Ernest Orlando Lawrence
Berkeley National Laboratory

Stephen Wiel, Head
Energy Analysis Department
Environmental Energy Technologies Division

MS 90R4000
1 Cyclotron Road
Berkeley, CA 94720-8136

Tel. 510-486-5396
Fax: 510-486-6996
e-mail: Swiel@lbl.gov

April 14, 2003

To: Chris Scruton (CEC)
From: Steve Wiel
Subject: **Cool Roof Colored Materials**: Monthly Progress Report for March 2003 (revised)
CC: Hashem Akbari, Paul Berdahl, Andre Desjarlais, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of March 31, 2003 is presented in Attachment 1.

HIGHLIGHTS

- The second project advisory committee (PAC) meeting was held through a conference call on March 11, 2003.
- The project team visited the ISP Mineral Corporation's granule manufacturing plant in Ione, 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 essentially completed. We have added two new members to the PAC.

2.2 Software Standardization
(No activity.)

2.3 PAC Meetings
We held our second PAC meeting on March 11, 2003, through a conference call. The agenda for the PAC meeting, the minutes of the meeting, the list of attendants, and the presentation material for the PAC meeting is available at http://eden.lbl.gov/hashem/share/2003-03-11-mtg-min1-HA.pdf.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance
A. We have made a number of significant improvements/changes to our pigment-property calculations, including:

(1) Correcting the relationship of the estimated diffuseness of light exiting the top of the film to the estimated diffuseness of the light exiting the bottom of the film. This eliminates some physically impossible results.

Two previous approaches to this problem were (a) to assume that light exiting the top of the film was always fully diffuse, which overestimates the exiting-top-of-film diffuseness when the film is weakly scattering; and (b) to assume that the upward passage of light through the film increases diffuseness in the same manner as the downward passage of light through the film. The new relationship tracks instead the intensity of the collimated portion of the beam. The spectrometer beam is fully collimated when it strikes the top of the film from above. When it reaches the bottom of the film, the intensity of the collimated fraction of the beam has some value which we call "p_hat". Part of the collimated beam is reflected upward by the film-air interface at the bottom of the film. The intensity of the reflected collimated beam is attenuated by upward passage through the film. The intensity of the upwelling collimated beam exiting the top of the film is hence a function of p_hat, the ability of the film-air interface to reflect collimated light, and internal transmittance of the film. The diffuseness of the light exiting the top of the film is calculated as 1 minus the ratio of the intensity of collimated light exiting the top of the film to the intensity of all light exiting the top of the film. The latter value is determined from the film's measured reflectance.

(2) Preventing wild oscillation in the calculated diffuseness that resulted when the reflectance-over-void was slightly larger or smaller than reflectance-over-black by setting reflectance-over-void to reflectance-over-black when the difference between the two is small (≤ 0.01). Also, reflectance-over-void is set to reflectance-over-black when reflectance-over-void is less than reflectance-over-black (physically impossible for a single film, but can arise when the over-void sample is thinner than the over-black sample).

(3) Improving the algorithm that seeks diffuseness by (a) using a different (and simpler) element of the theory as the criterion for choosing diffuseness, and (b) making the search routine smarter by giving it more information to use.

The former is accomplished by noting that a film's reflectance-over-black can be calculated from measurements of its reflectance-over-void and its transmittance. The diffuseness (which affects the magnitude of interface reflections) is adjusted to minimize the difference between the measured and calculated over-black reflectances. This approach permits estimation of diffuseness fraction before calculation of the Kukelka-Munk coefficients, simplifying and accelerating the algorithm. The latter is accomplished by considering in the routine that optimizes diffuseness not only the difference between measured and calculated over-black reflectances, but also the extent to which the calculated value of reflectance-over-black value lies outside the physical range of 0 to 1. This allows the optimization routine to more quickly converge on a suitable diffuseness value.

(4) Using Gaussian, rather than median, smoothing to remove thin-film interference ripples in measurements of films on mylar.

(5) Setting a lower absorption coefficient limit of 0.1 mm^{-1}.

B. We continue to draft a journal paper reporting our pigment-characterization results to date.

C. We bought an inexpensive roller mill that will be used (a) to form paints from the dry pigments supplied by our industrial partners, and (b) to mix paints. The roller mill spins a jar (containing pigment, water, binder, and grinding media if dispersing pigment into a binder, or several paints and grinding media if mixing paints) on a pair of rollers.

D. We held discussions with various industry partners concerning possible joint proposals responding to the current DOE NETL solicitation.

E. We had discussions with Shepherd Color, Ferro, BASF and others concerning the identification of various pigments. The discussion indicated that this is a sensitive issue. For good characterization work, it is desirable to accurately identify each individual pigment by manufacturer and product number. On the other hand, some companies don't want the pigment characterization work to produce a catalog that customers use to select products. We will need eventually to come to consensus with the companies on a suitable format for publishing our characterization data.

2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings

See Task 2.4.1. No major progress in March.

2.4.3 Develop a Database of Cool-Colored Pigments

(No activity.)

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods

On March 12, Levinson, and Akbari visited the ISP Mineral Corporation's granule plant at Ione, CA. The trip was arranged by Ingo Joedicke (ISP Mineral Head Quarter). Mr. Dave Carlson, the plant manager at Ione, gave us a complete tour of the facilities from the rock quarries to final production of colored shingle granules. During the visit, we learned that it is feasible to produce novel cool-colored granules through a two-layer coating approach. It also appeared that the existing equipment for measuring the color of roofing granules may need to be expanded to afford capabilities for measuring reflectance in the near-infrared or solar spectra.

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

(No activity.)

2.5.3 Accelerated Weathering Testing

(No activity.)

2.6 Field-Testing and Product Useful Life Testing

MCA has made and shipped clay tile samples to ORNL for measurement of reflectance and emittance. The William Harrison Corporation is building the exposure rack sets, and will ship the racks complete with assembly instructions to the respective participating roofing manufacturers. BASF and Monier LifeTile are behind schedule for delivery of the painted metal and concrete tile samples. Coordination here is a critical path item, because ORNL must first receive these samples, measure reflectance and emittance of all the samples, place the samples in the "sure-grip" sub-assemblies and forward them to the respective sites for the start of exposure testing.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

Mike Evans Construction signed and returned the Memorandum of Understanding (MOU) that establishes the cooperation of SMUD and Evans to coordinate work through ORNL for the setup and maintenance of data acquisition systems and instruments to be installed in the demonstration homes. Evans has submitted his architectural plans for review and is awaiting approval by the Sacramento municipality before construction starts. ORNL is awaiting receipt of the MOU from the Sacramento Municipal Utility District (SMUD).

2.6.2 Materials Testing at Weathering Farms in California

During the Project Advisory Committee meeting held on March 11, 2003, Mike Rothenberg of the Bay Area Air Quality Management District raised the question about the criteria used for selecting the exposure sites and why two sites (Colton and Corona) were selected so close to one another. W. Miller spoke later with Mike Rothenberg on Friday March 14 and stated that site selection was based on climate, local energy usage, existing population sectors and expanding population. We also wanted to involve the respective roof manufacturers in CA. Therefore, Custom-Bilt Metal, Steelscape, BASF, MCA and Elk Corp. will field test CRCM at their respective manufacturing facilities. Efforts were made to locate a field site near San Diego or Palm Springs; however, no roof manufacturers have plants that far south. Rothenberg liked the idea of a site near San Diego, and stated he would try to find a site through the electric public utilities.

MCA has completed making the clay tile samples and materials are expected to arrive at ORNL on April 15, 2003. BASF is behind schedule because of a backlog of customer requests, and just started making the painted metal samples on April 11, 2003. Jerry Vandewater of Monier LifeTile is also behind schedule for developing the different color concrete tile samples with and without CRCM. Vandewater stated he would delegate the responsibility to others in his group to get the job done. Shephard Color Company and Monier LifeTile are to work together to make the CRCM tile samples. Coordination here is a critical path item, because ORNL must first receive these samples from Monier LifeTile and BASF, measure reflectance and emittance of all the samples, place the samples in the "sure-grip" sub-assemblies and forward them to the respective sites for the start of exposure testing.

The William Harrison Corporation is building the exposure rack sets, and will ship them with assembly instructions to the respective participating roofing manufacturers, Custom-Bilt, Steelscape, BASF, MCA and ELK. All participating manufacturers will install the exposure rack sets at their facilities. ORNL personnel will install the two sets shipped to the California Irrigation Management Information System (CIMIS) sites located in Shasta and Imperial counties.

2.6.3 Steep-slope Assembly Testing at ORNL

Computer simulations were conducted to better understand the effects of venting between a roof deck and clay or concrete tiles. This study was conducted to view the heat transfer dynamics within thin channels that are present in some steep-slope roofing systems. Parker, Sonne and Sherwin (2002) demonstrated that white barrel and white flat tiles reduced cooling energy consumption by 22% of the base load used by an adjacent and identical home having direct nailed dark shingles. Part of the savings was due to the reflectance of the white tiles; however, another part was due to the venting occurring within the counter-batten installation. Here wood furring strips are laid vertically (soffit-to-ridge) against the roof deck, and a second, counter-batten is laid horizontally across the vertical battens as a nailing surface for the concrete tile. The presence of the air space created by the counter-batten installation offers a unique improvement in the insulating effect of the roofing system. Heat transfer within this space is being studied, and it is believed that through proper design and installation, a counter-batten roofing system can substantially improve the thermal performance of a roofing system, particularly in predominantly cooling environments.

The regime of heat transfer within the air space between the roof deck and the roofing material is dependent on the physical specifics of a particular roofing system, and the associated mechanisms governing air flow in the channel, i.e. wind speed and direction, roof slope, presence of obstructions, channel geometry, material surface properties, etc. It is likely that the heat transfer within this region will vary between forced, natural and mixed convection, depending on the thermal and velocity boundary conditions for particular weather conditions. An understanding of the heat transfer regime as it depends on the associated thermal-fluid flow parameters and associated quantitative correlations for heat transfer for the associated regimes will be a valuable tool in the roofing industry.

Computations were run for several flow geometries and boundary conditions with the goal of shedding qualitative light on the dynamics of airflow in inclined ducts heated from the top surface. We modeled vented 2-D laminar airflow with convective heat transfer through a narrow channel, 0.1-m high and 2-m long, at various angles of inclination. The top and bottom surfaces were isothermal, and the left and right surfaces left open. The bottom deck surface was set at 20°C and the top roof surface was held at a constant ΔT with respect to the bottom surface. The channel slopes up toward the right for inclination angles > 0° (Figure 1). Airflow dynamics were modeled for four conditions:

a. 0° inclination 15°C ΔT,

b. 5° inclination 15°C ΔT,

c. 30° inclination 15°C ΔT, and

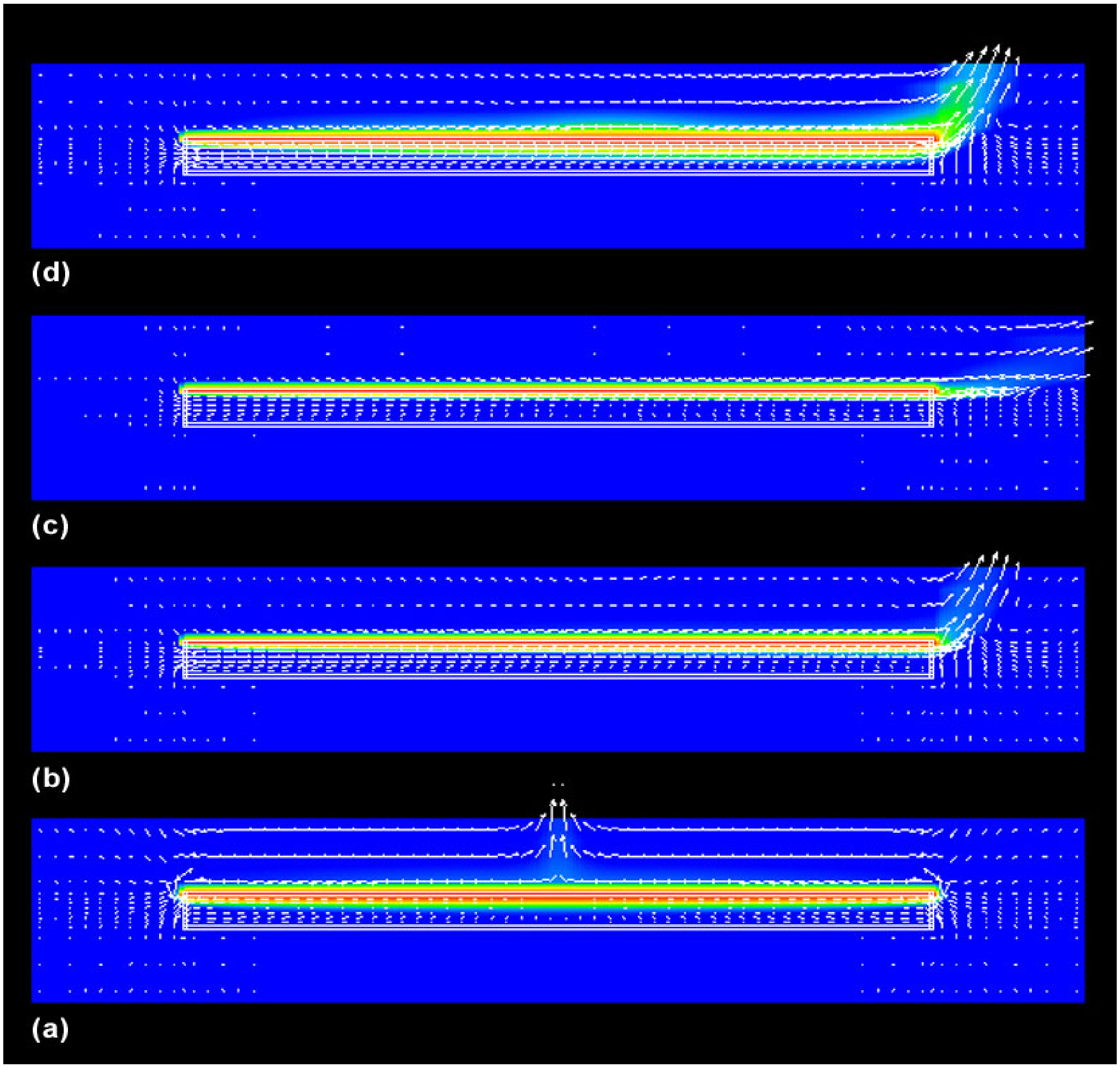
d. 5° inclination 1°C ΔT.

Results of the computational analysis are displayed in Figure 1 (a-d). The horizontal dashed lines represent the streamlines of constant velocity, and the colors are indicative of the temperature gradient across the height of the channel. With no inclination, natural convection flow develops in an expected manner with a plume forming above the heated surface and no net flow observed within the channel regardless of the ΔT through the duct (Figure 1a). In case "b" (Figure 1b) with 5° of inclination, there was observed a distinct flow into the duct from the left, through and out of the duct to the right (higher end). At a slope of 30° the same flow patterns are seen, but the exit jet is more in line with the duct axis, indicating of a greater exit velocity (Figure 1c).

Case "d" (Figure 1d) is of particular interest because with an inclination of 5° and a top surface of only 21°C, the same flow characteristics occur as observed for case "b" having the 15°C ΔT. These simulations indicate that naturally induced flow can be expected at very low inclination angles and very low temperature differences. Parker, Sonne and Sherwin (2002) had observed roof surface-to deck ΔT's for the white barrel and white flat tiles of about 8°C, indicating that natural convection effects are indeed prevalent in counter-batten roof systems.

The buoyancy induced flow carries heat away from the duct. However, these preliminary results do not take into account the effect of a forced flow component, which may aid or oppose the naturally induced flow. That work, and a formal study of the heat transfer effects of the associated flows are under current exploration.

Parker, D.S., Sonne, J. K., Sherwin, J. R. 2002. "Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida," 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.



2.6.4 Product Useful Life Testing
(No activity.)

2.7 Technology transfer and market plan

2.7.1 Technology Transfer
(No activity.)

2.7.2 Market Plan
(No activity.)

2.7.3 Title 24 Code Revisions
Akbari and CEC discussed the details of the code language for application of reflective low-sloped on non-residential buildings.

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 03/31/2003
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 03/31/2002
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		33% (2/6)
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		~ 30%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings *Deliverables:* • Computer Program	11/1/03		12/1/04		
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database	6/1/03		6/1/05		
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		~ 55%
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		< 5%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05		< 3%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2002
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		7%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05		15%
2.6.3	Steep-slope Assembly Testing at ORNL *Deliverables:* • Whole-Building Energy Model Validation Presentation at the Pacific Coast Builders ConferenceSteep Slope Assembly Test Report	6/1/02	10/1/02	10/1/05		14%
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		~ 3%
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		~ 5%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2002
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		28% (10/36)
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		