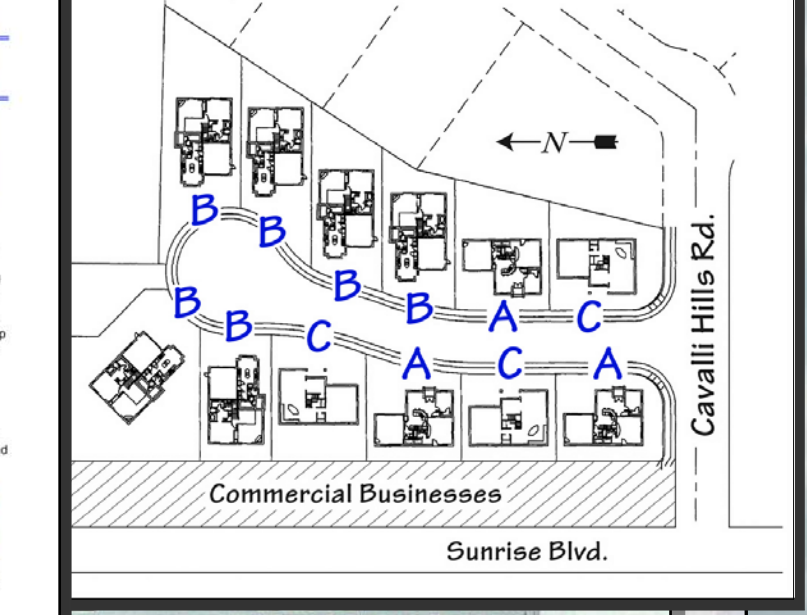


A Style Home Finished with Hanson Roof Tile and Stucco

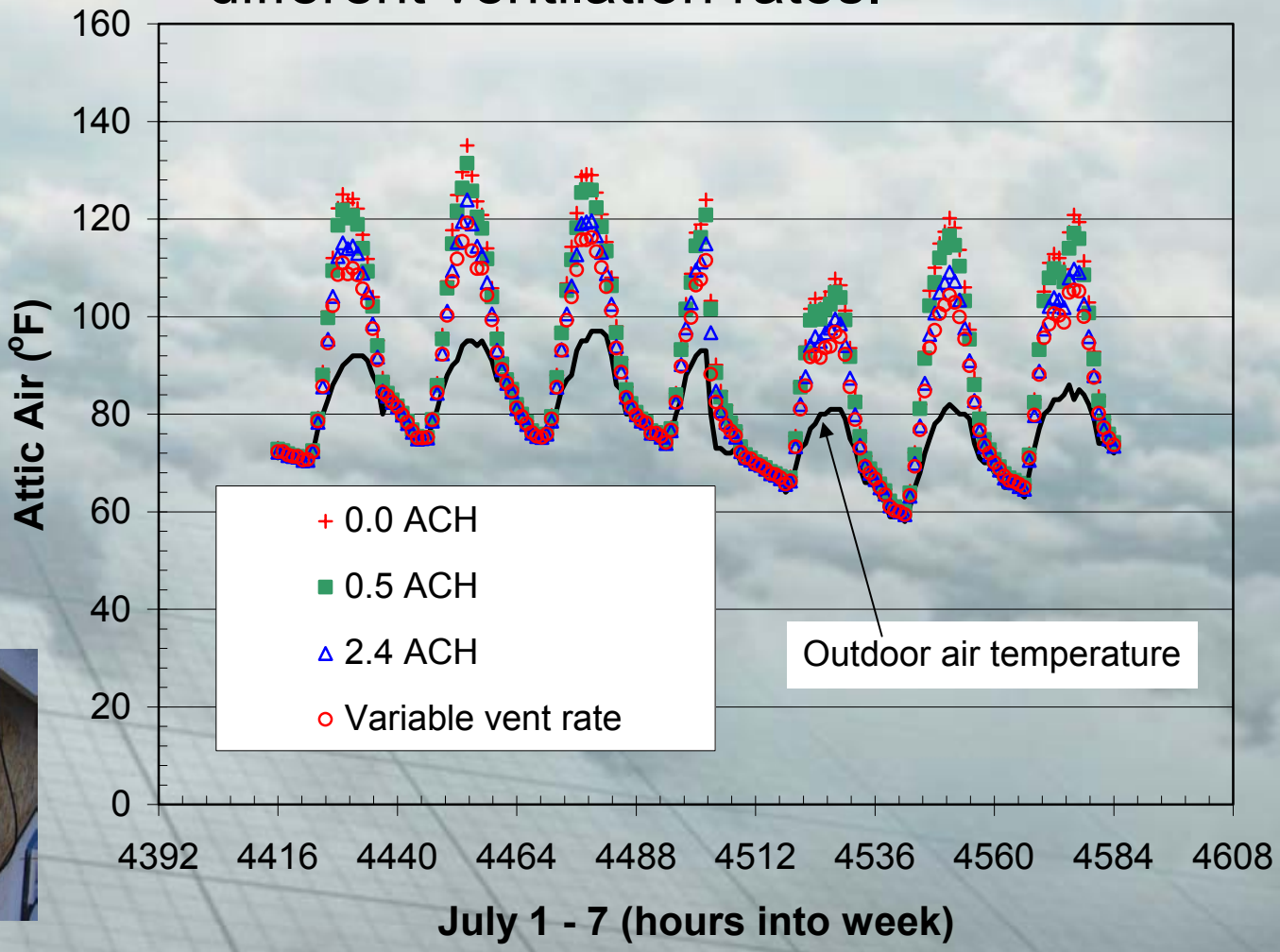
C Style Home Finished with Painted Metal Shingle and Stucco

Second A Style Home Finished with Hanson Roof CRCM Tile and Stucco

House Measurements

Thermal buoyancy and wind forces affect attic ventilation

- Attic air temperature calculated for several different ventilation rates.



2.6.1 Next Steps

- **American Roof Tile Coatings**

  Topcoat applied to Hanson's Hacienda concrete tile

- **Custom-Bilt Metals & Classic Products**

  Country Manor Shake: Musket Brown 31% reflective

- **ORNL and SMUD commission DAS**

- **Establish Second Demonstration Site**

  Composition shingles

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 40 %

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)

Samples exposed in substantially different CA climates

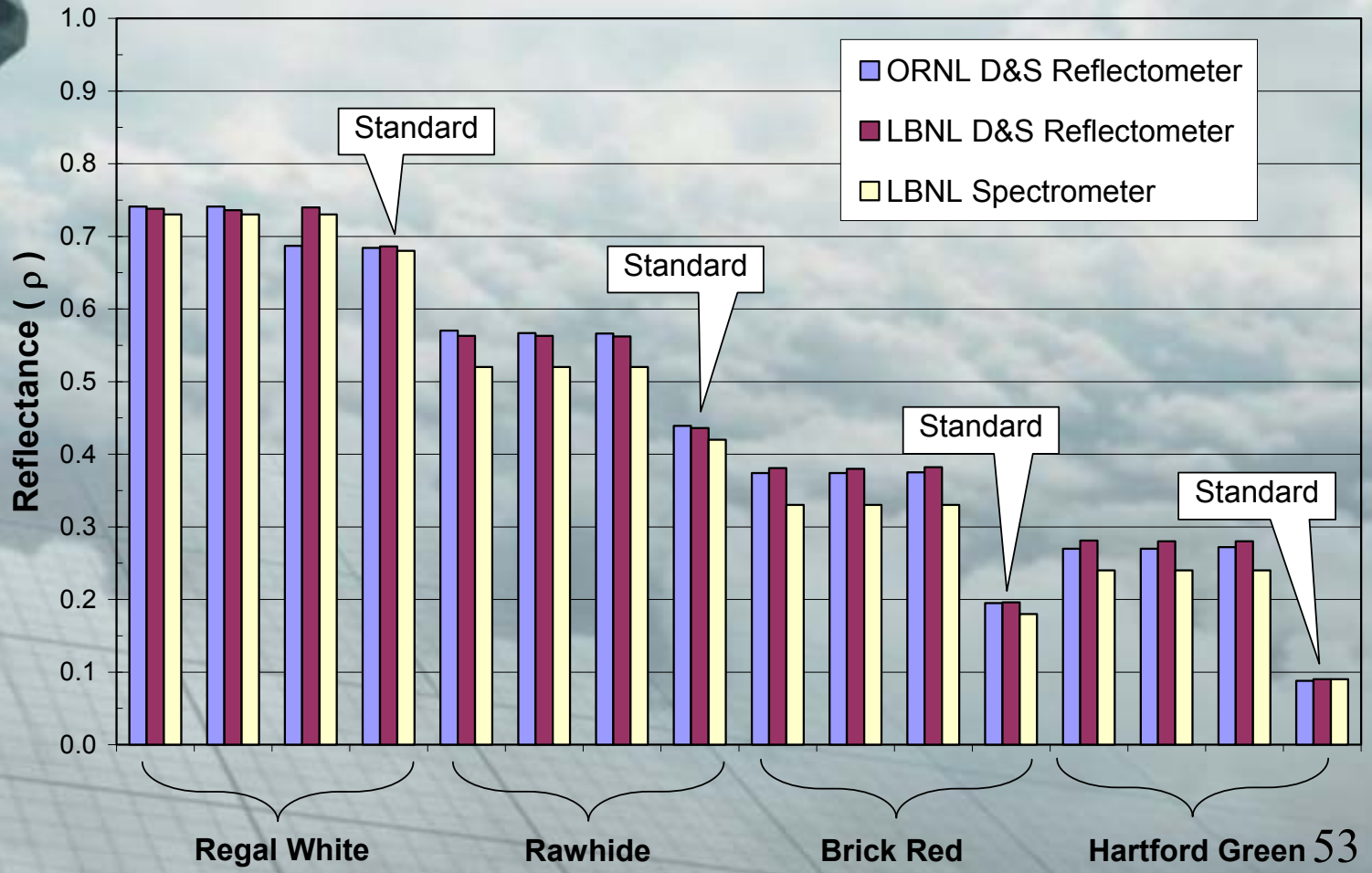
Shafter

Corona

Meloland

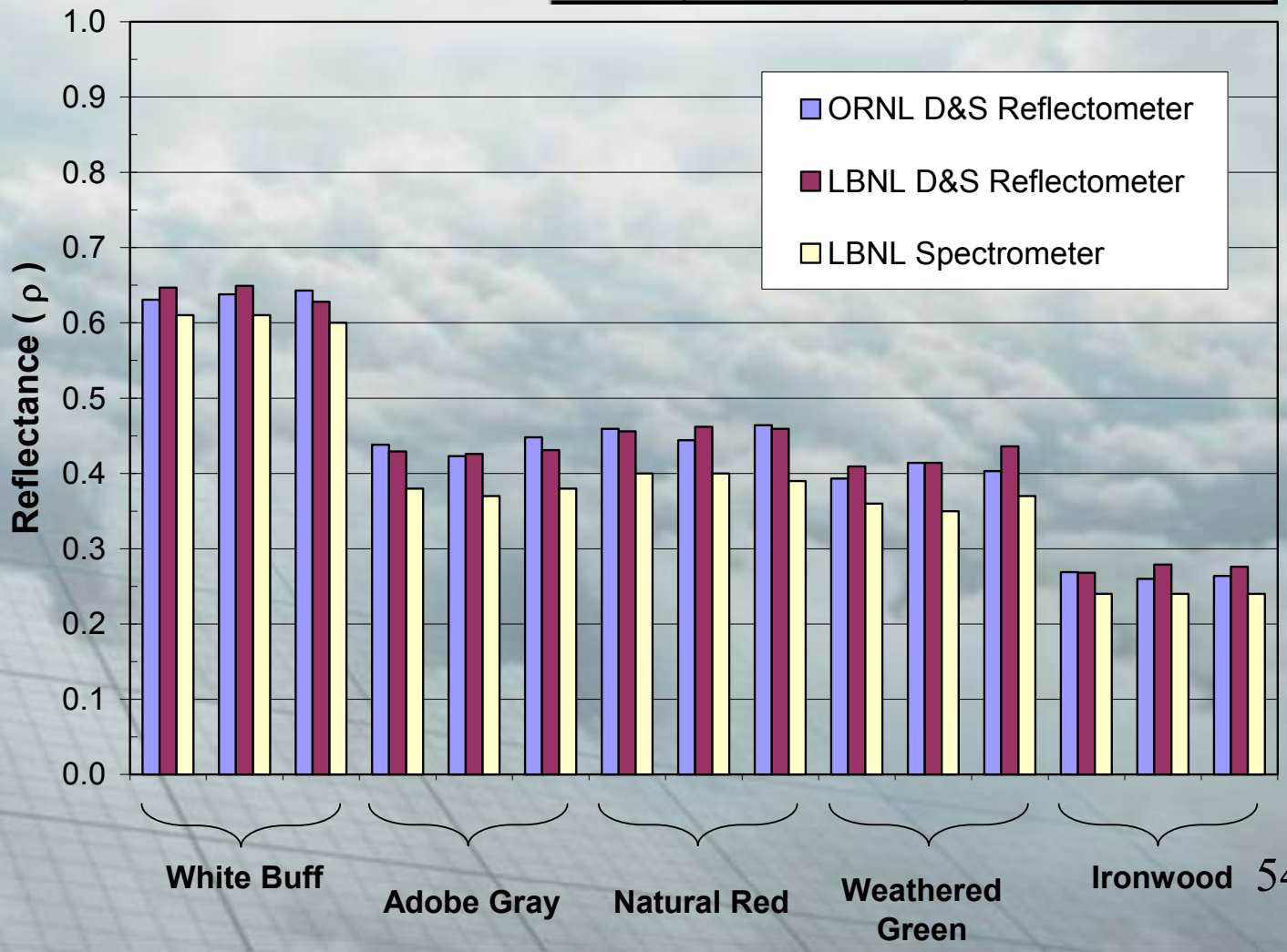
Reflectance Measures for Painted Metals

	D&S ρ minus Spectrometer ρ	
	ORNL	LBNL
Min	-0.009	-0.004
Max	0.078	0.051
Mean	0.022	0.019



Reflectance Measures for Clay Tile

	D&S ρ minus Spectrometer ρ	
	ORNL	LBNL
Min	0.024	0.019
Max	0.070	0.062
Mean	0.045	0.046



Reflectance and Emittance of painted metals at exposure sites

Reflectance (ρ)

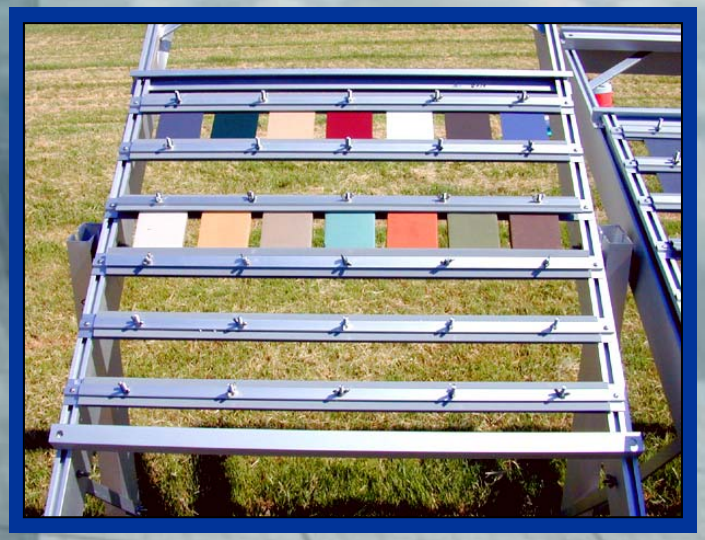
	Regal White	Rawhide	Brick red	Charcoal Gray	Hartford Green
Standard	0.69	0.44	0.20	0.12	0.09
CRCM	0.74	0.57	0.37	0.31	0.27
Difference	0.05	0.13	0.17	0.19	0.18

Emittance (ε)

	Regal White	Rawhide	Brick red	Charcoal Gray	Hartford Green
Standard	0.81	0.87	0.83	0.86	0.83
CRCM	0.82	0.83	0.82	0.83	0.81
Difference	+0.01	-0.04	+0.01	-0.03	-0.02

2.6.2 Next Steps

- Recall samples for measurements
- Deploy new concrete samples
- Develop CIMIS weather database
- Continue reflectance checks with spectrometer



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
  - Presentation at the Pacific Coast Builders Conference
  - Steep Slope Assembly Test Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 35 %

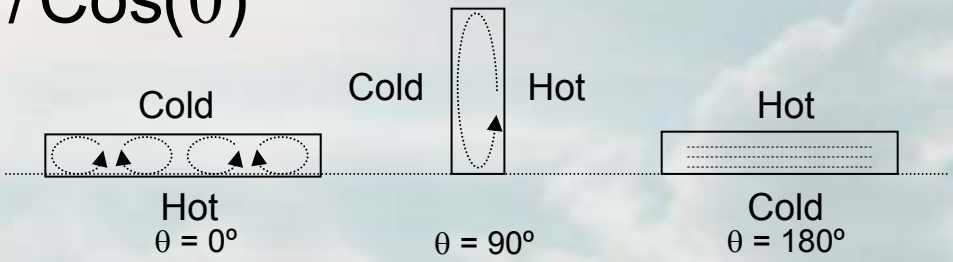
Roof Tile Institute installed five different tile assemblies on ESRA

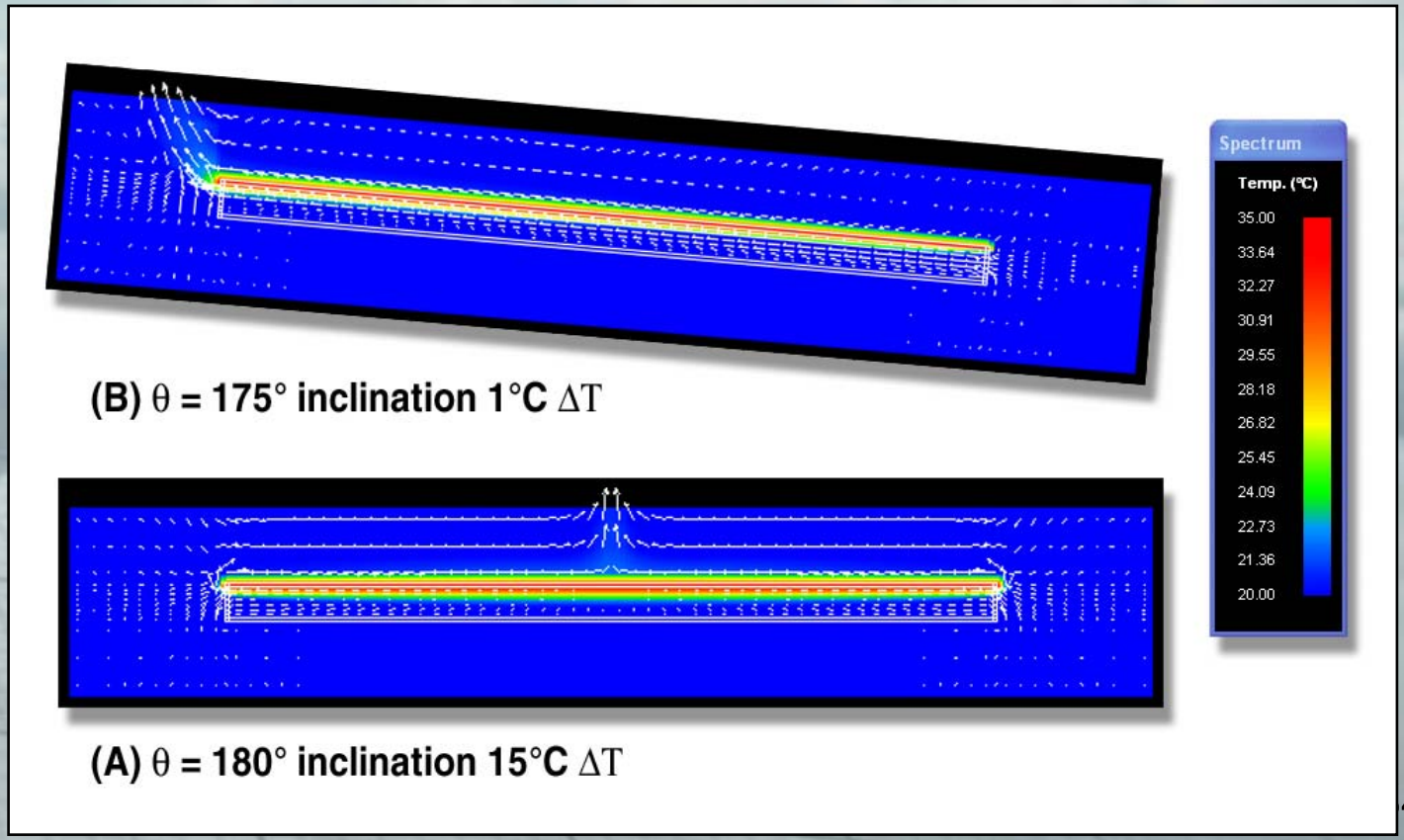
Lane	Type of Tile	Manufacturer	Application
1	Clay "S"	MCA	**Direct Deck**
2	Concrete Medium	Hanson	Direct Deck
3	Concrete Medium	MonierLife Tile	Direct Deck with foam
4	Concrete Flat	MonierLife Tile	**Counter Batten**
5	Concrete "S"	Eagle	**Batten**
6	Asphalt Shingle		Direct Deck

The ESRA has a New Look

Flat-plate solar collector excellent starting point for formulating tile roof heat transfer correlations

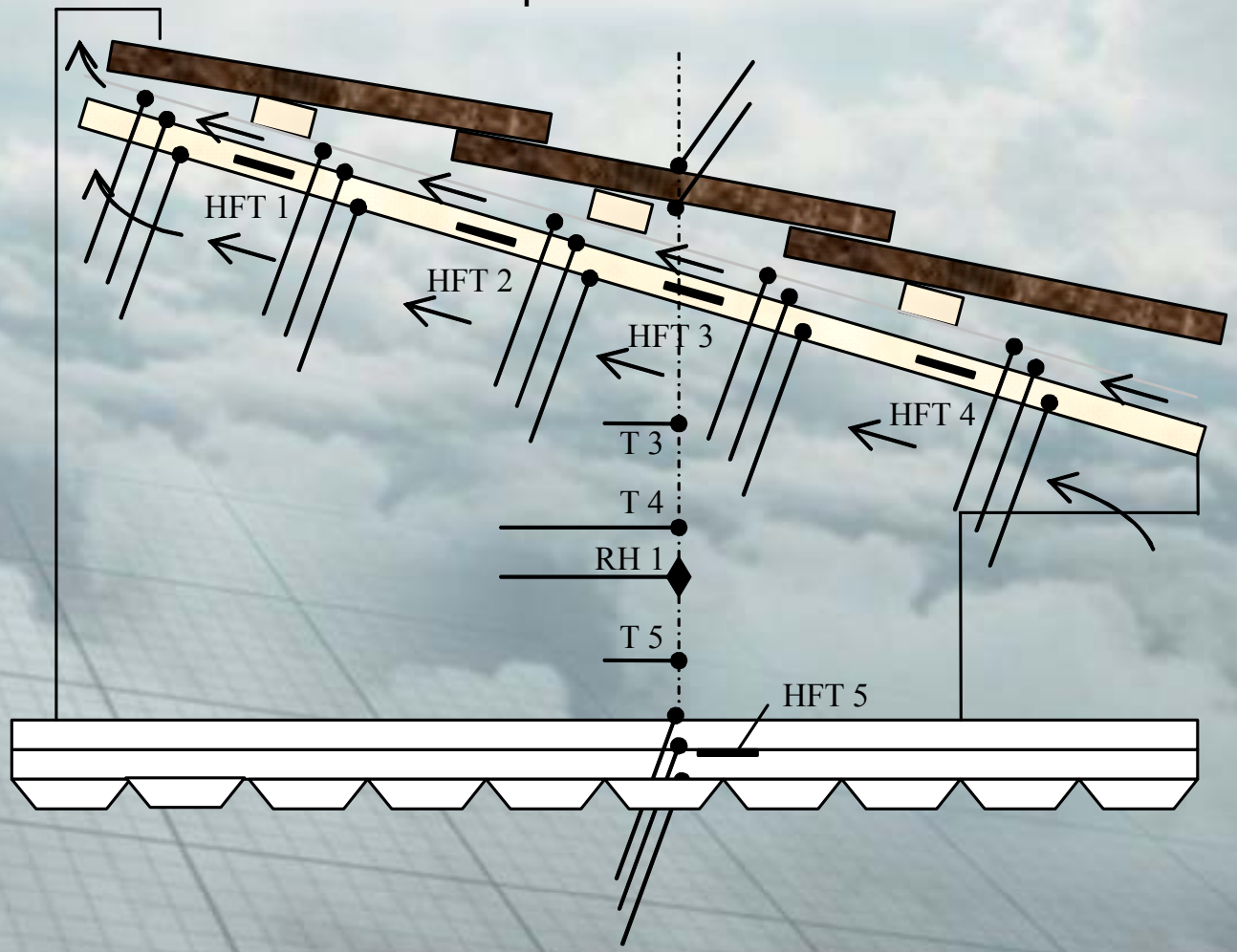
- $Ra_{L,Critical} \leq 1708 / Cos(\theta)$





Lafarge Roofing Technical Center (Sussex, UK) wants to collaborate

- radiant barriers in northern U.S. climates
  condensation prediction in batten roofs
  heat flux prediction in roofs



2.6.3 Next Steps

- **Programming of ESRA DAS**
  - Instrument attic cavities
- **Flow Visualization Studies**
  - Lafarge Roofing Technical Center
- **Validation of AtticSim code**
  - Venting between deck and roof tile

Collaboration and 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.
- Miller, W. A., Parker, D., Akbari, H. 2003. “Painted Metal Roofs Are Energy-Efficient, Durable And Sustainable,” in New Roofs for a New Century Conference, proceedings of the Environmental Business Association of New York State, Inc., New York, NY, April 2003.
- Miller, W.A., Loye, K. T., Desjarlais, A. O., and Blonski, R.P. 2002. “Cool Color Roofs with Complex Inorganic Color Pigments,” 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. 2002.

September 2004 Meeting

- September 9, 2004
- At ORNL, Oak Ridge, TN

Cool Colors Project Website

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

http://CoolColors.LBL.gov