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October 31, 2005

To: Chris Scruton (CEC)
From: Hashem Akbari
Subject: **Cool Roof Colored Materials**: Quarterly Progress Report for Summer 2005
CC: Steve Wiel, Paul Berdahl, Andre Desjarlais, Nancy Jenkins, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of September 30, 2005 is presented in Attachment 1.

HIGHLIGHTS

- We are working to complete the deliverable for Task 2.5.3 "Accelerated Weathering."
- We completed a draft report for the Task 2.6.3 deliverable "Steep-Slope Assembly Testing at ORNL."
- We completed the deliverable for Task 2.7.2 **"**The market plan". The plan was reviewed by several PAC members and all were in full agreement to implement the actions described in the report.
- We completed the draft deliverable for Task 2.6.4 "Product Useful Life Testing".
- George James, Leader of DOE's Building America, has shown interest for a collaborative work between LBNL and ORNL to couple their new PIER initiatives with Building America's goals.

Tasks

1.1 Attend Kick-Off Meeting
Task completed.

1.2 Describe Synergistic Projects
Task completed.

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

2.2 Software Standardization
(No activity.)

2.3 PAC Meetings
Task completed.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance
Task completed.

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

2.4.3 Develop a Database of Cool-Colored Pigments
Task completed.

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods
Task completed.

2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials
Task completed. Our paper "Methods of Creating Solar-Reflective Nonwhite Surfaces and their Application to Residential Roofing Materials" was accepted for publication by *Solar Energy Materials & Solar Cells*.

2.5.3 Accelerated Weathering Testing
Work on the manuscript on accelerated weathering is continuing. An extensive bibliography was compiled earlier. Recent newsletters by ATLAS Materials Testing Solutions have been identified as good sources on the current state of the art. These newsletters are proving helpful in identifying some of the best recent references out of the hundreds available.

Often (for example, especially for polymers), ultraviolet radiation is a key weathering influence. An emphasis of current research is ensuring a better match between natural UV spectra and those produced by accelerated test equipment.

Earlier in this project, accelerated weathering data on roofing materials were obtained from BASF and Ferro. Currently data are being collected and provided to ORNL by 3M and Shepherd Color Company. Both companies continue to expose roof samples with and without cool colored materials to accelerated fluorescent light and Xenon-arc irradiance. Shepherd and 3M have logged over 2000 hours of exposure. A tabulation of the solar reflectance, total color change and surface gloss are provided in Appendix A. There are no noticeable drops in solar reflectance for either fluorescent or Xenon-arc exposures with exception of some of the cool colored clay tiles. As example, the natural red clay tile (code 241) with cool colored coatings dropped from an initial solar reflectance of 0.44 to 0.40 after 1000 hours and continued to drop to 0.38 after 2000 hours. Gloss retention remains indistinguishable among the cool colored painted metals, the cool pigmented asphalt shingles and their respective counterparts having conventional pigments. Changes in total color (ΔE) were almost all less than 2.0 color units with exception of the natural red and ironwood clay tiles.

Some manufacturers of roofing materials have been harshly critical of attempts to correlate accelerated weathering testing to in-field exposure. This just emphasizes the point that if the in-field degradation mechanisms are poorly understood, then accelerated weathering tests can be inappropriate and misleading.

Concrete corrodes due to reaction with carbon dioxide in the air. Basically, calcium hydroxide is transformed into calcium carbonate and water. (This is essentially the inverse of the manufacturing process in which $CaCO_3$ is heated to a high temperature, yielding CaO and CO_2.) We located an interesting paper on the accelerated weathering of concrete by aging it in high concentrations of CO_2 (5% vs. 0.3% in natural air).

2.6 Field-Testing and Product Useful Life Testing

A draft report for deliverable 2.6.3 was completed that summarizes the field testing of clay and concrete tile roofs on the steep-slope assembly at ORNL. Field data for the residential demonstrations at Fair Oaks and Redding, CA were presented at the Building America quarterly review meeting. Lou Hahn of Elk Corp visited ORNL to review the thermal measurements made on test roofs with asphalt shingles exposed at ORNL and on the demonstration homes in Redding, CA. The Metal Construction Association (MCA) spent one day of their semi-annual conference with ORNL and reviewed the “cool roof” work among several other projects. Tracer gas experiments successfully measured the airflow rates occurring with sub-tile venting of the clay and concrete tile under study at ORNL.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

Tile and Painted Metal Demonstrations: The Sacramento Municipal Utility District forwarded the summer revenue meter readings for the two pair of demonstration homes in Fair Oaks, CA (Table 1). The kWh use during the summer for the home with cool

Table 1. Revenue Meter Readings for Demonstration Homes in Fair Oaks CA

	Whole House Energy (kWh)		Whole House Energy (kWh)	
Date	Metal Shake Conventional Color	Metal Shake Cool Color	Medium-Profile Tile Conventional Color	Medium-Profile Tile Cool Color
6/18/05	409	552	734	993
7/20/05	1433	749	891	1511
8/18/05	1034	807	884	1412

color metal shakes was 26% less than that for the same home with conventional metal shakes. However, the cool tile used 56% more energy to comfort condition the home than did the home with standard tile. Solar reflectance of the cool tile is about 0.41 as compared to 0.08 for the standard tile and should therefore show some energy savings. However, a review of the data indicates that the homeowner with standard tile roof did not maintain the thermostat at 72°F until after August 19, 2005. The individual stated she was not at home for part of July and August. After returning home and conditioning the house, the data for the last week of August showed the heat flux through the ceiling of the home with cool coated tile was 20% less during the daylight hours than the heat penetrating into the conditioned space of the demonstration home with conventional tile (Fig. 1).

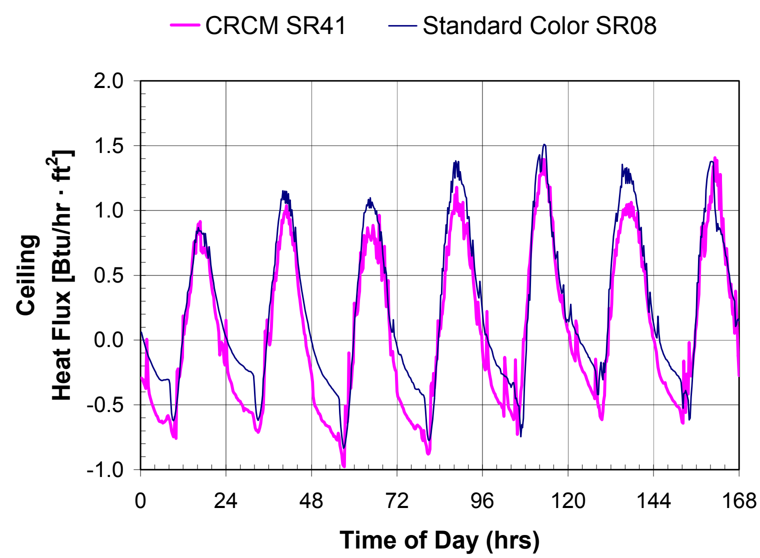

Figure 1. Ceiling heat flux measured for the pair of homes with concrete tile roofs in Fair Oaks CA. The one tile roof has conventional pigmented color the other tile roof has cool-colored coatings that match the color of its conventional counterpart.

Occupancy habits are confounding the data. Efforts will be made to plot the daily HVAC power use against the daily average outside air-to-indoor air temperature difference to see whether a correction can be applied to the difference in thermostat settings. The Florida Solar Energy Center showed good correlation using the approach and successfully corrected discrepancies between thermostat set points for two different homes.

Asphalt Shingle Demonstrations: Lou Hahn, Technology Center Manager for Elk Corporation, visited ORNL to review and discuss the data acquired on the Redding, CA demonstrations. Mr. Hahn was very interested in the deck temperatures and the heat flows penetrating the roof decks for the pair of homes with and without cool colored materials. July and August ambient air temperatures at solar noon exceeded 110°F (45°C) in Redding, CA (Fig. 2). Similar data for the ongoing field tests at the ORNL campus showed peak temperatures very close to those for the shingles exposed in Redding. During late July, the conventional shingles exposed in Oak Ridge had peak temperatures of about 165°F as compared to peak shingle temperatures of about 170°F in Redding for the same conventional shingle (Fig. 2). The difference in surface temperature between the conventional and cool colored shingle is about 10°F for both locations. Air temperature in late July was about 20°F cooler in Oak Ridge; however, the steep-slope assembly in Oak Ridge is oriented south facing and receives a more intense irradiance than that incident on the Redding homes.

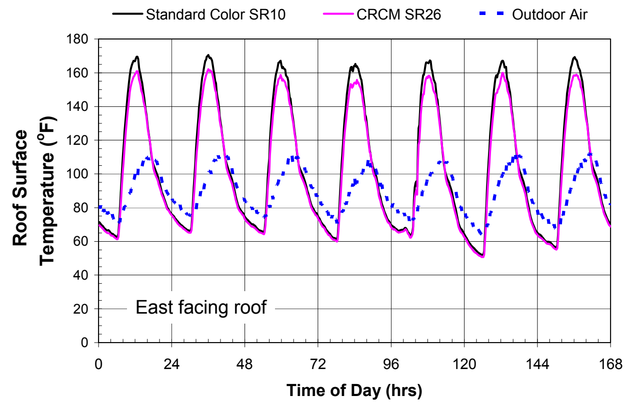

Figure 2. The pair of demonstration homes in Redding, CA with asphalt shingle roofs. The shingles underside temperatures reveal the advantage of cool colored roofing materials.

The air temperatures returning to the indoor air handlers of each home are quite often different, implying that the thermostats are at different set point temperatures. The house with cool colored shingles on Loggerhead Street has return air temperatures that are always below those measured for the other home with conventional shingles. As result power measurements for the air-conditioners of the two homes do not always show an energy benefit for the roof with cool-colored shingles (Table 2).

Table 2. HVAC Energy for Homes in Redding CA

	Air-Conditioner Energy (kWh)	
Date	Eel Street (Conventional Shingle)	Loggerhead Street (CRCM shingle)
7/01/05 - 7/08/05	172.5	86.1
7/22/05 - 7/29/05	47.2	204.4
8/12/05 - 8/19/05	142.1	123.5
8/26/05 - 9/02/05	139.1	148.0

A review of return and supply air temperatures for the two homes showed the week August 12 through the 19th had similar comfort conditions. The air-conditioner energy for the home with cool-colored roof was 13% less than the electrical draw for the air-conditioner of the home with conventional shingles. However, the effect of the two different thermostat settings causes the house on Loggerhead to consume more air-conditioning energy than the house on EEL Street a couple weeks later (Aug 26 through Sept. 2). The results again show the strong effects occupancy habits and comfort cooling preferences have on residential energy use.

2.6.2 Materials Testing at Weathering Farms in California

All samples continue to be exposed in the seven weathering sites in California. Dr. Susan Pfiffner continues working on the biomass analysis of similar samples. Samples are being fractionated for determining lipid content from which biomass is evaluated as either fungal or bacterial mass. Samples continue to be exposed in the seven weathering sites in California.

2.6.3 Steep-slope Assembly Testing at ORNL

Field data for the clay and concrete tile exposed on the steep-slope assembly were searched for summer days having the same solar irradiance and the same outdoor air temperature. Two days were found one with the ridge vent closed the other with the ridge vent open that had very similar outdoor air temperatures and solar irradiance. The soffit vent was open for both summer days of field testing.

Opening the ridge vent reduced the bulk air temperature within the inclined air channel for the slate tile (SR10E83) and also for the clay (SR54E90) tile. At solar noon, the bulk air temperature near the underside of the slate tile was 10°F cooler than observed for the same slate tile with the ridge vent closed the previous summer. The effect for the S-Mission clay was about a 5°F drop in the bulk air temperature for the two different summer days having very similar weather. Slate tile are laid one atop another and have little clearance for the seepage of air between overlapped tiles. The S-Mission tiles are designed porous for minimizing wind uplift forces. Therefore the clay tile allowed more leakage of air between overlapped tiles than observed for the slate tile system. As result, opening the ridge vent caused a more significant drop in heat flow crossing the roof deck for the slate tile roof as compared to the clay tile roof (Fig. 3). The results imply that opening the ridge caused more daytime heat to be exhausted out the ridges of both the S-Mission clay and the slate tile systems. There is also another very interesting trend observed from 8 p.m. until about 4 a.m. Having the ridge vent open during the nighttime caused the bulk air temperature near the tile underside to be warmer than that observed for both tile roofs with the ridge closed. Hence, the heat lost from the attic is reduced with the ridge vent open (Fig. 3). The thermal mass of the tile keep them warm during the evening whether the ridge vent is open or closed. However, when colder and denser air overlays a warmer and less dense air convective roll waves may form that enhance heat transfer to the air on the underside of the tile. This is not the situation for the two different days of data – one with ridge venting the other without. The actual mechanism is not fully understood and is possibly simply conduction dominated at night dependent of temperature gradients across the roof deck.

Tracer Gas Experiments: Measurements were made of the airflow occurring underneath the clay and concrete tile roofs as the buoyancy-driven airflow moved from the soffit to the ridge of each roof. The goal is to predict that portion of heat transfer that penetrates the tile and is swept by thermal buoyancy toward the ridge vent. The calculation requires an accurate prediction of the airflow rate under the enclosed vent cavity of the tile. We designed a procedure using tracer gas techniques outlined in ASTM E 741 and also by Lagus et al. (1988). The procedure requires monitoring the decay rate of the tracer gas CO_2 with time. Three CO_2 monitors were placed inside each attic space and sampling tubes were inserted into the vent cavity from the underside of the oriented strand board

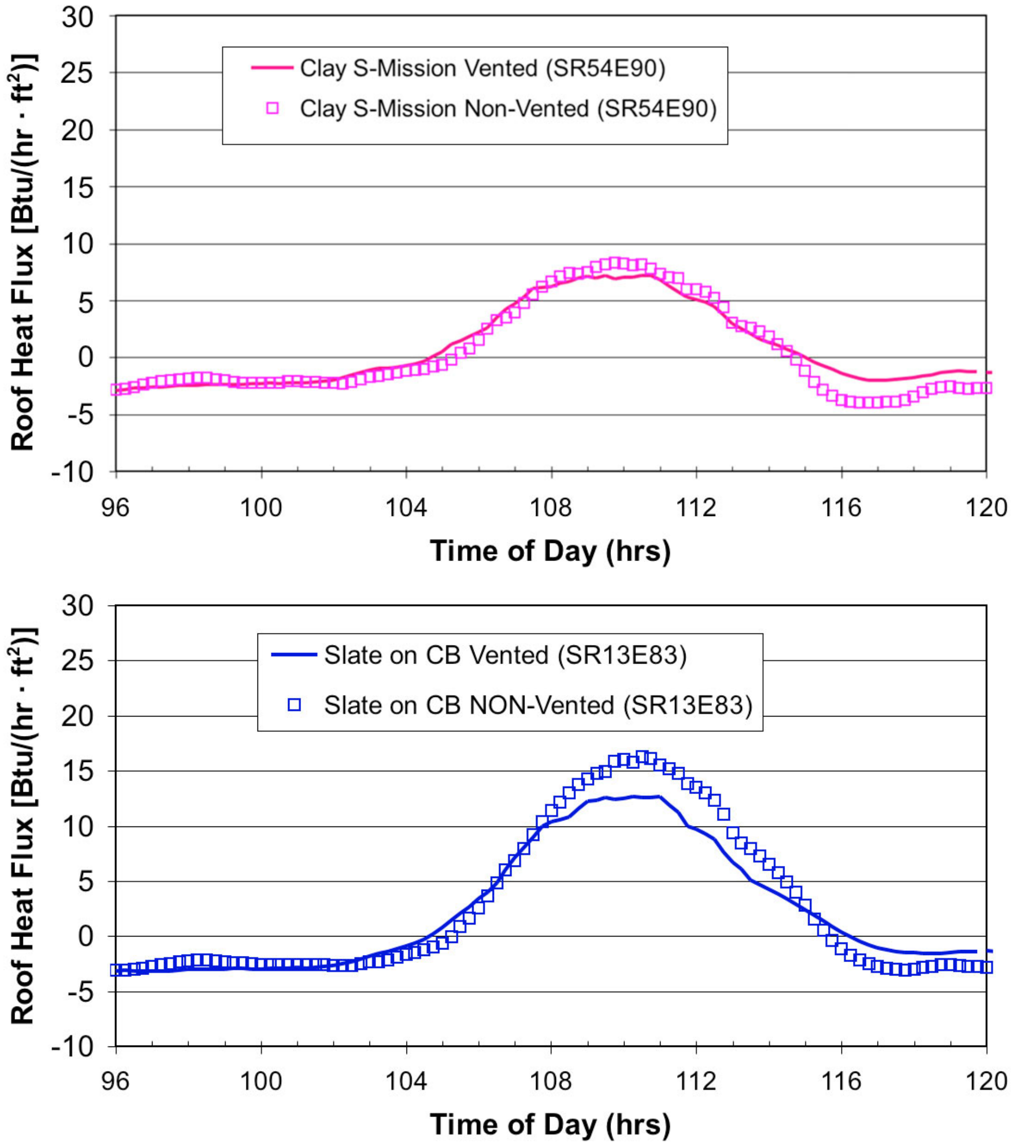

Figure 3. Heat penetrating through the roof deck of the S-Mission clay tile and the concrete slate tile with and without venting of the roof deck.

(OSB) decking. The monitors sampled the gas concentration near the soffit, at the center of the roof and within two-feet of the ridge vent. We injected the gas into the vent gap at the soffit at a relatively high rate to saturate the cavity with CO_2 gas. After a substantial buildup of concentration registered on each monitor (i.e., 20,000 PPMV of CO_2) the gas injection was stopped and CO_2 concentration was recorded at timed intervals. Data for the five vented clay and concrete tile roofs were collected (Table 3) and the calculated airflows ranged from about 12 to 40 cfm (0.005 to 0.02 m^3/sec). The average velocity ranged from about 0.4 to 0.9 ft/s (0.12 to 0.27 m/s), which is consistent with results calculated from the velocity profile generated by numerical simulations using FEMLAB; computed bulk velocity being 0.6 ft per sec.

Table 3. Airflow rate and bulk velocity measured under the clay and concrete tile roofs using tracer gas techniques.

	S-Mission	Medium Profile	S-Mission with foam	Slate on Counter Batten	S_Mission on Batten
	Clay	Concrete Tile			
Volume (in^3)	7910.9	5831.7	5531.5	5433.1	6914.4
Airflow (cfm)	36.8	12.5	17.6	19.3	23.3
Average Velocity (ft/s)	0.879	0.405	0.600	0.672	0.636

All data were collected at solar noon when the roofs had their highest respective roof temperatures and heat flows penetrating into the attic. The clay tile yielded the highest measured buoyancy induced airflow, which is very interesting because the combination of its solar reflectance and airflow underneath the S-mission tile are believed the drivers causing the 72% reduction in deck heat flow as compared to a direct nailed shingle roof.

Energy balances for internal duct flow were derived using constant wall and constant heat flux boundary conditions and the airflow in the enclosed cavity was calculated using the measured temperature and heat flow data for the five tile roof systems. Using a constant temperature boundary condition yields the expression:

$$LN\left[\frac{T_{Wall} - T_{Air\,out}}{T_{Wall} - T_{Air\,in}}\right] = -\frac{\hbar\{P \cdot L\}}{\dot{m}\left(C_{P\,Air}\right)}$$

while the constant flux condition yields the expression:

$$\dot{m} \cdot C_{P\,Air}\left(T_{Air\,out} - T_{Air\,in}\right) = q''_{solar}\left(P \cdot L\right)$$

where

- T represents field temperature data
- P perimeter of the duct
- L length of the duct

The constant surface temperature scenario gave mass flow rate calculations of about 0.03 to 0.04 lbm/s. The constant heat flux condition yielded mass flow rates around 0.05 to 0.10 lbm/s, which is high probably because we used the measured solar irradiance rather than the flux from the underside of the tile (not easily known from field data). The corresponding airflow values range from 24 to a high of 80 cfm, and are within reason of the airflows determined from the tracer gas experiments (Table 3). We therefore have good representative airflow measures for sub-tile venting and are in good position to implement an algorithm for use in AtticSim to predict tile roof thermal performance.

2.6.4 Product Useful Life Testing

Our review paper "Weathering of Roofing Materials-An Overview," by Berdahl, Akbari, Levinson, and Miller, was substantially completed earlier. Each of the coauthors has now provided various suggestions for improvements (e.g., more figures, more discussion of the connections between weathering generally and cool roofing specifically, more data on long-term weathering of coated metal). We expect to submit this paper to the CEC and for peer review next month. Construction and Building Materials is the prospective journal.

2.7 Technology transfer and market plan

2.7.1 Technology Transfer

W. Miller presented results of the residential field demonstrations at the quarterly Building America meeting held at the Department of Energy headquarters in Washington, DC. Building America has targeted 30, 40 and 50% decreases in whole house energy for communities of homes by the dates set in Table 4. The savings are based on a benchmark that is generally consistent with mid-1990s standard practice (for specifics of the benchmark see http://www.nrel.gov/docs/fy05osti/36429.pdf).

Table 4. Building America Target Dates for Establishing Communities Showcasing Energy savings.

Savings	Marine	Hot Humid	Hot/Dry/Humid	Mixed	Cold
30%	2006	2007	2005	2006	2005
40%	2008	2010	2007	2008	2009
50%	2011	2015	2012	2013	2014

George James, Leader of Building America, stated he wants the LBNL and ORNL team to couple their new PIER initiatives with Building America's goals. He wants the community of homes that Building America is establishing to have cool pigmented roofs that will help meet the goals set in Table 4.

On September 13, 2005, at the Build Green San Diego conference, Akbari gave a presentation on the topic of "Potentials of Urban Heat Island Mitigation to Reduce Energy Use and Improve Air Quality in Urban Areas."

The Metal Construction Association (MCA) spent one day of their semi-annual conference meeting with the Building Envelope Program (BEP) staff at ORNL. The BEP hosted over 150 MCA members from the United States, Canada, Mexico, Germany, and France. W. Miler gave presentation of the residential "cool roof" field studies being conducted at ORNL and described the benefits of cool colored materials and venting of the roof deck.

Akbari gave a lecture titled "Cool Roofs for Urban Heat Island Mitigation," at the Andhra Pradesh Chambers of Commerce and Industry (FAPPCI), Hyderabad, India, July 2, 2005.

Akbari gave a lecture titled "Urban Heat Islands and Mitigation Technologies," at the International Institute for Information Technology, Hyderabad, India, July 4, 2005.

Akbari gave a lecture titled "Urban Heat Islands and Mitigation Technologies," at the Indian Institute of Technology, Mumbai, India, July 5, 2005.

2.7.2 Market Plan

Task completed.

2.7.3 Title 24 Code Revisions

Task completed.

Management Issues

- Since the project has been extended through December 2006 to accommodate additional testing (Tasks 2.6.1, 2.6.2, and 2.6.3), Akbari and Scruton agreed to submit quarterly progress report until the completion of the project.

Attachment 1

Project Tasks and Schedules (*Approved on May 16, 2002; Revised schedules approved November 2004*)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 9/30/2005
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**) • Finalize Initial PAC Organization Membership List (**Completed**) • PAC Meeting Schedule (**Completed)** • Letters of Acceptance (**Completed)**	6/1/02	5/17/02	9/1/02	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 9/30/2005
2.3	PAC meetings (**Completed**) *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		100% (6/6)
2.4	Development of cool colored coatings					
2.4.1	Identify and Characterize Pigments with High Solar Reflectance *Deliverables:* • Pigment Characterization Data Report (**Completed**)	6/1/02	6/1/02	12/1/04 → 12/31/04	12/31/04	100%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings *Deliverables:* • Computer Program (**Completed**)	11/1/03	11/1/03	12/1/04 → 5/1/05	5/30/05	100%
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database (**Completed**)	6/1/03	7/1/03	6/1/05 → 12/31/04	12/31/04	100%
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 (**Completed**)	6/1/02	6/1/02	6/1/03	4/1/05	100%
2.5.2	Design Innovative Methods for Application of Cool Coatings to Roofing Materials *Deliverables:* • Summary Coating Report **(Completed)** • Prototype Performance Report **(Completed)**	6/1/02	6/1/02	12/1/04 → 5/1/05	6/30/05	~ 100%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05 → 10/1/05		~ 85%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 9/30/2005
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 (**Completed)** • Test Site Report	6/1/02	9/1/02	10/1/05 → 10/1/06		93%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05 → 10/1/06		90%
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		95%
2.6.4	Product Useful Life Testing *Deliverables:* • Solar Reflectance Test Report **(Draft Prepared)**	5/1/04	5/1/04	6/1/05 → 10/1/05		98%
2.7	Technology transfer and market plan					
2.7.1	Technology Transfer (**Completed)** *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	6/1/05	100%
2.7.2	Market Plan *Deliverables:* • Market Plan(s) **(Completed)**	5/1/05	4/1/05	6/1/05	7/10/05	100%
2.7.3	Title 24 Code Revisions *Deliverables:* • Document coordination with Cool Roofs Rating Council in monthly progress reports (**Completed)** • Title 24 Database **(Completed)**	6/1/02	5/16/02	6/1/05	6/30/05	100%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 9/30/2005
VII	Critical Project Review(s) *Deliverables:* • Minutes of the CPR meeting					
XII (C)	Monthly Progress Reports *Deliverables:* • Monthly Progress Reports (**Completed)**	6/1/02	6/1/02	6/1/05		112% (40/36)
XII (D)	Final Report *Deliverables:* • Final Report Outline • Final Report	3/1/05 → 3/31/06		10/1/05 → 10/1/06		
	Final Meeting *Deliverables:* • Minutes of the final meeting	10/15/05		10/31/05		

Appendix A
Accelerated Fluorescent Light Test Data

Shepherd Color Company is conducting the fluorescent light exposure testing according to ASTM G154-04 using a 340 nm lamp for daylight UV irradiance. Exposure conditions are 8 hours of UV light at 60°C black panel temperature followed by 4 hours of condensation at 50°C. Total color change is measured using a Hunter Labscan instrument. Solar reflectance is measured using the Device & Services reflectometer. Gloss is measured using a BYK Gardner Micro-TRI-gloss device.

Table A1. Solar reflectance, Total Color Change and the Gloss of Roof Samples Exposed to Fluorescent Light at Shepherd Color Company.

		Initial Measures		1000 hours of Fluorescent light exposure			2000 hours of Fluorescent light exposure		
Material Code	Roof Product	Solar Reflectance	Gloss	Solar Reflectance	Total ΔE	Gloss	Solar Reflectance	Total ΔE	Gloss
Natural Red Cool 140	Clay tile	44.6	2.0	44.6	1.4	2.0	45.0	0.5	2.0
Natural Red Cool 141		44.8	2.0	45.0	0.8	2.0	45.0	0.3	2.0
Natural Red Cool 142		44.7	2.0	44.6	0.7	2.0	45.0	0.7	2.0
Ironwood Cool 146		25.9	1.0	25.9	0.2	1.0	26.0	0.2	1.0
Ironwood Cool 147		27.3	1.0	26.8	0.5	1.0	27.0	0.5	1.0
Ironwood Cool 148		26.7	1.0	26.4	0.5	1.0	26.0	0.6	1.0
872T3 Slate Bronze Cool 124	PVDF Metal	26.0	28.0	25.8	0.3	29.0	26.0	0.5	29.0
872T3 Slate Bronze Cool 125		25.9	28.0	25.7	0.4	28.0	26.0	0.7	27.0
872T3 Slate Bronze Cool 126		25.9	28.0	25.8	0.3	29.0	26.0	0.5	29.0
815T119 Slate Bronze Std 127		11.7	28.0	11.7	0.4	28.0	12.0	0.6	28.0
872R10 Brick Red Cool 112		36.7	36.0	36.0	0.3	36.0	35.0	1.2	36.0
872R10 Brick Red Cool 113		36.6	37.0	36.3	0.2	37.0	36.0	0.3	37.0
872R10 Brick Red Cool 114		36.6	36.0	36.2	0.3	37.0	36.0	0.4	36.0
815R71 Brick Red Std 115		19.0	29.0	19.2	0.8	30.0	19.0	0.8	30.0
Terracotta M3308	Concrete tile	30.8	8.0	30.1	1.7	9.0	30.0	1.6	7.0
Terracotta IR3308		46.9	11.0	45.9	1.6	14.0	46.0	1.3	6.0
Chocolate M3808		12.9	4.0	12.1	1.3	4.0	12.0	1.3	4.0
Chocolate IR3808		39.2	12.0	38.2	1.6	12.0	38.0	1.9	7.0
Cool IRR - A1	Asphalt Shingle	25.8	0.0	25.5	0.8	0.0	26.0	1.0	0.0
Cool IRR - A2		25.3	0.0	24.6	1.8	0.0	25.0	1.1	0.0
Std - B1		6.7	0.0	7.2	1.3	0.0	7.0	1.6	0.0
Std - B2		7.4	0.0	7.7	0.3	0.0	8.0	0.2	0.0
Cool - C1		26.9	0.0	26.8	2.0	0.0	27.0	1.8	0.0
Cool - C2		26.1	0.0	25.2	2.5	0.0	25.0	1.2	0.0
Std - D1		10.0	0.0	10.5	1.2	0.0	11.0	0.7	0.0
Std - D2		11.3	0.0	11.5	0.2	0.0	11.0	0.9	0.0
Std Premium - E1		6.5	0.0	6.8	1.1	0.0	8.0	2.3	0.0
Std Premium - E2		6.5	0.0	6.4	1.0	0.0	7.0	1.8	0.0
Cool Premium - F1		23.6	0.0	23.8	0.6	0.0	24.0	0.3	0.0
Cool Premium - F2		25.0	0.0	23.8	0.6	0.0	25.0	0.6	0.0

[1] A1,B1,C1,D1,E1,F1 are samples of asphalt shingles cut from valley of shingle

[2] A2,B2,C2,D2,E2,F2 are samples of asphalt shingles cut from tooth of shingle

[3] Premium refers to a top-of-the-line shingle having a 50 year warranty

- American Society for Testing and Materials (ASTM). 2005. Designation G 154-04: Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials. West Conshohocken, Pa.: American Society for Testing and Materials.

Appendix A
Xenon-Arc Exposure Test Data

Xenon-arc exposure testing is \being conducted according to ASTM G155-04a. A daylight filters is used to simulate daylight UV irradiance. The exposure conditions require 102 minutes of light at 63°C black panel temperature followed by 18 minutes of light with condensation. Panel temperature is not controlled during condensation. A radiometer monitors the irradiance and the measurement is used in a feed back control loop to control the radiant energy incident on the samples. Total color change is measured using a Hunter Labscan instrument. Solar reflectance is measured using the Device & Services reflectometer. Gloss is measured using a BYK Gardner Micro-TRI-gloss device.

Table A2. Solar Reflectance, Total Color Change And Gloss Of Roof Samples Exposed To Xenon-Arc Exposure At 3M Minerals Company.

		Initial Measures		1000 hours of Xenon-Arc exposure			2000 hours of Xenon-Arc exposure		
Material Code	Roof Product	Solar Reflectance	Gloss	Solar Reflectance	Total ΔE	Gloss	Solar Reflectance	Total ΔE	Gloss
Natural Red Cool 240	Clay tile	43.3	1.8	44.2	5.5	1.3	43.6	3.4	1.2
Natural Red Cool 241		43.5	1.9	40.4	3.9	1.7	37.9	6.5	1.7
Natural Red Cool 242		43.8	1.8	36.7	7.7	1.4	34.4	8.7	1.3
Ironwood Cool 246		25.5	0.6	20.6	6.8	0.5	21.0	6.1	0.5
Ironwood Cool 247		26.5	0.6	27.5	1.5	0.6	27.4	1.8	0.6
Ironwood Cool 248		25.8	0.6	23.6	4.4	0.5	24.1	4.3	0.5
872T3 Slate Bronze Cool 224	PVDF Metal	25.3	29.3	26.6	0.2	29.3	26.6	0.7	27.4
872T3 Slate Bronze Cool 225		25.3	29.0	26.5	0.2	28.9	26.7	0.8	27.1
872T3 Slate Bronze Cool 226		25.2	27.2	26.4	0.3	27.1	26.7	0.6	26.1
815T119 Slate Bronze Std 227		11.5	29.6	11.7	0.2	28.9	12.0	0.3	27.9
872R10 Brick Red Cool 212		35.9	37.6	37.4	0.3	36.9	37.5	0.5	35.4
872R10 Brick Red Cool 213		36.0	37.3	37.6	0.2	37.3	37.6	0.6	36.1
872R10 Brick Red Cool 214		35.8	37.4	37.5	0.2	36.8	37.6	0.5	35.7
815R71 Brick Red Std 215		18.6	29.8	19.2	0.1	30.6	19.6	0.7	29.5
Terracotta M3308	Concrete tile	29.9	12.6	30.6	2.7	12.8	30.7	2.9	13.5
Terracotta IR3308		45.4	6.3	46.7	2.0	6.3	46.9	2.8	5.7
Chocolate M3808		12.3	4.7	12.1	1.2	5.5	12.3	1.5	5.8
Chocolate IR3808		38.4	5.1	39.6	1.2	5.4	39.6	1.7	4.9
Cool IRR - A1	Asphalt Shingle	27.2	0.4	28.0	0.5	0.4	28.4	1.7	0.4
Cool IRR - A2		26.3	0.4	26.3	0.8	0.3	27.4	0.9	0.4
Std - B1		8.6	0.2	8.6	1.7	0.2	9.5	1.7	0.2
Std - B2		8.0	0.3	8.1	1.5	0.2	8.5	1.6	0.1
Cool - C1		27.3	0.4	28.5	1.7	0.5	29.8	1.8	0.5
Cool - C2		26.3	0.3	27.7	1.3	0.3	27.9	1.2	0.4
Std - D1		12.3	0.4	12.2	0.6	0.3	12.7	1.2	0.3
Std - D2		12.1	0.3	12.1	0.9	0.3	13.2	1.2	0.4
Std Premium - E1		6.8	0.2	7.0	0.4	0.3	7.6	2.1	0.4
Std Premium - E2		6.7	0.3	6.8	0.7	0.3	7.4	0.7	0.4
Cool Premium - F1		25.1	0.4	26.2	0.2	0.6	27.1	0.3	0.4
Cool Premium - F2		27.4	0.5	28.3	0.8	0.5	29.2	0.7	0.4

[1] A1,B1,C1,D1,E1,F1 are samples of asphalt shingles cut from valley of shingle

[2] A2,B2,C2,D2,E2,F2 are samples of asphalt shingles cut from tooth of shingle

[3] Premium refers to a top-of-the-line shingle having a 50 year warranty

- American Society for Testing and Materials (ASTM). 2005. Designation G 155-04a: Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials. West Conshohocken, Pa.: American Society for Testing and Materials.