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

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

HIGHLIGHTS

- March 4, 2004 PAC meeting was held at CEC office in Sacramento. The meeting agenda and presentation materials are attached.
- On March 3, 2004, the project team and industrial partners met at LBNL and discussed the technical elements of the project.
- We completed two major papers that summarize LBNL's 2001-2004 pigment characterization research.
- We continue to work with tile, granule, and shingle manufacturers to develop cooler products. Our recent efforts have focused on increasing granule and shingle reflectance, with particular attention to helping manufacturers produce cool shingles for a demonstration site in colors that match conventional (hot) shingles.
- John Goveia and Phil Dregger of Technical Roof Services have offered their respective homes to demonstrate cool-colored asphalt shingles and wood shakes. Goveia's home has composition shingles and Dregger has a wood shake roof.

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
March 4, 2004 PAC meeting was held at CEC office in Sacramento. The meeting agenda and presentation materials are attached. On March 3, 2004, the project team and industrial partners met at LBNL and discussed the technical elements of the project.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance
We completed two major papers that summarize LBNL's 2001-2004 pigment characterization research. The first, "Spectral Solar Optical Properties of Pigments, Part I: Model for Deriving Scattering and Absorption Coefficients from Transmittance and Reflectance Measurements", presents and validates the model that we use to compute the solar spectral absorption and backscattering coefficients that characterize the radiative properties of pigments. The second, "Spectral Solar Optical Properties of Pigments, Part II: Survey of Common Colorants", presents and discusses the radiative (and other) properties of more than 80 pigments that may be considered for use in architectural coatings. The papers are currently undergoing peer review at LBNL prior to journal submission. The abstracts are attached.

2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings
See Task 2.4.1.

2.4.3 Develop a Database of Cool-Colored Pigments
We shared the pigment database with another industrial partner this month.

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods
We obtained some information on manufacturing and coloring of wood shake.

2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials
Recent efforts have focused on the technical challenges associated with improving shingle reflectance; we have collaborated with manufacturers to produce, evaluate, and improve several generations of prototypes over the past few months. We are also working with manufacturers to explore novel techniques for applying colorants to roofing products.

2.5.3 Accelerated Weathering Testing
Akbari and Berdahl had further discussions with our industrial partners about the development of a plan for accelerated testing of cool colored materials.

2.6 Field-Testing and Product Useful Life Testing
Two of the four demonstration houses in Cavalli Hills are up for resale by speculators trying to sell the homes at about $420k, a $100k price jump from the original sales price. The builder checked with the original real estate agent Steve Burke who stated that the homes would not likely sell at that high a price. The occurrence may work to our advantage and provide the Cool Guys with a summer of field data for unoccupied homes.

Meters in three of the four demonstration homes are taking field data with the exception of power measurements. Inspectors approved the electrical systems for each house including the LBNL, ORNL and SMUD data acquisition system setup. Wim Boss of

SMUD is installing the power transducers for each house. ORNL personnel completed wiring of the fourth house.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

ORNL and SMUD commissioned the data acquisition systems for three of the four demonstration homes in Cavalli Hills. Each DAS was connected to an independent phone line and data was successfully downloaded at ORNL. We are waiting on SMUD to install the power meters for measuring total house and HVAC power.

ORNL personnel ran wiring and installed instruments in the fourth demonstration home, and will revisit Cavalli Hills in mid-May to install the data logger and connect instrument wiring. Rinkydink Builders installed Custom-Bilt Metals ultra-cool painted metal shake on the fourth demonstration home in Cavalli Hills (location of C-style house with cool-colored material is highlighted in Fig. 1). They will apply roof trim after workers finish the eaves and walls with stucco. Rinkydink also helped ORNL personnel repair the two thermocouples measuring the roof temperature of the C-style home having metal shakes with standard walnut brown color.

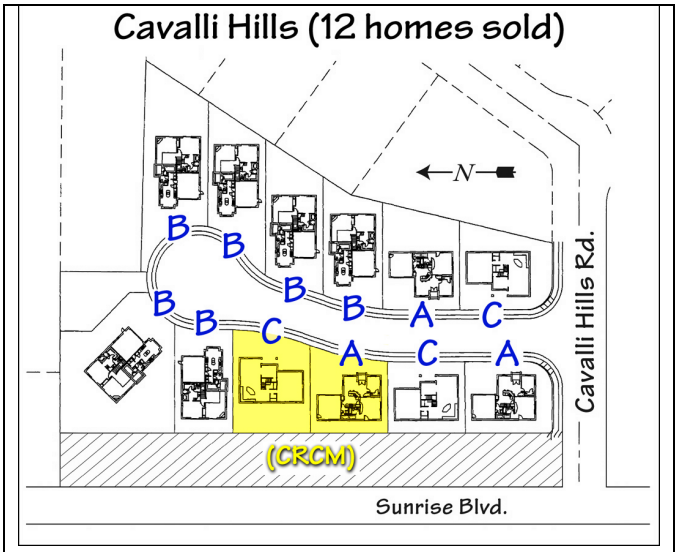

Figure 1. Cavalli Hills demonstration homes.

Joe Riley of American Roof Tile Coatings and Lou Zumpano of Hanson Roof Tile applied a cool-colored topcoat finish to one of the two A-style homes having Hanson's concrete tile roof (location of A-style house with CRCM is highlighted in Fig. 1). Riley stated that the weather was perfect and they were able to successfully apply several topcoats. Pictures of the newest metal roof and the concrete roof with applied cool-colored coating are shown in Fig. 2 and 3 respectively.

Fig. 2. Bustom-Bilt Metals ultra-cool metal shake was installed on the fourth demonstration house in Cavalli Hills.

Fig. 3. Concrete tile roof with cool-colored coating from American Roof Tile Coatings.

2.6.2 Materials Testing at Weathering Farms in California

ORNL personnel will revisit the exposure sites, make surface measures and install concrete and clay tile samples prepared by US Tile, MonierLife Tile and Shepherd Color Co. ORNL will also send concrete samples first to LBNL and, pending results, several more samples to America Roof Tile Coatings for Joe Riley to apply his topcoat in five different colors. LBNL will make reflectance measures of these new samples, and Riley will deliver the samples to Yoshihiro of MCA's Clay Tile plant. Game plan is to place these samples at the seven established exposure sites in CA.

2.6.3 Steep-slope Assembly Testing at ORNL

The Cool Metal Roof Coalition (CMRC) wants information on the energy benefits of cool-colored coatings applied to polyvinylidene fluoride (PVDF) metal roofing. They requested ORNL to run simulations for Florida, Texas, Vermont and Colorado climates. AticSim was run for a roof with soffit and ridge venting having forced and natural ventilation forces. Roof slope was set at 18.4º and the ridge vent was oriented east-west. The results in Figure 4 compare Custom Bilt Metal's walnut brown ($\rho = 0.08$) to their ultra-cool musket brown ($\rho = 0.31$) painted metal shingles.

The predominately cooling load climates of Miami, FL and Dallas TX show about a 15% reduction in the energy penetrating the ceiling for a roof with R-19 insulation. Winter energy penalties occur in Burlington, VT and Boulder, CO; however, despite the 6011 heating degree-days for Boulder, it shows a net benefit because the solar irradiance in Boulder is close to that incident in either Dallas or Miami. As stated, these results are for CRCMs available on the open market. As work progresses to improve reflectance to about 60%, as evident in LBNL's pigment optimizations, savings are expected to be ~20%.

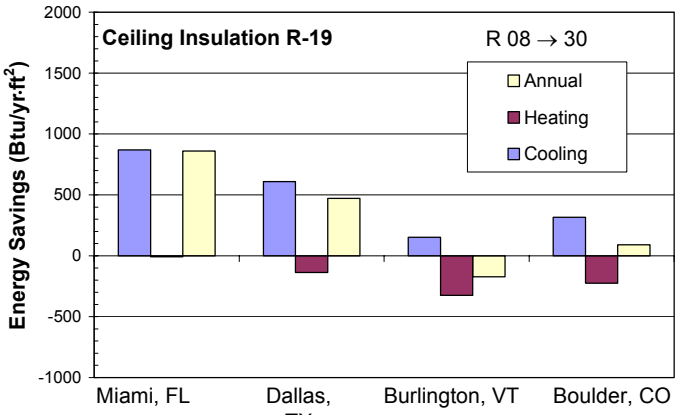

Figure 4. Savings from replacing Custom Bilt Metal's walnut brown ($\rho = 0.08$) with their ultra-cool musket brown ($\rho = 0.31$) painted metal shingles).

2.6.4 Product Useful Life Testing

Akbari discussed with our industrial partners the development of a plan to design an experiment for testing the useful life of cool colored materials.

2.7 Technology transfer and market plan

2.7.1 Technology Transfer
On March 30, Akbari gave a key-note speech on development of cool colored roofing materials at the Kobe University in Japan.

2.7.2 Market Plan
(No activity.)

2.7.3 Title 24 Code Revisions
(No activity.)

Management Issues

- We are reviewing our project plan in response to the received comments at the PAC meeting.

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 03/31/2004
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 03/31/2004
2.3	PAC meetings *Deliverables:* • Draft PAC meeting agenda(s) with back-up materials for agenda itemsFinal PAC meeting agenda(s) with back-up materials for agenda items Schedule of Critical Project ReviewsDraft 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		~ 90%
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		~ 15%
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database	6/1/03	7/1/03	6/1/05		~ 20%
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		~ 95%
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		~ 60%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05		~ 5%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2004
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		72%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05		50%
2.6.3	Steep-slope Assembly Testing at ORNL *Deliverables:* • Whole-Building Energy Model ValidationPresentation at the Pacific Coast Builders ConferenceSteep Slope Assembly Test Report	6/1/02	10/1/02	10/1/05		48%
2.6.4	Product Useful Life Testing *Deliverables:* • Solar Reflectance Test Report	5/1/04		6/1/05		
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		~ 10%
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 01/31/2004
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		61% (22/36)
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		

Abstract

Spectral Solar Optical Properties of Pigments, Part I: Model for Deriving Scattering and Absorption Coefficients from Transmittance and Reflectance Measurements

Ronnen Levinson, Paul Berdahl, and Hashem Akbari

Pigment characterization is performed by dispersing the pigment into a transparent film of refractive index 1.5, and measuring spectral transmittance and reflectance. Measurements of the film reflectance backed with black and white substrates are also used. A model for extracting the spectral backscattering coefficient S and absorption coefficient K from spectrometer measurements is presented. Interface reflectances complicate the model. The film's diffuse reflectance and transmittance measurements are used to determine S and K as functions of a model parameter sigma that represents the ratio of forward to total scattering. Sigma is used to estimate the rate at which incident collimated light becomes diffuse, and is determined by fitting the measured film reflectance backed by black. A typical value is sigma=0.8. Then, the measured film reflectance backed by white is compared with a computed value as a self-consistency check. Measurements on several common pigments are used to illustrate the method.

Abstract

Spectral Solar Optical Properties of Pigments, Part II: Survey of Common Colorants

Ronnen Levinson, Paul Berdahl, and Hashem Akbari

Various pigments are characterized by determination of parameters S (backscattering) and K (absorption) as functions of wavelength in the solar spectral range of 300 to 2500 nm. Measured values of S for generic titanium dioxide (rutile) white pigment are in rough agreement with values computed from the Mie theory, supplemented by a simple multiple scattering model. Pigments in widespread use are examined, with particular emphasis on those that may be useful for formulating non-white materials that can reflect the near-infrared (NIR) portion of sunlight, such as the complex inorganic color pigments (mixed metal oxides). These materials remain cooler in sunlight than comparable colors. NIR-absorptive pigments are to be avoided. High NIR reflectance can be produced by a reflective metal substrate, a NIR-reflective underlayer, or directly by the use of a pigment that scatters strongly in the NIR.