Cool Roofing Technologies

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STEAB Visit to LBNL
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Orthophoto of Sacramento
Under the Canopy Fabric of Sacramento, CA

- Grass
- Roofs
- Pavements
- Others

% of surface area

--- | --- | --- | --- | --- | --- | ---
Cooling roofs by increasing solar reflectance

• A conventional dark roof absorbs most sunlight

• Increasing solar reflectance
  - reduces solar heat gain
  - lowers roof temperature

• High thermal emittance
  - facilitates radiative cooling
  - helps keep roof temperature low

• Lowering roof temperature can reduce
  - building cooling electricity use
  - peak power demand
  - ambient air temperature
Environmental impacts of cooling roofs

• **Benefits**
  - increased human comfort
  - slowed smog formation
  - mitigation of urban heat islands in summer
  - decreased waste from disposal of roofs

• **Penalties**
  - slightly higher wintertime heating energy use
  - degraded wintertime urban air quality
Direct and Indirect Effects of Light-Colored Surfaces

• **Direct Effect**
  - Light-colored roofs reflect solar radiation, reduce air-conditioning use

• **Indirect Effect**
  - Light-colored surfaces in a neighborhood alter surface energy balance; result in lower ambient temperature
Methodology: Energy and Air-Quality Analysis

Strategies:
- Cooler Roofs
- Shade Trees
- Cooler Pavements
- All Vegetation

Processes:
- Reduces A/C Use
- Reduces Demand at Power Plants
- Area Sources Emit Less
- Slows Reaction Rates

Results:
- Less Energy Consumed
- Lower CO₂, NOₓ, and VOC Levels
- Lower Ozone Levels
White Roofs: Measured Cooling Savings

• **Sacramento**: 80% in a house; 35% in two school bungalows
• **Florida**: 10%-43% in several houses, average 19%
• **California and Florida**: 5%–20% in several commercial buildings
Potential National Savings from Changing Roof Reflectivity
Peak Demand Savings in All U.S.

- Los Angeles: $37M
- Phoenix: $35M
- Dallas/Ft. Worth: $27M
- Houston: $20M
- New Orleans: $16M
- Atlanta: $9M
- Chicago: $10M
- Miami/Ft. Lauderdale: $8M
- New York: $3M
- Philadelphia: $27M
- DC/Baltimore: $20M
“Cool” products for low-sloped roofs

• Many materials available
  - coating (white)
  - single-ply membrane (white)
  - painted metal (white, cool colored)

• Products are rated by the Cool Roof Rating Council (CRRC)
  - labels solar reflectance, thermal emittance
  - website: www.coolroofs.org
Cool Roofing Materials Availability
High-Sloped Roofs

- **Limited but expanding material availability**
  - Tile (several manufacturers)
  - Coatings (one manufacturer)
  - Metal (many manufacturers)
  - Shake (only for custom application)
  - Shingles (one manufacturer)

- **Over 70% of high-sloped roofs use hot asphalt shingles**
ISP/LBNL Shingle With Whiter Roofing Granules

Reflecting Solar Heat

- Black Shingle: R = 5%, T = 180 °F
- Conventional White Shingle: R = 29%, T = 157 °F
- Advanced White Shingle: R = 60%, T = 128 °F
White is ‘cool’ in Bermuda
and in Santorini, Greece
Cool Roof Technologies

**Old**
- flat, white

**New**
- pitched, cool & colored

- pitched, white
Cool Colors Reflect Invisible Near-Infrared Sunlight

Solar Energy Distribution
- 5% ultraviolet (300-400 nm)
- 43% visible (400-700 nm)
- 52% near-infrared (700-2500 nm)
Cool and Standard Brown Metal Roofing Panels

- Solar reflectance ~ 0.2 higher
- Afternoon surface temperature ~ 10°C lower
Example: Dioxazine Purple Over Various Undercoats

- Two-layer system
  - top coat: thin layer of dioxazine purple (14-27 µm)
  - undercoat or substrate:
    - aluminum foil (~ 25 µm)
    - opaque white paint (~1000 µm)
    - non-opaque white paint (~ 25 µm)
    - opaque black paint (~ 25 µm)
Dioxazine Purple Reflectances

- Over aluminum: $R_{\text{solar}} = 0.41$
- Over opaque white: $R_{\text{solar}} = 0.42$
- Over non-opaque white: $R_{\text{solar}} = 0.30$
- Over opaque black: $R_{\text{solar}} = 0.05$
National Labs and Industrial Partnership

- Program is sponsored by CEC/PIER
- ORNL and LBNL are teaming with industry
- Broad industrial partnership

Industry partners
- 3M (granules)
- American Roof Tile Coating
- BASF (metal)
- Custom-Bilt Metals
- Elk Manufacturing (shingles)
- Ferro
- GAF (shingles)
- Hanson Roof Tile
- ISP Minerals (granules)
- MCA (tiles)
- Monier Lifetile (tile)
- Shepherd Color Company
Cool and Standard Color-Matched Concrete Tiles

- Can increase solar reflectance by up to 0.5
- Gain greatest for dark colors
Increasing solar reflectance of fiberglass asphalt shingles: prototypes

**cooler:** $\rho=0.28$

**warmer:** $\rho=0.23$

$\rho = \text{solar reflectance}$
Increasing solar reflectance of fiberglass asphalt shingles: Elk Prestique® Cool Color Series
Increasing solar reflectance of metal roofing: BASF Ultra-Cool® metal roof coatings

<table>
<thead>
<tr>
<th>Color Name</th>
<th>Code</th>
<th>Solar Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concord Cream 872T4</td>
<td>872T4</td>
<td>67.8 (66.4)</td>
</tr>
<tr>
<td>Slate Gray 870D3</td>
<td>870D3</td>
<td>39 (19.6)</td>
</tr>
<tr>
<td>Evergreen 870G4</td>
<td>870G4</td>
<td>29.4 (12.5)</td>
</tr>
<tr>
<td>Rawhide 872T6</td>
<td>872T6</td>
<td>57 (47)</td>
</tr>
<tr>
<td>Bright Red 872R5</td>
<td>872R5</td>
<td>38.5 (38.5)</td>
</tr>
<tr>
<td>Hartford Green 872G3</td>
<td>872G3</td>
<td>28.3 (10.8)</td>
</tr>
<tr>
<td>Sierra Tan 870T7</td>
<td>870T7</td>
<td>53.6 (37.6)</td>
</tr>
<tr>
<td>Brick Red 872R6</td>
<td>872R6</td>
<td>36.6 (24.7)</td>
</tr>
<tr>
<td>Teal 872G4</td>
<td>872G4</td>
<td>26.1 (24.8)</td>
</tr>
<tr>
<td>Pearl Gray 872D4</td>
<td>872D4</td>
<td>48.7 (31.5)</td>
</tr>
<tr>
<td>Medium Bronze 872T10</td>
<td>872T10</td>
<td>34.6 (12)</td>
</tr>
<tr>
<td>Regal Blue 872B4</td>
<td>872B4</td>
<td>27.5 (19.8)</td>
</tr>
<tr>
<td>Marine Green 870G2</td>
<td>870G2</td>
<td>41 (31.9)</td>
</tr>
<tr>
<td>Slate Blue 872B6</td>
<td>872B6</td>
<td>34.4 (21.3)</td>
</tr>
<tr>
<td>Charcoal Gray 872D2</td>
<td>872D2</td>
<td>27.4 (14.2)</td>
</tr>
<tr>
<td>Patina Green 872G5</td>
<td>872G5</td>
<td>41 (29.2)</td>
</tr>
<tr>
<td>Slate Bronze 870T5</td>
<td>870T5</td>
<td>30.6 (9.6)</td>
</tr>
<tr>
<td>Dark Bronze 872T9</td>
<td>872T9</td>
<td>26.6 (8)</td>
</tr>
</tbody>
</table>

Numbers denote solar reflectances: cooler (warmer)
Cool Metal Roofs
Increasing solar reflectance of clay tiles: MCA Clay Tile cool colored tiles

<table>
<thead>
<tr>
<th>Model</th>
<th>Color</th>
<th>Initial solar reflectance</th>
<th>Solar reflectance after 3 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathered Green Blend</td>
<td></td>
<td>0.43</td>
<td>0.49</td>
</tr>
<tr>
<td>Natural Red</td>
<td></td>
<td>0.43</td>
<td>0.38</td>
</tr>
<tr>
<td>Brick Red</td>
<td></td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>White Buff</td>
<td></td>
<td>0.68</td>
<td>0.56</td>
</tr>
<tr>
<td>Tobacco</td>
<td></td>
<td>0.43</td>
<td>0.41</td>
</tr>
</tbody>
</table>
Non-residential building energy and equipment savings: 15-year net present value of savings ($/1000 ft²)
30-year net present value of savings ($/1000 ft²): concrete tile roofs

<table>
<thead>
<tr>
<th>California Climate Zone</th>
<th>Equip</th>
<th>Energy</th>
<th>Total Savings [Equipment + 30-Year NPV Energy] ($/1000 ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>406</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
<td>917</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>726</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>56</td>
<td>992</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>42</td>
<td>781</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>58</td>
<td>1,593</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>39</td>
<td>1,432</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>71</td>
<td>1,822</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
<td>1,862</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>1,390</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>64</td>
<td>1,190</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>55</td>
<td>1,109</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>68</td>
<td>1,355</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>66</td>
<td>1,477</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>66</td>
<td>1,900</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>60</td>
<td>791</td>
<td>100</td>
</tr>
</tbody>
</table>

- Equip: Equipment cost
- Energy: Energy savings
- $0.10/ft²: Cost of energy savings

Note: Total savings include both equipment and 30-year NPV energy savings.
30-year net present value of savings ($/1000 ft²): **metal roofs**

![Graph showing total savings for different California Climate Zones](image)

- **Total Savings [Equipment + 30-Year NPV Energy] ($/1000 ft²)**
  - **Equip**: 41, 57, 41, 61, 47, 57, 48, 83, 88, 65, 71, 60, 73, 72, 71, 65
  - **Energy**: 495, 1,053, 847, 1,128, 919, 1,162, 1,621, 2,141, 2,181, 1,561, 1,330, 1,243, 1,507, 1,648, 2,093, 918
  - **$0.10/ft²**: 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100
Cool Roofs Standards

• Building standards for reflective roofs
  - American Society of Heating and Air-conditioning Engineers (ASHRAE): New commercial and residential buildings
  - Many state: California, Georgia, Florida, Hawaii, …

• Air quality standards
  - South Coast AQMD
  - S.F. Bay Area AQMD
  - EPA’s SIP (State Implementation Plans)
White Roofs Programs in California

• One Time CEC Incentive -- $20 Million
  ➢ at $0.15 to $0.20 per square foot
• California utilities incentives
• 2001 to 2005-- credits white and cool colored roofs
• 2005 requires cool flat roofs
• 2008 may require cool roofs for all buildings
Cool Roof Programs around the World

- U.S.
- Europe
- Asia
- Middle East
- China
- India (Hyderabad demos; see graphs; funded by U.S.AID)
Cool Roofs to Save CO2
Cool Surfaces also Cool the Globe

- Cool roof standards are designed to reduce a/c demand, save money, and save emissions. In Los Angeles they will eventually save ~$100,000 per hour.
- Annual savings in the U.S. = $1-2B; ~ 7 M tons CO$_2$
- Annual savings in the world = $10-15B; ~ 100 M tons CO$_2$
- But higher albedo surfaces (roofs and pavements) directly cool the world (0.01 K) quite independent of avoided CO$_2$. So we discuss the effect of cool surfaces for tropical, temperate cities.
100 Largest Cities have 670 M People

- Mean = 560 m²/p
- Med = 430 m²/p

- Tokyo
- Mexico City
- New York City
- Mumbai
- São Paulo

Population (M)

Area Density (m²/person)
Dense Urban Areas are 1% of Land

- Area of the Earth = $511 \times 10^{12}$ m$^2$
- Land Area (29%) = $148 \times 10^{12}$ m$^2$ [1]
- Area of the 100 largest cities = $0.38 \times 10^{12}$ m$^2$ = 0.26% of Land Area for 670 M people
- Assuming 3B live in urban area, urban areas = $[3000/670] \times 0.26\% = 1.2\%$ of land
- But smaller cities have lower population density, hence, urban areas = 2% of land
- Dense, developed urban areas only 1% of land [2]
Potentials to Increase Urban Albedo is 0.1

- Typical urban area is 25% roof and 35% paved surfaces
- Roof albedo can increase by 0.25 for a net change of 0.25x0.25=0.063
- Paved surfaces albedo can increase by 0.15 for a net change of 0.35x0.15=0.052
- Net urban area albedo change at least 0.10
Effect of Increasing Urban Albedo by 0.1

- Net Change in Global albedo
  \[ \text{Net Change in Global albedo} = \text{[City/Land]} \times \text{[Land/Globe]} \times \Delta a = 2 \times 1 \times \Delta a \]
  \[ = 0.01 \times 0.29 \times 0.1 = 0.0003 \]

- The effect on global temperature
  - Using three different calculations is about 0.01K
Carbon Equivalency

- Modelers estimate a warming of 2K in 60 years, so 0.03K/year
- Change of 0.1 in urban albedo will result in 0.01K, a delay of ~0.3 years in global warming
- World’s current rate of CO$_2$ emissions = 25 G tons/year (4.1 tons/year per person)
- World’s rate of CO$_2$ emissions averaged over next 60 years = 40 G tons/year
- Hence 0.3 years delay is worth 12 Gt CO$_2$; ~ 200 Mt CO$_2$/year
Equivalent Value of Avoided CO$_2$

• CO$_2$ currently trade at ~$10/ton
• 12Gt worth $120 billion, for changing albedo of roofs and paved surface
• Cooler roofs alone worth $60B
• Cooler roofs also save air conditioning (and provide comfort) worth over $6,00B - $900B over 60 years; 100 Mt CO$_2$/year
• We would like to start an international organization where the developed countries offer $1 million per large city in a developing country, to trigger a cool roof/pavement program in that city
Market Deployment of Cool Color Cars

- Toyota experiment (surface temperature 10 °C cooler with cool coatings.)
- Ford is also working on a similar technology.
## Effect of A/C on fuel consumption

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Vehicles ((10^6))</td>
<td>213</td>
<td>26</td>
</tr>
<tr>
<td>Miles/year/car ((10^3))</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Fuel Eff [mpg]</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Annual fuel use ([10^9]\text{gal})</td>
<td>130</td>
<td>15</td>
</tr>
<tr>
<td>Annual fuel expense at 2.5 $/gal ([$B])</td>
<td>230</td>
<td>38</td>
</tr>
<tr>
<td>Reduced efficiency due to A/C</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>% time AC runs</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>A/C contribution to fuel use ([10^9]\text{gal})</td>
<td>9.6</td>
<td>1.2</td>
</tr>
<tr>
<td>A/C contribution to fuel expense ([$B])</td>
<td>24</td>
<td>3</td>
</tr>
</tbody>
</table>
### Benefits of 2.8K (5°F) reduction in soak temperature

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in AC capacity</td>
<td>11%</td>
<td>11%</td>
</tr>
<tr>
<td>Improvement in mpg</td>
<td>1.8%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Reduced NOx emission</td>
<td>4.5%</td>
<td>4.5%</td>
</tr>
<tr>
<td>Reduced fuel expense ($M)</td>
<td>2876</td>
<td>346</td>
</tr>
<tr>
<td>Reduced CO emission (tonne/day)</td>
<td>978</td>
<td>117.8</td>
</tr>
<tr>
<td>Reduced NOx emission (tonne/day)</td>
<td>103</td>
<td>12.4</td>
</tr>
<tr>
<td>Reduced NMHC emission (tonne/day)</td>
<td>18</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Practical Guidelines

- EPA Guidebook (1992)
  - Good practical information
  - Greatest focus on trees

- EPA is working on a new edition