# Steep-Slope Assembly Testing of Clay and Concrete Tile Roofs

# WITH AND WITHOUT COOL PIGMENT

### Part I of II

### By William A. Miller, PhD, PE

*This is the first of a two-part series. This section addresses the effects of cool color pigments on solar reflectance and reviews the effects of climatic soiling. The reasons and methods behind a three-year regimen of testing of sample roof systems are discussed and performance metrics will be presented in a second article showing the effectiveness of cool color pigments on clay and concrete tiles. The study was done for the California Energy Commission and is published with the approval of CEC. An abbreviated report from the study was delivered at the RCI Foundation's 2005 Cool Roofing...Cutting Through the Glare Symposium in Atlanta. The second part of this article will be published in the January 2007 issue of* Interface.

A new generation of roofing products is being introduced that will bring relief to homeowners and utilities alike. Cool color pigments used to color paints are reducing the amount of energy needed to cool buildings, which in turn helps power companies to reduce hot-weather energy consumption. Cool color pigments will also positively impact the environment by helping reduce carbon dioxide emissions, metropolitan heat build-up, and urban smog.

Industry researchers, including those working with the Department of Defense, developed the first prototype cool color pigments for military camouflage to closely match the near-infrared reflectance of background foliage. The high infrared reflectance of these pigments can be exploited to manufacture roofing materials that reflect more sunlight than conventionally pigmented roofing products. Therefore, Oak Ridge National Laboratory (ORNL) and the Lawrence Berkeley National Laboratory (LBNL) initiated a three-year project to bring cool-colored roofing materials to the roofing market. The sister laboratories, in conjunction with pigment (colorant) and roof manufacturers, selected appropriate cool color pigments, applied them to roofing materials, and field tested the roof products. Testing occurred at demonstration homes and seven weathering farms in California and at the campus of the Buildings Technology Center (BTC), using the steep-slope attic assembly on the Envelope Systems Research Apparatus (ESRA).

## ABSTRACT

Cool-color pigments and above-sheathing ventilation of clay and concrete tile roofs significantly impact the heat flow crossing the roof deck of a steep-slope roof. Field measures for the tile roofs revealed a 70% drop in the peak heat flow crossing the deck as compared to a direct-nailed asphalt shingle roof. The Tile Roofing Institute (TRI) and its affiliate members are keenly interested in documenting the magnitude of the drop for obtaining solar reflectance credits with state and federal "cool roof" building efficiency standards. Tile roofs are direct-nailed or are attached to a deck with batten or batten and counter-batten construction.

S-Mission clay and concrete tile roofs, a medium-profile concrete tile roof, and a flat "slate" roof were installed on fully instrumented attic test assemblies. Temperatures of the roof, deck, attic, and ceiling; heat flows; solar reflectance; thermal emittance; and the ambient weather were recorded for each of the tile roofs and also on an adjacent attic cavity covered with a conventional pigmented and direct-nailed asphalt shingle roof. ORNL measured each tile's underside temperature and the bulk air temperature and heat flows just underneath the tile for batten and counter-batten tile systems and compared the results to the conventional asphalt shingle.

## INTRODUCTION

Parker, Sonne, and Sherwin (2002) demonstrated that a Florida home with a "white, reflective," barrel-shaped concrete tile roof used 22% less annual cooling energy than an identical and adjacent home

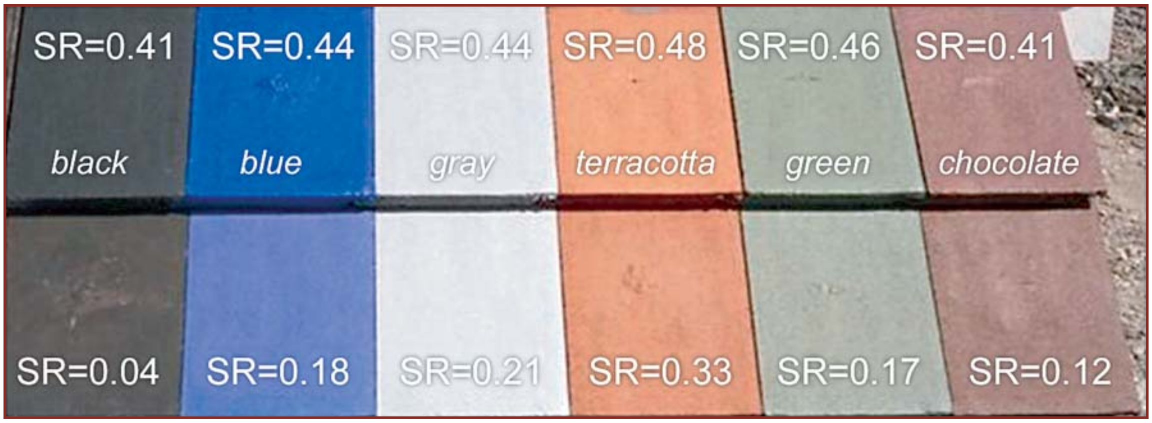

*Figure 1 – Cooltile IR Coatings™ developed by American Rooftile Coatings and LBNL increase the solar reflectance of coated tiles by as much as 0.37 (black tile) without changing color.*

having a dark, absorptive, asphalt shingle roof. The annual cost savings due to the reduced use of comfort-cooling energy was about $120, or approximately 6.7¢ per square foot per year.

The energy and cost savings reported by Parker *et al.* (2002) for white reflective concrete tile are promising; however, in the residential market, the issues of aesthetics and durability have limited the acceptance of "white" residential roofing. To homeowners, dark roofs simply blend better with the surroundings than their counterpart, a highly reflective "white" roof. What the public is not aware of, however, is that the aesthetically pleasing dark roof can be made to reflect like a "white" roof in the near-infrared spectrum. Miller et al. (2004), Akbari *et al.* (2004b), and Levinson *et al.* (2005a and 2005b) provide further details about the potential energy benefits, identification, and characterization of dark, yet highly reflective, color pigments.

Coating tile with cool pigmented colors has been successfully demonstrated by American Rooftile Coatings, which applied its Cooltile IR Coating™ to several samples of concrete tiles of different colors (*Figure 1*). The solar reflectance for all colors tested exceeded 0.40. Most dramatic is the effect of the dark colors. The black coating increased the solar reflectance from 0.04 to 0.41, while the chocolate brown coating jumped from 0.12 to 0.41, a 250% increase in solar reflectance! The coating can certainly help tile roof products comply with legislation being proposed for California's Title 24 building energy efficiency standards for residential buildings. Levinson, Akbari, and Reilly (2004) found that applying the Cooltile IR Coating™ yielded measurable reductions in roof surface temperature, attic air temperature, and ceiling heat flux for scaled buildings field-tested in Riverside, California (*Figure 1*).

### STEEP-SLOPE ATTIC ASSEMBLY

The ESRA is a one-story building used to expose large areas of low-slope and steep-slope roofs to East Tennessee's climate. Two sides of the building are mostly below grade, while the other two sides are mostly above grade. The interior of the ESRA is conditioned to a constant temperature of 70°F year-round. The long axis of the building is oriented east to west, and the test roofs on the ESRA face directly south to receive full exposure from the sun.

Members of TRI installed clay and concrete tile on a fully instrumented, steep-slope attic assembly (*Figure 2*). High-profile S-Mission clay and concrete tile, medium-profile concrete, and a flat concrete "slate" tile were exposed to East Tennessee's climate for two full years. The clay S-Mission tile and the medium-profile concrete tile were direct-nailed to the roof deck; high-profile S-Mission concrete tile was spot-adhered with foam to the roof deck; the flat concrete "slate" tile was fastened to a batten and counter-batten system; and another concrete S-Mission tile was fastened to battens (*Table 1*). The sixth lane (see far left lane in *Figure 2*) has a conventional asphalt shingle roof for comparing energy savings. The tile roofs are approximately 5 ft wide with 16 ft of length. *Table 1* provides the salient features of the test concrete and clay tiles. All tiles, whether direct-nailed or installed on battens, have above-sheathing ventilation along the underside of the tile traveling from soffit to ridge and transversely along the width of the test roofs. Parapet partitions with channel flashing were installed between lanes to keep transverse airflows within a given type of tile (*Figures 2* and *3*).

Each test roof has its own attic cavity, with 11 inches of expanded polystyrene insulation installed between adjacent cavities. This reduces the heat leakage between cavities to less than 0.5% of the solar flux incident at solar noon on a test roof. Therefore, each lane can be tested as a stand-alone entity. Salient features of the ESRA facility are fully discussed by Miller et al. (2002).

As mentioned, above-sheathing ventilation occurs on the underside of the tile roofs because of the design of the tile and the construction of the roof deck. The batten and batten with counter-batten installations provide a unique inclined air channel running from the soffit to the ridge. The bottom surface of the air channel is formed by the roof deck and 30# felt and is relatively in plane and smooth. The top surface is cre-

| **Roof Cover** | **Attachment to Deck** | **Reflectance Emittance** |
|---|---|---|
| | | SR*xx*E*yy*[1] |
| S-Mission Clay | Direct to Deck | SR54E90 |
| Medium-Profile Concrete | Direct to Deck | SR10E93 |
| S-Mission Concrete | Spot Adhered to Deck Using Foam | SR26E86 |
| "Slate" Concrete | Counter-Batten and Batten | SR13E83 |
| S-Mission Concrete | Batten | SR34E83 |
| Asphalt Shingle | Direct to Deck | SR10E89 |

[1] SR*xx* states the solar reflectance of a new sample. E*yy* reports the thermal emittance of the new sample. For example, the asphalt-shingle roof is labeled SR10E89; its freshly manufactured surface properties are therefore 0.10-reflectance and 0.89-emittance.

*Table 1 – Clay and concrete tile placed on the ESRA's steep-slope attic assembly.*

*Figure 2 – An assembly of steep-slope attics was placed on top of the ESRA. Clay and concrete tiles were installed by the Tile Roofing Institute.*

ated by the underside of the roofing tiles and is broken at regular intervals by a batten[1] wood furring strip (into which the tiles are fastened).

For batten and counter-batten construction, the counter-batten is fastened to the roof deck and run from soffit to ridge, and the batten is nailed on top of the counter-battens (*Figure 3*). The underside of the roof tiles establishes the upper surface of the inclined air channel. Tiles are designed with a gap at the respective overlap where one tile lies atop the other. The design allows wind pressures to equalize, reducing uplift. The design further complicates solution of the heat transfer because an accurate prediction of the airflow is required to predict the heat transfer crossing the roof boundary.

*Figure 3 – Construction of the roof deck showing battens and counter-battens for attaching the slate tile. The parapets are used to limit airflow on the underside of the tile to within a given test roof.*

## SOLAR REFLECTANCE AND THERMAL EMITTANCE INSTRUMENTS

A Device and Services solar spectrum reflectometer was used to measure the solar reflectance (near normal, hemispherical reflectance of sunlight) of the roof samples. The device uses a tungsten halogen lamp to diffusely illuminate a sample. Four detectors, each fitted with differently colored filters, measure the reflected light in different wavelength ranges. The four signals are weighted in appropriate proportions to yield the total hemispherical reflectance. The device was proven accurate to within ±0.003 units (Petrie et al., 2000) through validation against the ASTM E-903 method (ASTM 1996). However, because the cool color pigments exhibit high near-infrared reflectance, some of the field samples were also measured at LBNL using a spectrometer to check the portable reflectometer. The average absolute difference between the Device and Services reflectometer and the spectrometer was about 0.02 points of reflectance.

The impact of emittance on roof temperature is almost as important as that of reflectance (Levinson 2005). A portable Device and Services emissometer was used to measure the thermal emittance using the procedures in ASTM C-1371 (ASTM 2004). The device has a thermopile radiation detector, which is heated to 180°F. The detector has two high-e and two low-e elements and is designed to respond only to radiation heat transfer between itself and the sample. Because the device is comparative between the high-e and the low-e elements, it must be calibrated *in-situ* using two standards, one having an emittance of 0.89, the other having an emittance of 0.06. Kollie, Weaver, and McElroy (1990) verified the instrument's precision as ±0.008 units.

## SOLAR REFLECTANCE AND THERMAL EMITTANCE

The solar reflectance and the thermal emittance of a roof surface are important surface properties affecting the roof temperature, which, in turn, drives the heat flow through the roof. The solar reflectance (ρ) is the fraction of incident sunlight that is reflected by the surface. The thermal emittance (ε) characterizes the efficiency with which a surface cools itself by emitting radiation. It is the ratio of the total flux (power per unit area) radiated by the surface to that radiated by a black body (perfect absorber of radiation) at the same temperature. Our emphasis on the long-term benefits of cool roofing systems recognizes the potential for a significant loss in solar reflectance in the first few years of service life. Surface contamination and climatic exposure cause the loss. If a roof product is severely soiled, then the benefits of cool color pigments diminish.

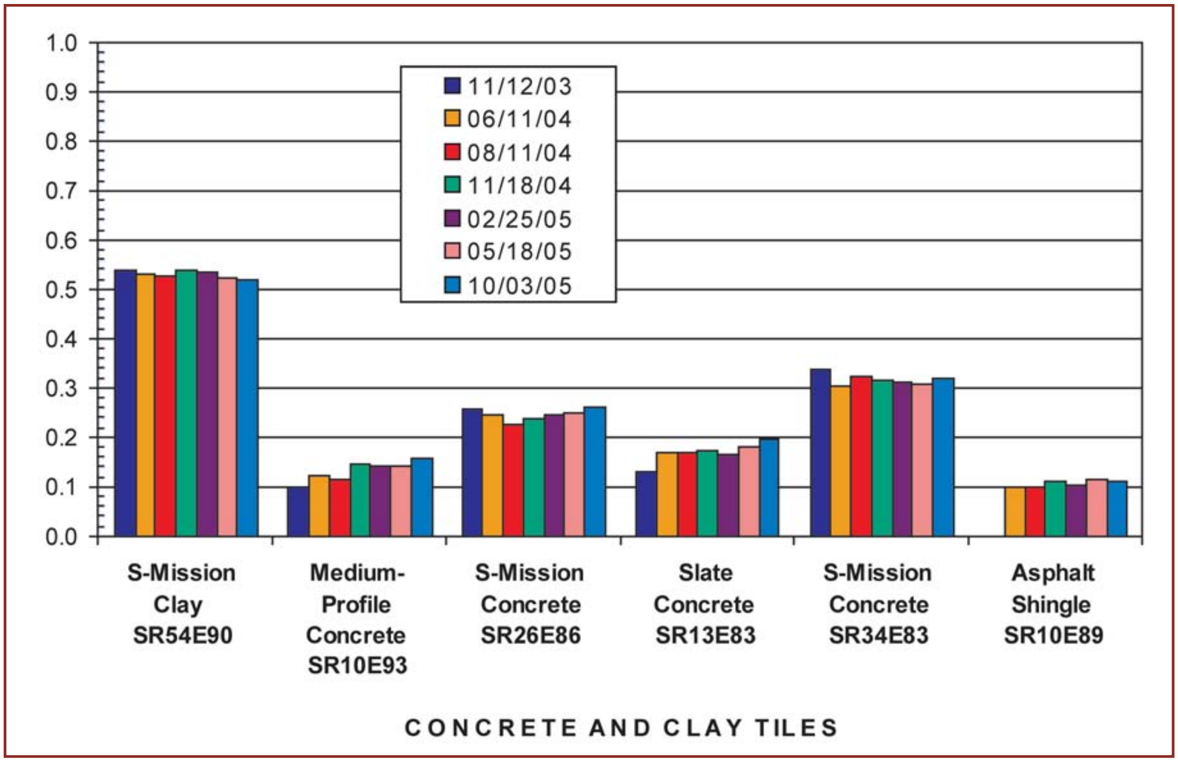

*Figure 4 – Solar reflectance of the clay and concrete tile exposed on the ESRA.*

## EFFECTS OF CLIMATIC SOILING

The initial solar reflectance and initial thermal emittance are identified for each tile using the abbreviation SRxxEyy described in *Table 1*. After two years of exposure, the S-Mission tiles (SR54E90, SR26E86, and SR34E83) show little drop in solar reflectance (*Figure 4*). The clay tile (SR54E90) exceeds the solar reflectance of all the other tiles (*Figure 4*), because it contains cool color pigments that boost its reflectance in the near-infrared spectrum. A slurry coating process is used to add color to the surface of a clay tile. Once coated, the clay is kiln-fired, and the firing temperature, the atmosphere, and the pigments affect the final color and solar reflectance [Akbari, et al. (2004a)].

Data for clay tiles are also shown for field exposure testing in three of the 16 climatic zones of California. The clay samples are identical to those tested at ORNL. They show a loss of solar reflectance that occurs because of climatic soiling. The worst soiling observed occurs in the urban area of Colton and the desert area of El Centro (*Figure 5*). However, the crisp and clear alpine climate of McArthur shows the lowest loss of solar reflectance, because fewer contaminants pollute the air.

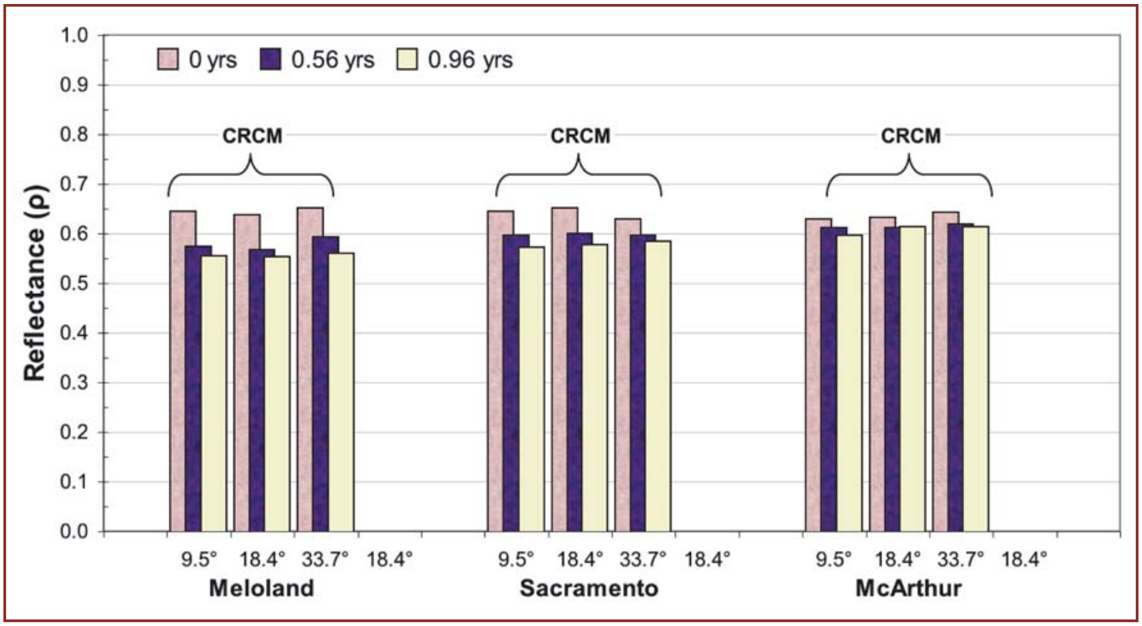

*Figure 5 – Solar reflectance of clay tile exposed at weathering sites in California.*

Roof slope appears to affect the loss of solar reflectance (*Figure 5*). Testing at the slope of 8 inches of rise per 12 inches of run (33.7˚ slope) has less reflectance loss compared to testing at 2 inches of rise per 12 inches of run (9.5˚) for all three exposure sites (*Figure 5*). Precipitation is not believed to be the dominant player, especially when one considers that El Centro has less than 3 inches of annual rainfall! Rather, wind may be causing the different losses of solar reflectance as roof slope changes from 9.5 to 33.7 degrees.

The results in *Figures 4* and *5* show that exposure testing differed between the western and mid-eastern climates of the United States, possibly because of differences in precipitation and wind. East Tennessee's climate caused little, if any, soiling of the non-white tiles.

The thermal emittance of the clay and concrete tile has not changed much after two years of exposure in California or Tennessee. It remains relatively constant at about 0.85.

**Part II of II will appear in the January issue of *Interface* and describe field test results, conclusions, and recommendations.**

### William A. Miller, PhD

Dr. Miller is a specialist with 25 years of experience in vapor compression refrigeration systems, absorption heat, and mass transfer and building science technologies. He has a PhD in mechanical engineering and works for the Engineering Science and Technology Division of the Oak Ridge National Laboratory. He has conducted cool roof studies for the California Energy Commission, SPRI, and a consortium of metal industries to quantify the energy savings and affordable cost premiums for highly reflective roof products as compared to dark, absorptive roof systems. He has expertise in finite difference heat conduction for application to forced convection, natural convection, and mixed convection finite-difference simulations.

**FOOTNOTES**

[1] Battens are either fastened directly to the roof deck or fastened atop a counter batten. Battens run parallel to the roof's ridge.

## LARGEST ROOFING COMPANIES LISTED

*ENR* has released its "Top 600 Specialty Contractors" list. Ranked by 2005 revenue, the top 20 roofing contractors are listed below:

| Rank | Firm | 2005 Revenue ($ Mil.) | Chg. % '04-'05 |
|---|---|---|---|
| 1 | Centimark Corp., Canonsburg, PA | 347.5 | +14 |
| 2 | Tecta America Corp., Skokie, IL | 334.6 | +42 |
| 3 | Latite Roofing & Sheetmetal Co. Inc., Pompano Beach, FL | 108.4 | +43 |
| 4 | Baker Roofing Co., Raleigh, NC | 100.1 | +40 |
| 5 | Best Roofing & Waterproofing Inc., Gardena, CA | 65.0 | +49 |
| 6 | Crowther Roofing & Sheet Metal of Fl. Inc., Fort Myers, FL | 56.4 | +33 |
| 7 | Holland Roofing, Florence, KY | 52.0 | +11 |
| 8 | The Campbell Cos., Memphis, TN | 48.2 | +27 |
| 9 | Advanced Roofing Inc., Fort Lauderdale, FL | 46.4 | +37 |
| 10 | Beldon Enterprises Inc., San Antonio, TX | 36.0 | NA |
| 11 | Schreiber Roofing Corp., Detroit, MI | 33.8 | +2 |
| 12 | Kalkreuth Roofing & Sheet Metal Inc., Wheeling, WV | 33.1 | +27 |
| 13 | The Young Group Ltd., St. Louis, MO | 32.6 | +29 |
| 14 | Douglass Roofing Co., Commerce City, CO | 32.0 | +20 |
| 15 | The Fred Christen & Sons Co., Toledo, OH | 30.8 | NA |
| 16 | All-South Subcontractors Inc., Birmingham, AL | 29.8 | +31 |
| 17 | Orndorff & Spaid Inc., Beltsville, MD | 29.4 | +16 |
| 18 | Commercial Roofers Inc., Las Vegas, NV | 25.5 | NA |
| 19 | Hamlin Roofing Co. Inc., Garner, NC | 22.8 | +20 |
| 20 | Burns & Scalo Roofing Co. Inc., Pittsburgh, PA | 18.5 | +1 |