Cool colored roofs to save energy and improve air quality

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ABSTRACT

Raising the solar reflectance of a roof from a typical value of 0.1–0.2 to an achievable 0.6 can reduce cooling-energy use in buildings by more than 20%. Cool roofs also reduce ambient outside air temperature, thus further decreasing the need for air conditioning and retarding smog formation.

We are collaborating with pigment manufacturers to characterize colorants, and with manufacturers of roofing materials to produce cool colored products, including asphalt shingles, concrete and clay tiles, metal roofing, wood shakes, and coatings. In this collaboration, we have identified and characterized pigments suitable for cool-colored coatings, and developed engineering methods for applying cool coatings to roofing materials. We are also measuring and documenting the laboratory and *in-situ* performances of roofing products. Demonstration of energy savings can accelerate the market penetration of cool-colored roofing materials. Early results from this effort have yielded colored concrete, clay, and metal roofing products with solar reflectances exceeding 0.4. Obtaining equally high reflectances for roofing shingles is more challenging, but some manufacturers have already developed several cost-effective colored shingles with solar reflectances of at least 0.25.

1. INTRODUCTION

Coatings colored with conventional pigments tend to absorb the invisible "near-infrared" (NIR) radiation that bears more than half of the power in sunlight (Fig. 1). Replacing conventional pigments with "cool" pigments that absorb less NIR radiation can yield similarly colored coatings with higher solar reflectance. These cool coatings lower roof surface temperature, reducing the need for cooling energy in conditioned buildings and making unconditioned buildings more comfortable.

Field studies in California and Florida have demonstrated cooling-energy savings in excess of 20% upon raising the solar reflectance of a roof to 0.6 from a prior value of 0.1–0.2 (Konopacki and Akbari, 2001; Konopacki et al., 1998; Parker et al., 2002). Energy savings are particularly pronounced in older houses that have little or no attic insulation, especially if the attic contains the air distribution ducts. At 8¢/kWh, the value of U.S. potential nationwide net commercial and residential energy savings (cooling savings minus heating penalties) exceeds $750 million per year (Akbari et al., 1999). Cool roofs also significantly reduce peak electric demand in summer (Akbari et al., 1997; Levinson et al., 2005a). The widespread installation of cool roofs can lower the ambient air temperature in a neighborhood or city, decreasing the need for air conditioning, retarding smog formation, and improving environmental comfort. These "indirect" benefits of reduced ambient air temperatures have roughly the same economic value as the direct energy savings (Rosenfeld et al., 1998). Lower surface temperatures may also increase the lifetime of roofing products (particularly asphalt shingles), reducing replacement and disposal costs.

According to Western Roofing Insulation and Siding magazine (2002), the total value of the 2002 projected residential roofing market in 14 western U.S. states (AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, TX, UT, WA, and WY) was about $3.6 billion (B). We estimate that 40%

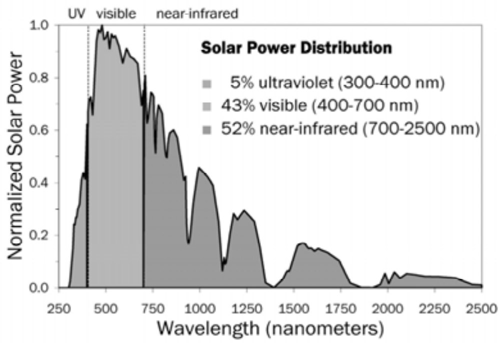


Figure 1: Peak-normalized solar spectral power; over half of all solar power arrives as invisible, "near-infrared" radiation.

($1.4B) of that amount was spent in California. The lion's share of residential roofing expenditure was for fiberglass shingle, which accounted for $1.7B, or 47% of sales. Concrete and clay roof tiles made up $0.95B (27%), while wood, metal, and slate roofing collectively represented another $0.55B (15%). The value of all other roofing projects was about $0.41B (11%). We estimate that the roofing market area distribution was 54–58% fiberglass shingle, 8–10% concrete tile, 8–10% clay tile, 7% metal, 3% wood shake, and 3% slate (Table 1).

Suitable cool *white* materials are available for most roofing products, with the notable exception (prior to March 2005*) of asphalt shingles. Cool nonwhite materials are needed for all types of roofing. Industry researchers have developed complex inorganic color pigments that are dark in color but highly reflective in the near infrared (NIR) portion of the solar spectrum. The high near-infrared reflectance of coatings formulated with these and other "cool" pigments—e.g., chromium oxide green, cobalt blue, phthalocyanine blue, Hansa yellow—can be exploited to manufacture roofing materials that reflect more sunlight than conventionally pigmented roofing products.

Cool colored roofing materials are expected to penetrate the roofing market within the next few years. Preliminary analysis suggests that they may cost up to $\$1/m^2$ more than conventionally colored roofing materials. However, this would raise the total cost of a new roof (material plus labor) by only 2 to 5%.

Table 1: Project residential roofing market in the U.S. western region surveyed by Western Roofing (2002). The 14 states included in the U.S. western region are AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, TX, UT, WA, and WY.

Roofing Type	Market share by $		Estimated market share by roofing area
	$B	%	%
Fiberglass Shingle	1.70	47.2	53.6-57.5
Concrete Tile	0.50	13.8	8.4-10.4
Clay Tile	0.45	12.6	7.7-9.5
Wood Shingle/Shake	0.17	4.7	2.9-3.6
Metal/Architectural	0.21	5.9	6.7-7.2
Slate	0.17	4.7	2.9-3.6
Other	0.13	3.6	4.1-4.4
SBC Modified	0.08	2.1	2.4-2.6
APP Modified	0.07	1.9	2.2-2.3
Metal/Structural	0.07	1.9	2.2-2.3
Cementitious	0.04	1.1	1.2-1.3
Organic Shingles	0.02	0.5	0.6
Total	**3.60**	**100**	**100**

We have collaborated with 12 companies that manufacture roofing materials, including shingles, roofing granules, clay tiles, concrete tiles, tile coatings, metal panels, metal coatings, and pigments. The development work with our industrial partners has been iterative and has included selection of cool pigments, choice of base coats for the two-layer applications (discussed later in this paper), and identification of pigments to avoid.

2. CREATING COOL NONWHITE COATINGS

In order to determine how to optimize the solar reflectance of a pigmented coating matching a particular color, and how the performance of cool-colored roofing products compares to those of a standard materials, we (a) have identified and characterized the optical properties of over 100 pigmented coatings; (b) have created a database of pigment characteristics; and (c) are developing a computer model to maximize the solar reflectance of roofing materials for a choice of visible color.

Pigment analysis begins with measurement

* In March 2005, a major manufacturer of roofing shingles in California announced availability of cool colored shingles in four popular colors.

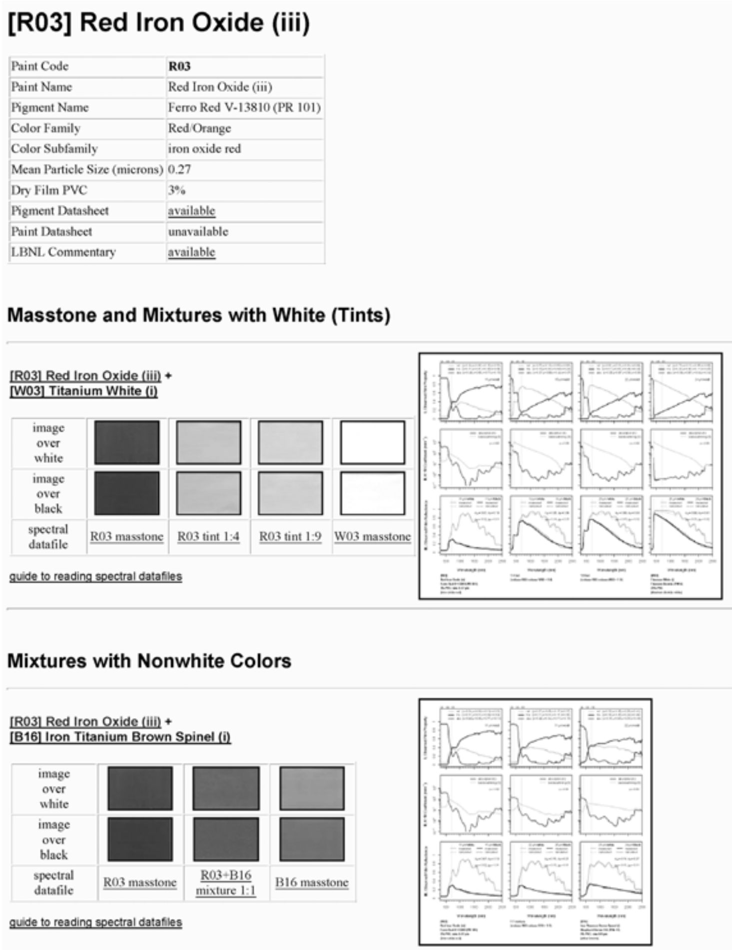


Figure 2: Description of an iron oxide red pigment in the Lawrence Berkeley National Lab pigment database.

of the reflectance *r* and transmittance *t* of a thin coating containing single pigment or binary mix of pigments (Levinson et al., 2005b,c). These "spectral", or wavelength-dependent, properties of the pigmented coating are measured at 441 evenly spaced wavelengths spanning the solar spectrum (300 – 2,500 nanometers). In addition, each sample is characterized by its computed spectral absorption coefficient *K* and backscattering coefficient *S*. A cool color is defined by a large absorption coefficient *K* in parts of the visible spectral range, to permit the attainment of desired colors, and a small absorption coefficient *K* in the near infrared (NIR). For cool colors, the backscattering coefficient *S* is small (or large) in the visible spectral range for formulating dark (or light) colors, and large in the NIR.

Inspection of the film's spectral absorptance (calculated as 1-*r*-*t*) reveals whether a pigmented coating is cool (has low NIR absorptance) or hot (has high NIR absorptance). The spectral reflectance and transmittance measurements are also used to compute spectral rates of light absorption and backscattering (reflection) per unit depth of film. The spectral reflectance of a coating colored with a mixture of pigments can then be estimated from the spectral absorption and backscattering rates of its components.

We have produced a database detailing the optical properties of the characterized pigmented coatings (Fig. 2). We are currently developing coating formulation software intended to minimize the NIR absorptance (and hence maximize the solar reflectance) of a color-matched pigmented coating.

3. CREATING COOL NONWHITE ROOFING PRODUCTS

We estimate that roofing shingles, tiles, and metal panels comprise more than 80% (by roof area) of the residential roofing market in the western United States. In this project, we have collaborated with manufacturers of many roofing materials in order to evaluate the best ways to increase the solar reflectance of these products. The results of our research have been utilized by the manufacturers to produce cool roofing materials. To date and as the direct result of this collaborative effort, manufactures of roofing materials have introduced cool shingles, clay tiles, concrete tiles, metal roofs, and concrete tile coatings.

In addition to using NIR reflective pigments in manufacturing of cool roofing materials, application of novel engineering techniques can further economically enhance the solar reflectance of colored roofing materials. Cool-colored pigments are partly transparent to NIR light; thus, any NIR light not reflected by the cool pigment is transmitted to the underneath layer, where it can be absorbed. To increase the solar reflectance of colored materials with cool pigments, multiple color layers, a reflective undercoating can be used. This method is referred as a two-layered technique.

Figure 3 demonstrates the application of the two-layered technique to manufacture cool colored materials. A thin layer of dioxazine purple (14–27 μm) is applied on four substrates: (a) aluminum foil (~ 25 μm), (b) opaque white paint (~1000 μm), (c) non-opaque white paint (~ 25 μm), and (d) opaque black paint (~ 25 μm). As it can be seen (and is confirmed by visible reflectance spectrum), the color of the material is black. However, the solar reflectance of the sample exceeds 0.4 when applied to an opaque white or aluminum foil substrate; while its solar reflectance over a black substrate is only 0.05.

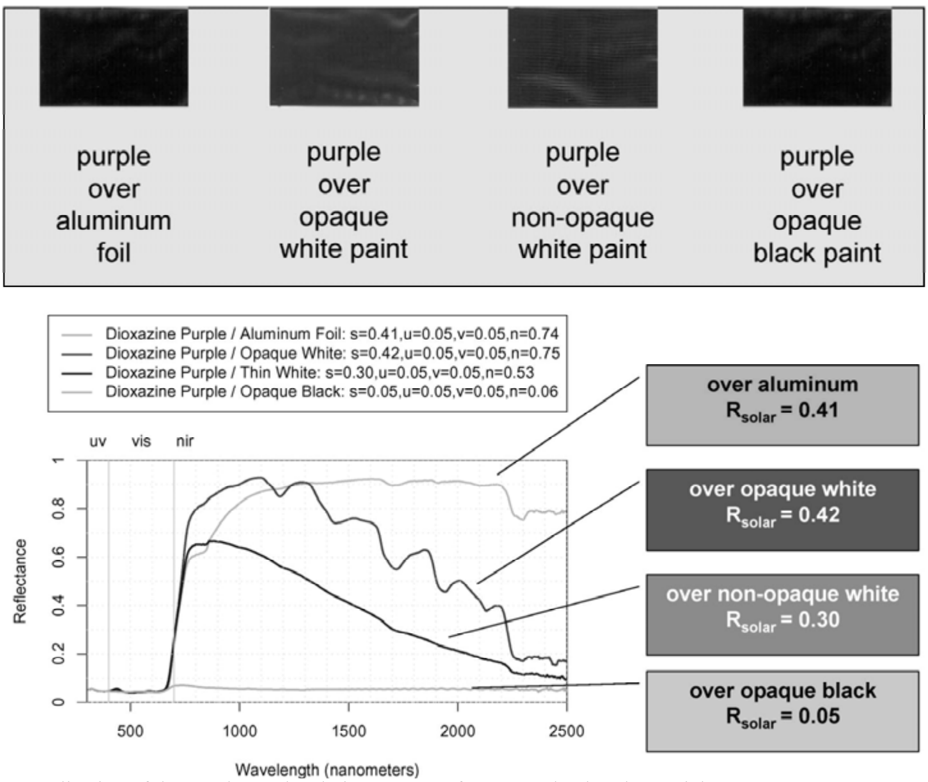


Figure 3: Application of the two-layered technique to manufacture cool colored materials.

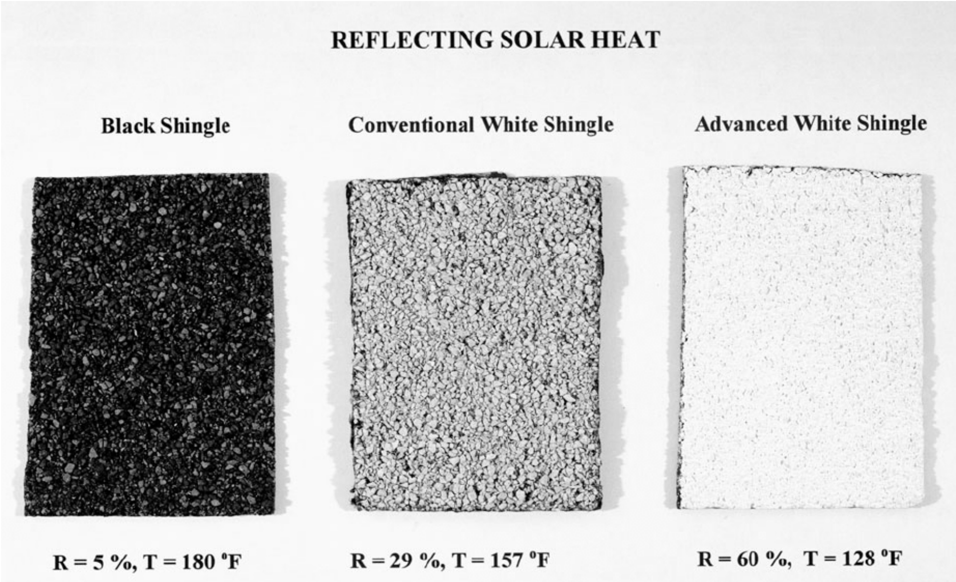


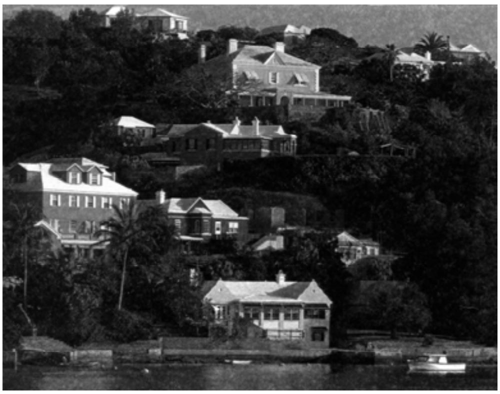
Figure 4: Development of super white shingles.

3.1 Shingles

The solar reflectance of a new shingle, by design, is dominated by the solar reflectance of its granules, which cover over 97% of its surface. Until recently, the way to produce granules with high solar reflectance has been to use a coating pigmented with titanium dioxide (TiO_2) rutile white. Because a thin TiO_2-pigmented coating is reflective but not opaque in the NIR, multiple layers are needed to obtain high solar reflectance. This technique has been used to produce "super-white" (meaning truly white, rather than gray) granulated shingles with solar reflectances exceeding 0.5 (Fig 4).

Although white roofing materials are popular in some areas (e.g., Greece, Bermuda; see Fig. 5), many consumers aesthetically prefer non-white roofs. Manufacturers have also tried to produce colored granules with high solar reflectance by using nonwhite pigments with high NIR reflectance. To increase the solar reflectance of colored granules with cool pigments, multiple color layers, a reflective undercoating, and/or reflective aggregate should be used. Obviously, each additional coating increases the cost of production.

Several cool shingles have been developed



Bermuda

Santorini (Greece)

Figure 5: White roofs and walls are used in Bermuda and Santorini (Greece).

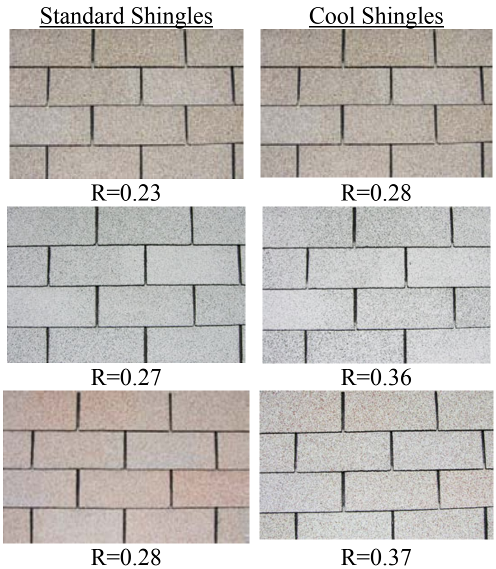


Figure 6: Examples of prototype cool shingles.

within the last year. Figure 6 shows examples of prototype cool shingles and compares their solar reflectances with those of the standard colors. Recently, a major manufacturer of roofing shingles in California announced availability of cool colored shingles in four popular colors. Figure 7 shows two houses with cool colored roofing shingles.

Figure 7: Test application of cool colored roofing shingles on two houses.

3.2 Tiles and Tile Coatings

Clay and concrete tiles are used in many areas around the world. In the U.S., clay and concrete tiles are more popular in the hot climate regions. There are three ways to improve the solar reflectance of colored tiles: (1) use clay or concrete with low concentrations of light-absorbing impurities, such as iron oxides and elemental carbon; (2) color the tile with cool pigments contained in a surface coating or mixed integrally; and/or (3) include an NIR-reflective (e.g., white) sublayer beneath an NIR-transmitting colored topcoat. Although all these options are in principle easy to implement, they may require changes in the current production techniques that may add to cost of the finished products. Colorants can be included throughout the body of the tile, or used in a surface coating. Both methods need to be addressed.

One of our industrial partners has developed a palette of cool nonwhite coatings for concrete tiles. Each of the cool colored coatings shown in Figure 8 has a solar reflectance better than 0.40. The solar reflectance of each cool coating exceeds that of a color-matched, conventionally pigmented coating by 0.15 (terracotta) to 0.37 (black). Another industrial partner also manufactures clay tiles in many colors (glazed and unglazed) with solar reflectance greater than 0.4 (See Table 1).

3.3 Metal Panels

Metal roofing materials are installed on a small (but growing) fraction of the U.S. residential roofs. Historically metal roofs have had only about 3% of the residential market. However, the architectural appeal, flexibility, and durability, due in part to the cool-colored pigments, has steadily increased the sales of painted metal roofing, and as of 2003 its sales volume has increased to 8% of the residential market, making it the fastest growing residential roofing product (Dodge, 2003). Metal roofs are available in many colors and can simulate the shape and form of many other roofing materials (Fig. 9). Application of cool-colored pigments in metal roofing materials may require the fewest number of changes to the existing production

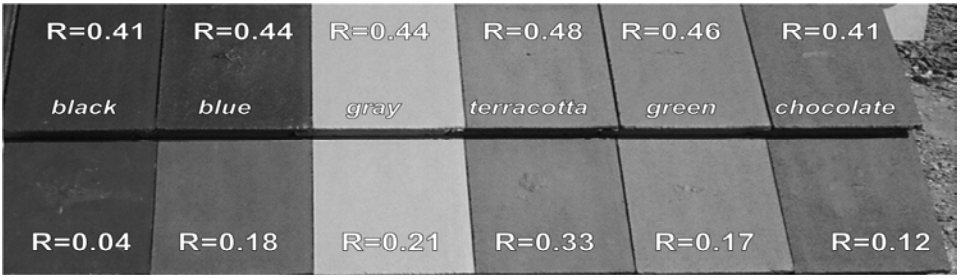


Figure 8: Palette of color-matched cool (top row) and conventional (bottom row) rooftile coatings developed by industrial partner American Rooftile Coatings. Shown on each coated tile is its solar reflectance R

Table 2. Sample cool colored clay tiles and their solar reflectances (Source: http://www.MCA-Tile.com)

Model	Color	Initial solar reflectance	Solar reflectance after 3 years
Weathered Green Blend		0.43	0.49
Natural Red		0.43	0.38
Brick Red		0.42	0.40
White Buff		0.68	0.56
Tobacco		0.43	0.41
Peach Buff		0.61	0.48
Regency Blue		0.38	0.34
Light Cactus Green		0.51	0.52

processes. As in the cases of tile and asphalt shingle, cool pigments can be applied to metal via a single or two-layered technique. If the metal substrate is highly reflective, a single-

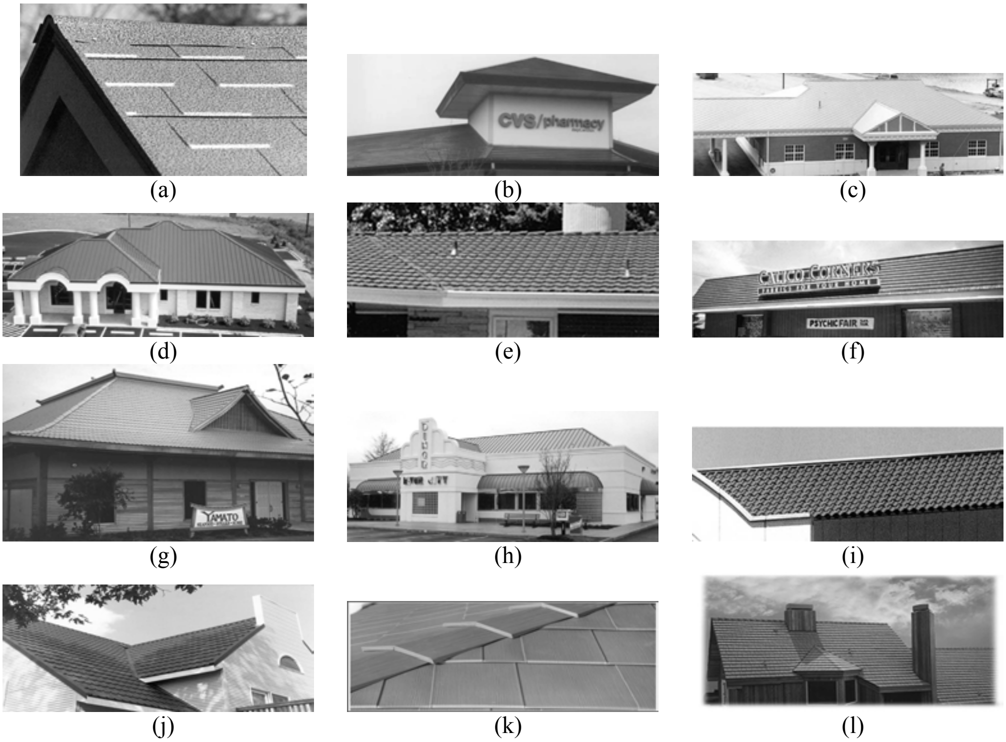


Figure 9: Simulated roofing products made from metal: (a) Advanta Shingles; (b) Bermuda Shakes; (c) Castle Top; (d) Dutch Seam Panel; (e) Granutile; (f) Perma Shakes; (g) Scan Roof Tile; (h) Snap Seam Tile; (i) Techo Tile; (j) Verona Tile; (k) Oxford Shingles; and (l) Timbercreek Shakes. Products a-j are manufactured by ATAS International, Inc., while products k and l are manufactured by Classic Products, Inc. (Photos courtesy of ATAS International and Classic Products).

layered technique may suffice. The coatings for metal shingles are thin, durable polymer materials. These thin layers use materials efficiently, but limit the maximum amount of pigment present. However, the metal substrate can provide some NIR reflectance if the coating is transparent in the NIR. Several manufactures develop cool colored metal roofs.

3.4 Durability of Cool Nonwhite Coatings

Roofing materials fail mainly because of three processes: (1) gradual changes to physical and chemical composition induced by the absorption of ultraviolet (UV) light; (2) aging and weathering (e.g., loss of plasticizers in polymers and low-molecular-weight components in asphalt), which may accelerate as temperature increases; and (3) diurnal thermal cycling, which stresses the material by expansion and contraction. Our goal is to clarify the material degradation effects due to UV absorption and those due to heating. The results will be used to quantify the effect of solar reflectance on the useful life of roofs, provide data to manufacturers to develop better materials, and support development of appropriate ASTM standards.

We are naturally weathering various types of conventionally- and cool-pigmented roofing products at seven California sites. Solar reflectance and thermal emittance are measured twice per year; weather data are available continuously. Solar spectral reflectance is measured annually to gauge soiling and to document imperceptible color changes.

We have also exposed roofing samples to 5,000 hours of xenon-arc light and to about 10,000 hours of fluorescent light in weatherometers, laboratory devices for accelerated aging. Figure 10 compares the total color change and reduction in gloss of cool roofing colored metals (CRCM) and standard colored metals exposed to accelerated fluorescent UV

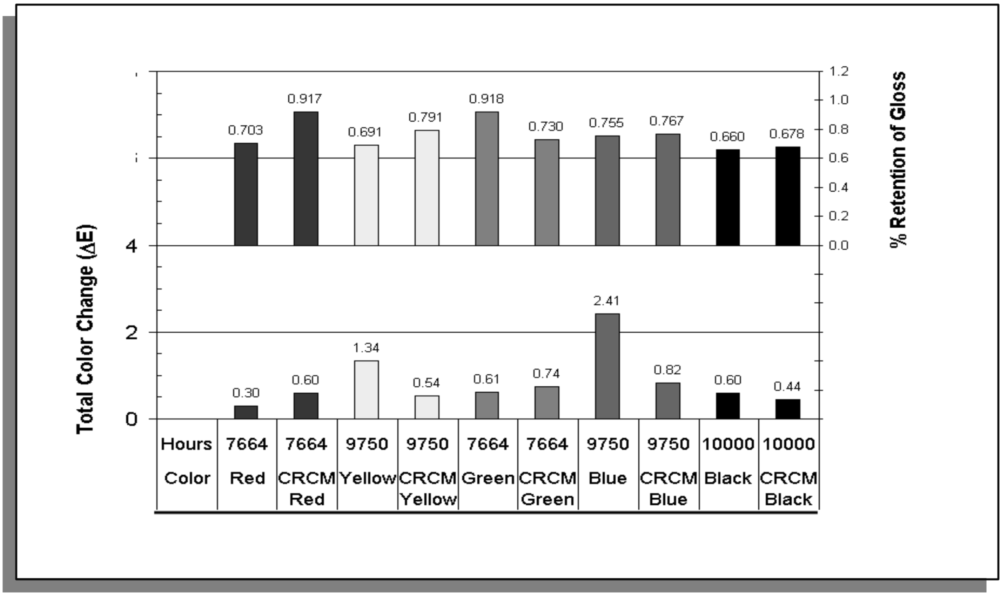


Figure 10: Fade resistance and gloss retention of painted metals (data courtesy of BASF).

light. In almost all cases cool materials have performed better than standard materials.

4. MEASUREMENT OF ENERGY SAVINGS

4.1 Demonstration Homes

We have set up a residential demonstration site in Fair Oaks, CA (near Sacramento) consisting of two pairs of single-family, detached houses roofed with metal and concrete tile. We are planning for another two pairs of houses to demonstrate asphalt shingles. The demonstration pairs each include one building roofed with a cool-pigmented product and a second building roofed with a conventionally (warmer) pigmented product of nearly the same color. The paired homes are adjacent, and share the same floor plan, roof orientation, and level of blown ceiling insulation of 3.37 m^2K/W (R-19 insulation). Each home will be monitored through at least summer 2006.

Solar reflectance and thermal emittance are measured twice a year. Temperatures at the roof surface, on the underside of the roof deck, in the mid-attic air, at the top of the insulation, on the interior ceiling's sheet rock surface, and inside the building are logged continuously by a data acquisition system. Relative humidity in the attic air and the residence are also measured. Heat flux transducers are embedded in the sloped roofs and the attic floor to measure the roof heat flows and the building heat leakage. We have instrumented the building to measure the total house and air-conditioning power demands. A fully instrumented meteorological weather station is set up to collect the ambient dry bulb temperature, the relative humidity, the solar irradiance, and the wind speed and wind direction.

One of the Fair Oaks homes roofed with low-profile concrete tile was colored with a conventional chocolate brown coating (solar reflectance 0.10), while the other was colored with a matching cool chocolate brown with solar reflectance 0.41. The attic air temperature beneath the cool brown tile roof has been measured to be 3 to 5 K cooler than that below the conventional brown tile roof during a typical hot summer afternoon. The results for the pair of homes roofed with painted metal shakes are just as promising. There the attic air temperature beneath the cool brown metal shake roof (solar reflectance 0.31) was measured to be 5 to 7 K cooler than that below the conventional brown metal shake roof.

The application of cool colored coatings is solely responsible for these reductions in attic temperature. The use of these cool colored coat-

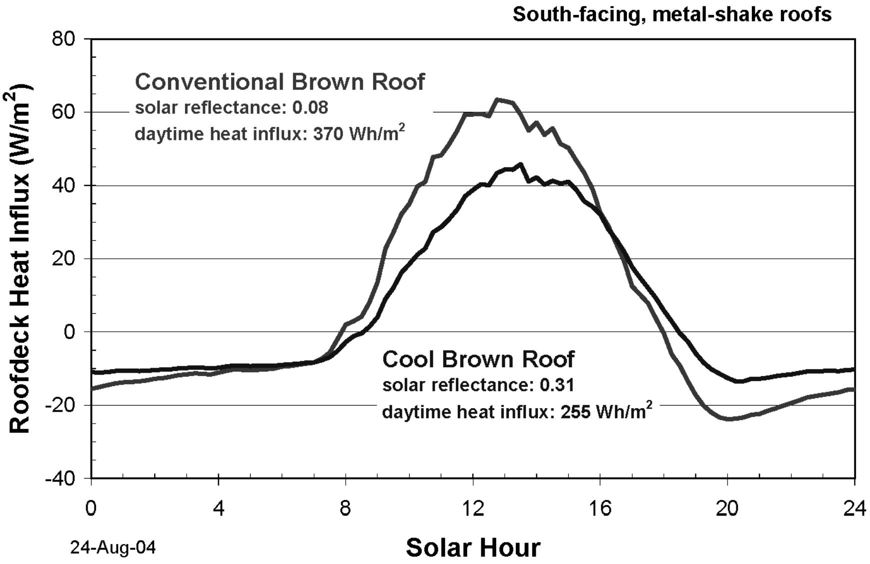


Figure 11: Heat flows through the roof decks of an adjacent pair of homes over the course of a hot summer day. The total daily heat influx through the cool brown metal shake roof (solar reflectance 0.31) between the solar hours of 8AM and 5PM is 31% lower than that through the conventional brown metal shake roof (solar reflectance 0.08).

ings also decreased the total daytime heat influx (solar hours 8AM – 5PM) through the south-facing metal shake roof by 31% (Fig. 11).

4.2 Estimates of Energy and Peak Demand Savings

To estimate the effect of cool-colored roofing materials, we calculated the annual cooling energy use of a prototypical house for most cooling dominant cities around the world. We used a simplified model that correlates the cool energy savings to annual cooling degree days (base 18°C) (CDD18*). The model is developed by regression of simulated cooling energy use against CDD18. We performed parametric analysis and simulated the cooling- and heating-energy use of a prototypical house with varying level of roof insulation (R-0, R-1, R-3, R-5, R-7, R-11, R-19, R-30, R-38, and R-49) and roof reflectance (0.05, 0.1, 0.2, 0.4, 0.6, and 0.8) in more than 250 climate regions, using the DOE-2 building energy use simulation program. For each prototypical analysis, the parametric analysis led to 15,000 DOE-2 simulations. Then the resulting cooling- and heating-energy use was correlated to CDD18.

The prototypical house used in this paper is assumed to have roofing insulation of 1.94 m^2K/W (R-11 insulation). The coefficient of performance (COP) of the prototype house air conditioner is assumed to be 2.3. The estimates of savings are for an increase in roof solar reflectance from a typical dark roof of 0.1 to a cool-colored roof of 0.4. These calculations present the variation in energy savings in different climates around the world. The typical building may not necessarily be representative of the stock of house in all countries. Here, we only report of cooling energy savings; potential wintertime heating energy penalties are not accounted for in these results.

Table 3 shows CDD18 and potential cooling energy savings in kWh per year for a house with $100m^2$ of roof area. The savings can be linearly adjusted for houses with larger or smaller roof

* To calculate the cooling degree days for a particular day, find the day's average temperature by adding the day's high and low temperatures and dividing by two. If the number is below 18°C, there are no cooling degree days that day. If the number is more than 18°C, subtract 18°C from it to find the number of cooling degree days. The annual cooling degree days is simply the sum of all daily cooling degree days.

Table 3: Cooling degree days (base 18°C) and potential cooling energy savings (kWh per 100m^2 of roof area)

Country	City	CDD18	Savings	Country	City	CDD18	Savings
Albania	Tirana	715	312	Morocco	Rabat-Sale	606	280
Algeria	Alger/Dar-El-Beida	899	366	Mozambique	Maputo	2,085	715
Argentina	Buenos Aires/Ezeiza	693	305	Pakistan	Karachi Airport	3,136	1025
Australia	Sydney/K Smith	678	301	Panama	Howard AFB	3,638	1173
Bahamas	Nassau	2,511	841	Paraguay	Asuncion/Stroessner	2,218	755
Bermuda	St Georges/Kindley	1,802	632	Peru	Lima-Callao/Chavez	906	368
Bolivia	Trinidad	2,879	949	Philippines	Manila Airport	3,438	1114
Brazil	Belo Horizonte	1,702	603	Puerto Rico	San Juan/Isla Verde	3,369	1094
	Brasilia	1,353	500	Saudi Arabia	Dhahran	3,340	1085
	Rio de Janeiro	2,360	796		Medina	3,691	1189
	Sao Paulo	1,187	451		Riyadh	3,304	1075
Brunei	Brunei Airport	3,516	1137	Senegal	Dakar/Yoff	2,445	822
China	Beijing (Peking)	840	349	Singapore	Singapore/Changi	3,647	1176
	Shanghai/Hongqiao	1,129	434	Spain	Barcelona	533	258
Cuba	Havana/Casa Blanca	2,700	897		Madrid	886	362
Cyprus	Akrotiri	1,139	437	Syria	Damascus Airport	1,074	417
Egypt	Aswan	3,187	1040	Taiwan	Taipei	2,204	750
	Cairo	1,833	641	Tajikistan	Dusanbe	1,081	420
France	Nice	545	262	Tanzania	Dar es Salaam	2,922	962
Greece	Athenai/Hellenikon	1,030	405	Thailand	Bangkok	3,962	1269
Hong Kong	Royal Observatory	2,136	730		Chiang Mau	3,140	1026
India	Bombay/Santa Cruz	3,386	1099	Tunisia	Tunis/El Aouina	1,102	426
	Calcutta/Dum Dum	3,211	1047	Turkey	Istanbul/Yesilkoy	567	268
	New Delhi/Safdarjung	2,881	950	Turkmenistan	Ashkhabad	1,442	526
Indonesia	Djakarta/Halimperda	3,390	1100	United States	Phoenix	2,579	861
Italy	Palermo/Punta Raisi	1,058	413		Burbank/Hollywood	920	372
	Roma/Fiumicino	621	284		Sacramento	743	320
Jamaica	Kingston/Manley	3,656	1178		Washington/National	930	375
	Montego Bay/Sangster	3,112	1018		Miami	2,516	842
Japan	Kyoto	1,084	420		Atlanta	1,104	426
	Osaka	1,180	449		Honolulu, Oahu	2,651	882
	Tokyo	938	377		New Orleans/Moisant	1,627	580
Jordan	Amman	1,063	414		Memphis	1,324	491
Kenya	Nairobi Airport	566	268		Dallas-Ft Worth	1,519	549
Korea	Seoul	746	321	Uruguay	Montevideo/Carrasco	595	276
Libya	Tripoli/Idris	1,686	598	Venezuela	Caracas/Maiquetia	3,331	1083
Madagascar	Antananarivo/Ivato	701	308	Vietnam	Saigon (Ho Chi Minh)	3,745	1205
Malaysia	Kuala Lumpur	3,475	1125	Zimbabwe	Harare Airport	775	329
Mexico	Chihuahua	1,058	413				
	Mexico City	245	173				
	Acapulco/Alvarez	3,623	1169				

areas. The savings range from approximately 250 kWh per year for mild climates to over 1000 kWh per year for very hot climates. For houses that are not air conditioned, cool-colored roofing materials offer comfort, typically at very reasonable costs.

5. CONCLUSION

The results from this program indicate significant success in developing cool-colored materials for concrete tile, clay tile, metal roofs, and shingles. Since the inception of this program, the solar reflectance of commercially available colored roofing products has increased to 0.30–0.45 from 0.05–0.25 for all materials but shingles. To be cost effective, shingle manufacturers apply a very thin layer of pigments on the roofing granules. Use of a reflective undercoated (two-layered coating) has yielded several cost-effective cool-colored shingle products, with solar reflectances in excess of 0.25. Our ongoing collaboration with granule and shingle manufacturers may yield shingles with solar reflectances exceeding 0.3. The energy savings from the installation of cool roofs range from approximately 250 kWh per year for mild climates to over 1000 kWh per year for very hot climates. For houses that are not air conditioned, cool-colored roofing materials offer comfort, typically at very reasonable costs.

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REFERENCES

Akbari, H., P. Berdahl, R. Levinson, S. Wiel, A. Desjarlais, W. Miller, N. Jenkins, A. Rosenfeld, and C. Scruton, 2004. Cool Colored Materials for Roofs. Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 1, p. 1, Pacific Grove, CA.

Akbari, H., S. Konopacki and M. Pomerantz, 1999. Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States, Energy, 24, 391-407.

Akbari, H., S. Bretz, H. Taha, D. Kurn and J. Hanford, 1997. Peak Power and Cooling Energy Savings of High-albedo Roofs, Energy and Buildings — Special Issue on Urban Heat Islands and Cool Communities, 25(2); 117–126.

Dodge, F.W., 2003. Construction Outlook Forecast, F.W. Dodge Market Analysis Group, 24 Hartwell Avenue, Lexington, MA 02421. Telephone 800-591-4462.

Konopacki, S. and H. Akbari, 2001. Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin. Lawrence Berkeley National Laboratory Report No. LBNL-47149, Berkeley, CA.

Konopacki, S., L. Gartland, H. Akbari and L. Rainer, 1998. Demonstration of Energy Savings of Cool Roofs. Lawrence Berkeley National Laboratory Report No. LBNL-40673, Berkeley, CA.

Levinson, R., H. Akbari, S. Konopacki and S. Bretz, 2005a. Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements, Energy Policy, 33 (2): 151-170.

Levinson, R., P. Berdahl and H. Akbari, 2005b. Spectral Solar Optical Properties of Pigments Part I: Model for Deriving Scattering and Absorption Coefficients from Transmittance and Reflectance Measurements. Solar Energy Materials & Solar Cells (in press).

Levinson et al., 2005c. Spectral Solar Optical Properties of Pigments Part II: Survey of Common Colorants. Solar Energy Materials & Solar Cells (in press).

Parker, D.S., J.K. Sonne and J.R. Sherwin, 2002. Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida, Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 1, p. 219, Pacific Grove, CA.

Rosenfeld, A.H., J.J. Romm, H. Akbari and M. Pomerantz. 1998. Cool Communities: Strategies for Heat Islands Mitigation and Smog Reduction, Energy and Buildings, 28(1); 51–62.

Western Roofing, 2005. Online at http://Western Roofing.net.