Development of Cool Color Roofing Materials

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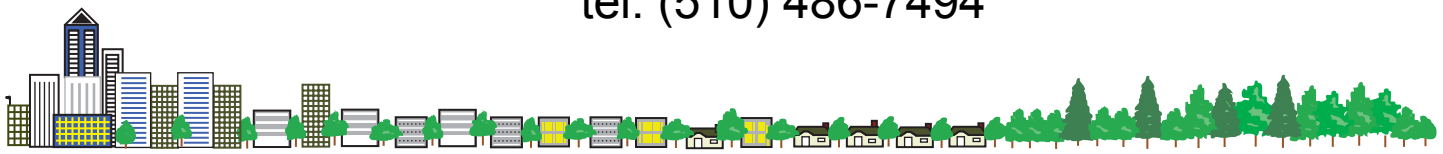

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The Cool Colors project

- Goal: develop “cool” non-white roofing products for homes
  - Dark concrete tile, clay tile, and coated metal products with solar reflectance ≥ 0.40
  - Dark fiberglass asphalt shingles with solar reflectance ≥ 0.25
- Collaborators
  - Lawrence Berkeley National Lab (material characterization & design)
  - Oak Ridge National Lab (product demonstration & weathering)
  - 16 industrial partners (prototype production by roofing, coating and pigment manufacturers)
- Sponsored by California Energy Commission
  - Phase 1: 2002-2005 (complete)
  - Phase 2: 2006-2009 (just awarded)

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Cool roof technologies

Old

flat, white

pitched, white

New

pitched, cool & colored

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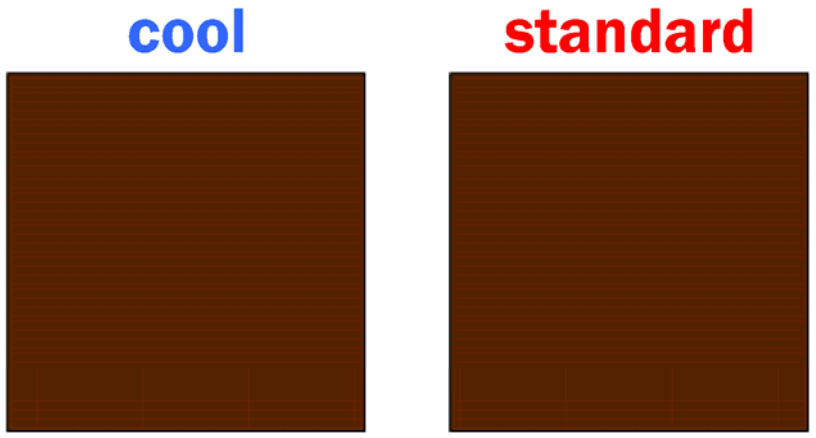
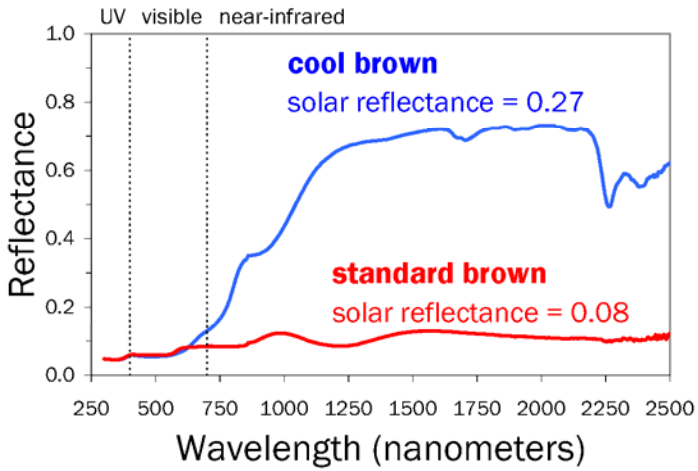
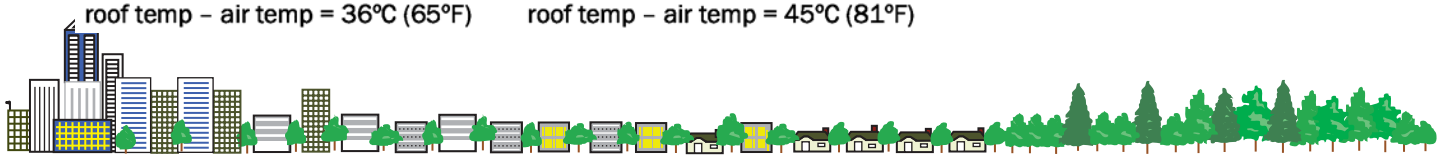
Example: brown metal roofing panels

- Solar reflectance of cool version ~ 0.2 higher
- Afternoon temperature of cool version ~ 10ºC lower

Courtesy BASF Industrial Coatings







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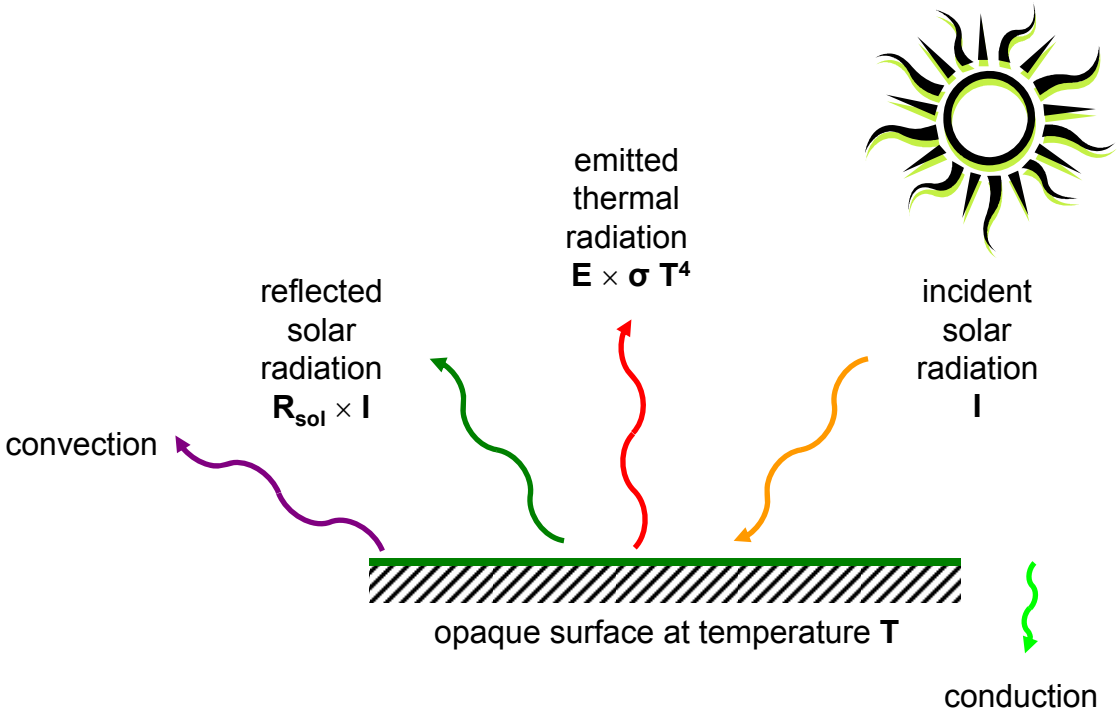
What makes a surface cool?



- **High solar reflectance** (R_{sol}) lowers solar heat gain (0.3 - 2.5 μm)
- **High thermal emittance** (E) enhances thermal radiative cooling (4 - 40 μm)

high solar reflectance + high thermal emittance = **low surface temperature**

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Thermal emittance

Nonmetallic surfaces, including most polymer-coated metals, have high thermal emittance because they strongly absorb and thus strongly emit thermal radiation (Kirchoff's law).

Only metallic surfaces (e.g., exposed aluminum flakes) have low thermal emittance.

Roofing with high thermal emittance

asphalt shingle

single-ply membrane

clay tile

polymer-coated metal

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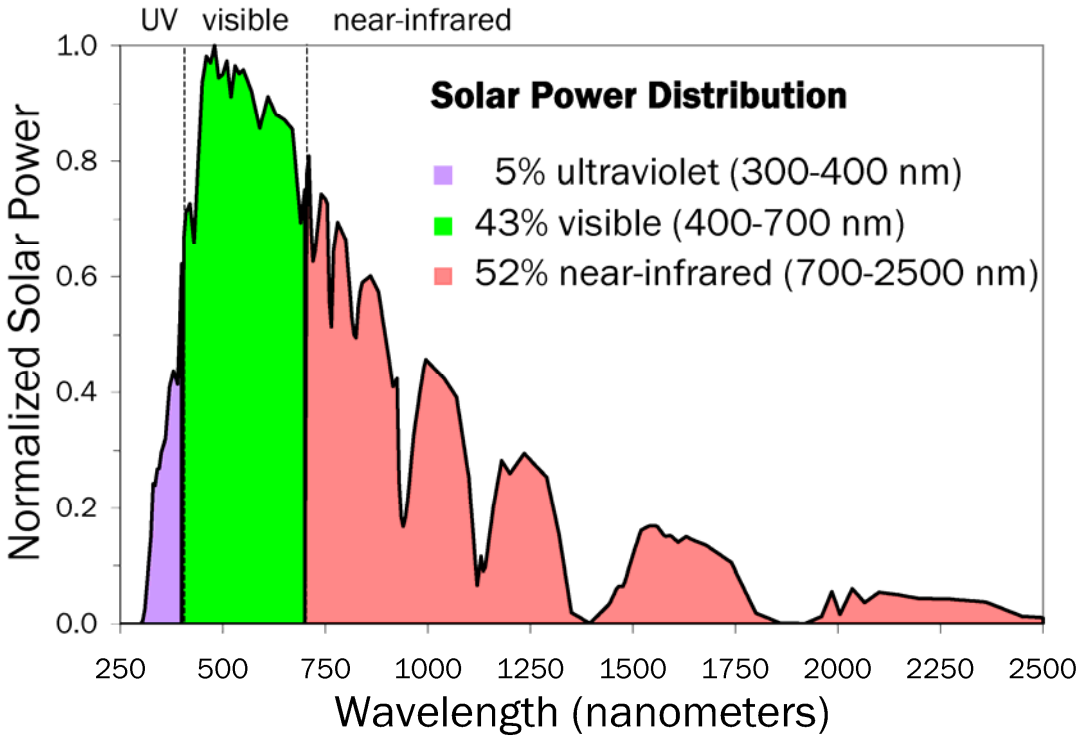
Solar reflectance



95% of sunlight arrives as visible or near-infrared (NIR) radiation.

Solar reflectance $\mathbf{R_{sol}}$ = 5% × ultraviolet reflectance $\mathbf{R_{uv}}$ +
43% × visible reflectance $\mathbf{R_{vis}}$ +
52% × near-infrared reflectance $\mathbf{R_{nir}}$

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Types of hot and cool surfaces

increasing visible reflectance

- Hot, light-colored surface
  - not normally encountered

- Cool, light-colored surface
  - **high** visible reflectance
  - **high** near-infrared reflectance
  - **high** solar reflectance
  - **coolest** type of surface

- Hot, dark-colored surface
  - **low** visible reflectance
  - **low** near-infrared reflectance
  - **low** solar reflectance
  - **warmest** type of surface

- Cool, dark-colored surface
  - **low** visible reflectance
  - **high** NIR reflectance
  - **medium** solar reflectance
  - **cooler** than hot & dark, **warmer** than cool & light

increasing near-infrared reflectance

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Examples of hot and cool surfaces

increasing solar reflectance

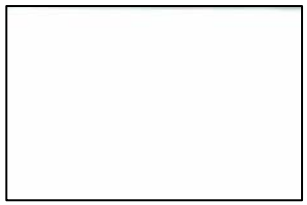
high

medium

low

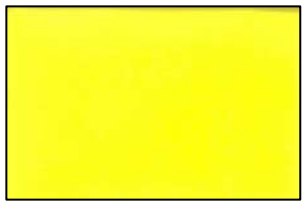
Cool light-colored surfaces

titanium dioxide white (opaque)



uv=0.13
vis=0.94
nir=0.88
sol=0.87

chrome yellow over opaque white



uv=0.05
vis=0.64
nir=0.87
sol=0.73

Cool dark-colored surfaces

perylene black over opaque white

uv=0.05
vis=0.06
nir=0.85
sol=0.47

iron oxide red over opaque white

uv=0.05
vis=0.17
nir=0.67
sol=0.43

Hot dark-colored surfaces

iron oxide black over opaque white

uv=0.04
vis=0.04
nir=0.04
sol=0.04

iron blue over opaque white

uv=0.06
vis=0.10
nir=0.25
sol=0.17

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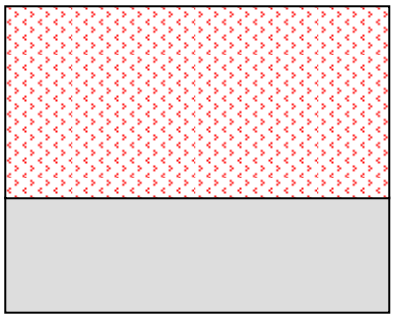
Components of a cool-coated system

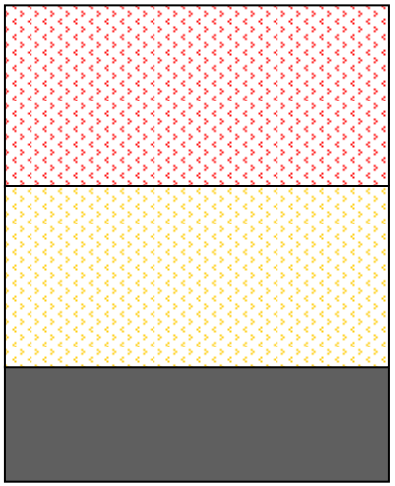
one-coat system (for NIR-reflective substrate)

cool topcoat
(e.g., iron oxide red in acrylic)

opaque substrate
(e.g., aluminum)



two-coat system (for NIR-absorbing substrate)



cool topcoat
(e.g., iron oxide red in acrylic)

NIR-reflective basecoat
(e.g., titanium dioxide white in acrylic)

opaque substrate
(e.g., gray granule)

- A substrate with high NIR reflectance requires only a topcoat
- A substrate with low NIR reflectance requires a topcoat and a basecoat

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Basecoat and topcoat design

NIR-reflecting basecoat

- Use pigment(s) with
  - **weak NIR absorption**
  - **strong NIR backscattering**
- Good pigments include
  - **titanium dioxide (rutile) white**
  - nickel titanate yellow
  - chrome titanate yellow
  - aluminum or coated mica flakes
- Thick and/or densely pigmented
  - 100s of microns (100 μm ~ 4 mil)
  - NIR reflectance produced by backscattering (inefficient)

Cool topcoat

- Use pigment(s) with
  - **weak NIR absorption**
  - strong NIR backscattering (optional)
  - strong visible absorption and/or backscattering (for color)
- May be thin
  - 10s of microns
  - color produced primarily by absorption (efficient)

Absorption
converts light to heat

Backscattering
reverses direction of light

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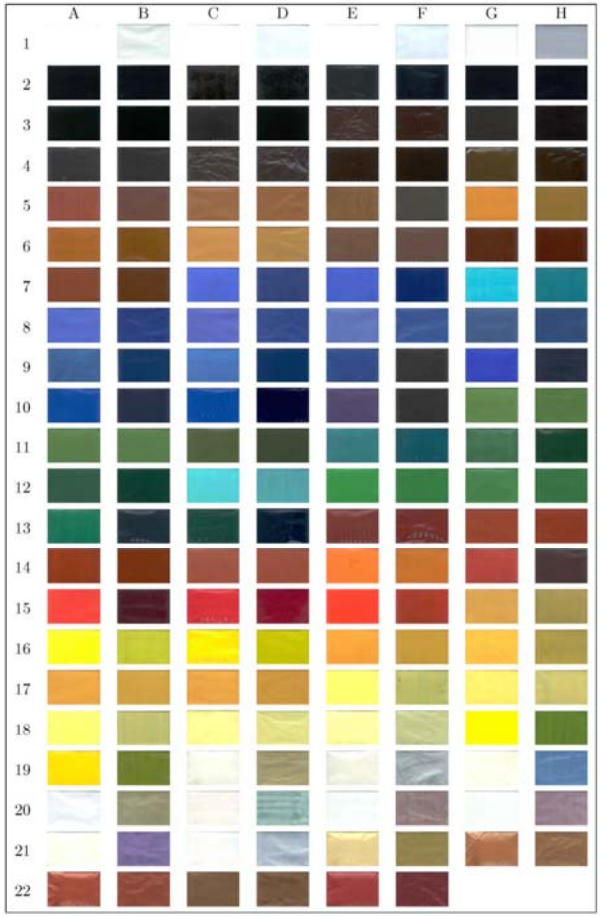
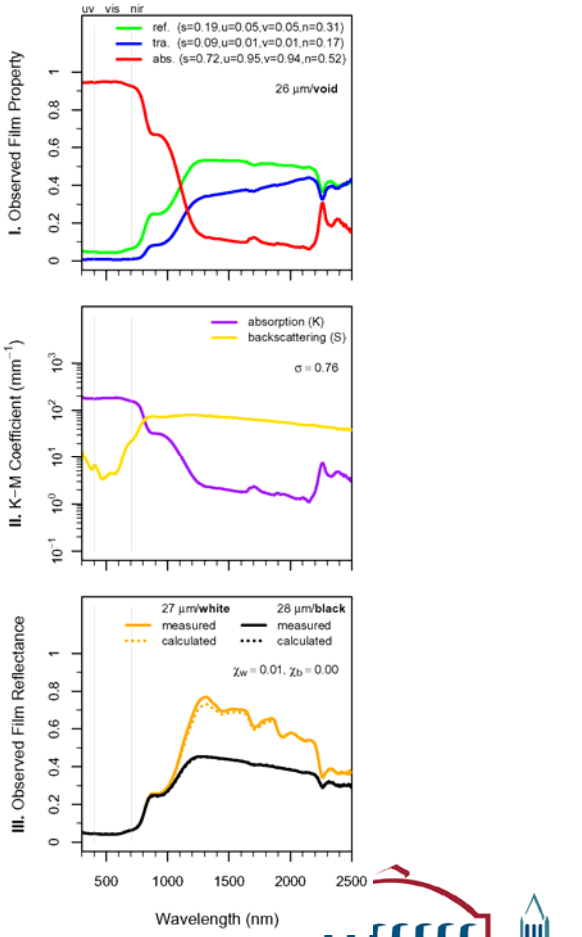
Survey of architectural, artist pigments

Prepared 87 pigments



…in polymer films over white, black backgrounds

…to characterize their solar spectral optical properties



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Some cool pigments (use in cool coatings)

…with strong NIR scattering

- white, yellow titanates
  - titanium dioxide white
  - nickel titanate yellow
  - chrome titanate yellow
  - cobalt titanate green
- titanium dioxide on mica flakes
  - various interference colors

…with moderate NIR scattering

- green, brown titanates
  - cobalt titanate green
  - iron titanium brown spinel
- red, brown iron oxides
- cadmium orange, yellow
- green, black mixed-metal oxides
  - modified chromium oxide green
  - chromium iron oxide black

… with weak NIR scattering

- cobalt blue, green
  - cobalt aluminate blue
  - cobalt chromite blue
  - cobalt chromite green
- ultramarine blue
- *many* organics, including
  - perylene black
  - phthalocyanine blue, green
  - quinacridone red
  - dioxazine purple

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Some hot pigments (avoid in cool coatings)

exclude these strong NIR absorbers
from topcoat, basecoat

- carbon black
- bone black (carbon black + calcium phosphate)
- copper chromite black
- iron oxide black (magnetite)
- iron blue [$KFe_2(CN)_6 \cdot H_20$]

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Summary of cool coating design

The principles

- High solar reflectance + high thermal emittance = low surface temperature
- Light-colored surfaces with high NIR reflectance are coolest
- Dark-colored surfaces with low NIR reflectance are hottest
- Dark-colored surfaces with high NIR reflectance lie in-between

The engineering

- Nonmetallic surfaces have high thermal emittance
- Use substrate or basecoat with high NIR reflectance
- Use pigments with low NIR absorption, and preferably high NIR backscattering
- **Avoid pigments with strong NIR absorption**

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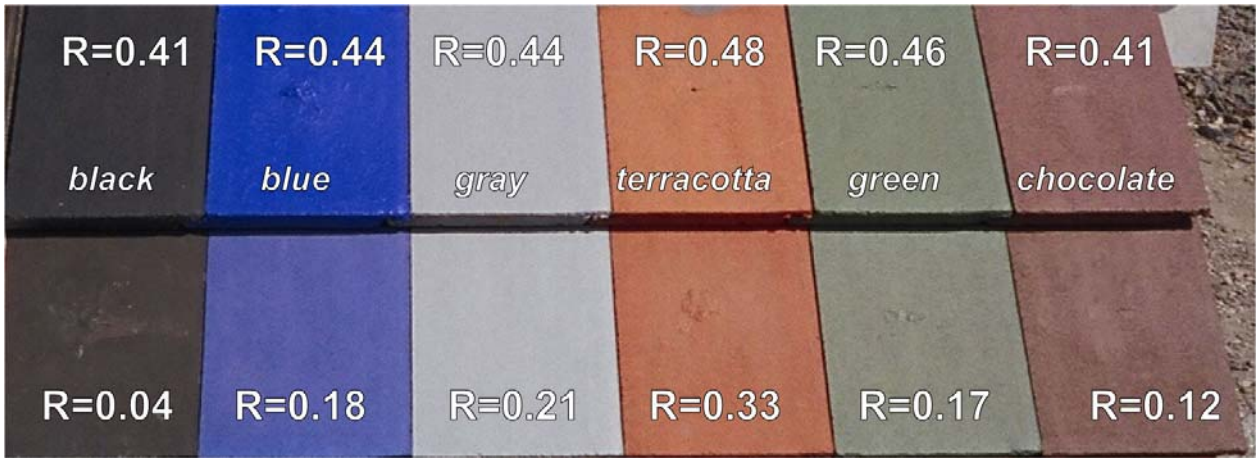
Cool and standard concrete tiles

Courtesy American Rooftile Coatings



cool

standard

ΔR=0.37 **ΔR=0.26** **ΔR=0.23** **ΔR=0.15** **ΔR=0.29** **ΔR=0.29**

- Can increase solar reflectance **R** by up to 0.5
- Gain greatest for dark colors

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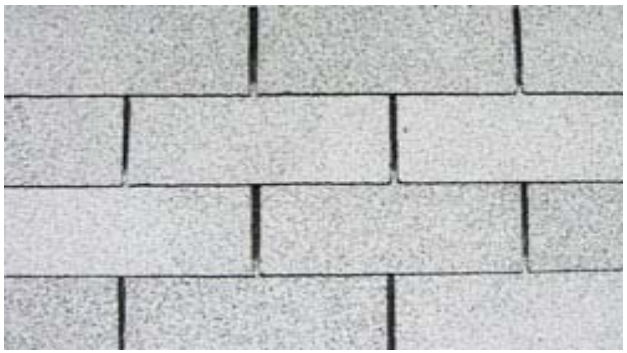
Cool and standard shingles (prototypes)

cool: R=0.28

R=0.36



R=0.37

standard: R=0.23

R=0.27

R=0.28

R = solar reflectance

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Elk Prestique® Cool Color Series shingles

Color swatches:


Cool Antique Slate


Cool Barkwood


Cool Weatheredwood

BASF Ultra-Cool® metal roof coatings

Concord Cream 872T4 67.3 (60.4)	Slate Gray 870D3 39 (19.6)	Evergreen 870G4 29.4 (12.5)
Rawhide 872T6 57 (47)	Bright Red 872R5 38.5 (38.5)	Hartford Green 872G3 28.3 (10.8)
Sierra Tan 870T7 53.6 (37.6)	Brick Red 872R6 36.6 (24.7)	Teal 872G4 28.1 (24.8)
Pearl Gray 872D4 48.7 (31.5)	Medium Bronze 872T10 34.6 (12)	Regal Blue 872B4 27.5 (19.6)
Marine Green 870G2 41 (31.9)	Slate Blue 872B6 34.4 (21.3)	Charcoal Gray 872D2 27.4 (14.2)
Patina Green 872G5 41 (29.2)	Slate Bronze 870T5 30.6 (9.6)	Dark Bronze 872T9 26.6 (8)

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MCA Clay Tile cool colored tiles

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

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Next steps: Cool Colors Phase II (2006)

- Help California utilities develop residential cool roofing programs
- Help manufacturers deploy cool color roofing products
  - Enhance solar reflectance of non-white roofing materials
  - Develop tools to measure solar reflectance in factories (QC)
  - Correlate solar reflectance of shingle to that of its granules
  - Develop industry-consensus energy savings calculator
  - Conduct natural exposure testing in California
  - Test roof assemblies at Oak Ridge National Lab
  - Showcase and evaluate new cool-color roofing materials in southern California

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For more information

Visit the website of the

Cool Colored Roofing Materials Project

http://CoolColors.LBL.gov

A collaboration of

Lawrence Berkeley National Laboratory
Oak Ridge National Laboratory
and
Industry

sponsored by the

California Energy Commission

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