Cool Roofs:
From Cool Cities to a Cooler World

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or just Google “Art Rosenfeld”
Santorini, Greece
White is ‘cool’ in Bermuda
and in Hyderabad, India

...and widely in the State of Gujarat, India
Reflective roofs have lower temperatures in sunlight

![Graph showing temperature rise vs. solar absorptance for various materials.](image)
Global Cooling: Increasing World-wide Urban Albedos to Offset CO₂

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A first step in geo-engineering which saves money and has known positive environmental consequences
Solar Reflective Surfaces Also Cool the Globe

Source: IPCC
Methodology

• Changing albedo of urban surfaces and changing atmospheric CO$_2$ concentrations both result in a change in radiative forcing.

• Comparing these two radiative forcings relates changes in solar reflectance of urban surfaces to the changes in atmospheric CO$_2$ content.
Caveats

• Time dependence of physical effects (e.g., sequestration in land or ocean) and economics are ignored.
• We account for the effect of multiple scattering and absorption of radiation within the atmosphere.
• Calculations are performed for the entire globe
Radiation Forcing of 2XCO$_2$

- Hansen et al (2005) estimate a 2XCO$_2$ radiation forcing (RF) on the top of the atmosphere of 3.95±0.11 W/m$^2$, yielding a RF of 0.93±0.03 kW/tonne of atmospheric CO$_2$
- IPPC [based on Myhre (1998) formula] estimate a RF of 3.71 W/m$^2$, yielding a RF of 0.88-0.91 kW/tonne of atmospheric CO$_2$
- Matthews and Caldeira (2008) found a 0.175 K temperature increase for every 100 GtC emitted, yielding a 0.47 kW/tonne of atmospheric CO$_2$
- We use a RF of 0.91 kW/tonne of atmospheric CO$_2$
Radiation Forcing of Cool Surfaces

- Hansen et al. (1997) estimate a RF of -3.70 Wm\(^{-2}\) for increasing the albedo of 'Tropicana' by 0.2. We estimate that Tropicana is 22% of the land area or about 1/16\(^{th}\) of the global surface. For the reflected surfaces, the RF per 0.01 increase in albedo is -2.92 W per m\(^2\) of Tropicana land.

- Using Kiehl and Trenberth (1997) and Hatzianastassiou et al. (2005), we calculate a RF of -1.27 W/m\(^2\) per 0.01 increase in albedo of modified surfaces.

- Note that our calculations apply for the average cloud cover over the earth; we estimate higher RF for CA
CO$_2$-Equalence of Reflective Surfaces

- RF of increasing atmospheric CO$_2$ = 0.91 kW/tonne = 0.91 W/kg
- RF of increasing solar reflectance of a surface by 0.01 = -1.27 W/m$^2$
- Atmospheric CO$_2$-equalence of increasing solar reflectance of a surface by 0.01 = -1.27 [W/m$^2$]/0.91 [W/kg] = -1.40 kg/m$^2$
- IPCC (2007) estimates that only 55% of the emitted CO$_2$ stays in the atmosphere
- Emitted CO$_2$-equalence of increasing solar reflectance of a surface by 0.01 = -1.40 [kg/m$^2$]/0.55 = -2.5 kg CO$_2$ per m$^2$
CO₂ Offset of Cool Roofs and Cool Pavements

- Δ albedo for aged white roofs = 0.40
- Emitted CO₂ offset for white roofs
  \[ = \frac{0.40}{0.01} \times [-2.5 \text{ kg CO}_2/\text{m}^2] = -100 \text{ kg CO}_2/\text{m}^2 \]
- It takes about 10 m² of roof with albedo increase of 0.40 to offset 1 T CO₂ emitted
- Δ albedo for typical residential and non-residential cool roofs = 0.25
- Emitted CO₂ offset for cool roofs
  \[ = \frac{0.25}{0.01} \times [-2.5 \text{ kg CO}_2/\text{m}^2] = -63 \text{ kg CO}_2/\text{m}^2 \]
- Δ albedo for cool pavement = 0.15
- Emitted CO₂ offset for cool pavements = -38 kg CO₂/m²
Dense Urban Areas are 1% of Land

- Area of the Earth = $508 \times 10^{12}$ m$^2$
- Land Area (29%) = $147 \times 10^{12}$ m$^2$ [3]
- 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 = $3 \times 10^{12}$ m$^2$ [4]
- Dense, developed urban areas only 1% of land = $1.5 \times 10^{12}$ m$^2$ [5]
CO₂ Equivalency of Cool Roofs and Pavements

• Typical urban area is 25% roof and 35% paved surfaces
• Roof area = 0.25*1.5x10^{12} m² = 3.8x10^{11} m²
• Emitted CO₂ offset for cool roofs
  = 63 kg CO₂/m² * 3.8x10^{11} m² = 24 GT CO₂

• Paved area = 0.35 *1.5x10^{12} m² = 5.3x10^{11} m²
• Emitted CO₂ offset for cool pavements
  = 38 kg CO₂/m² *5.3x10^{11} m² = 20 GT CO₂
• Total emitted CO₂ offset for cool roofs and cool pavements = 44 GT CO₂
CO$_2$ Equivalency of Cool Roofs and Pavements (cntd.)

- 44 GT CO$_2$ is over one year of the world 2025 emission of 37 GT CO$_2$
- At a growth rate of 1.5% in the world’s CO$_2$ -equivalent emission rate, 44 GT CO$_2$ would offset the effect of the growth in CO$_2$- equivalent emissions for 11 years
CO₂ Equivalency of Cool Roofs World-wide
(Tropics + Temperate)

• Cool roofs alone could offset a total of
  24 billion tons (Gt) CO₂ = world emissions this year !!!!
• Worth > €240 billion (pre-recession was €600B)
• To convert 24 Gt CO₂ one-time into a rate:
  – Assume 20 year roof service life, thus 1.2 Gt CO₂/year
  – Average world car emits 4 t CO₂/year

  equivalent to 300 million cars
  off the road for 20 years

(600 million passenger cars in the world today)
100m$^2$ (~1000 ft$^2$) of a white roof, replacing a dark roof, offset the emission of 10 tonnes of CO$_2$
How to Relate to 10 Tons of CO$_2$

- First – This is **10 tons ONCE**, not 10 tons/year;
- But familiar measures are usually in terms of **tons/year**;
- So we will look at how many **years of emissions** 10 tons will offset

<table>
<thead>
<tr>
<th></th>
<th>Tons CO$_2$/Yr</th>
<th>Years Equivalent to 10 Tons</th>
</tr>
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<tbody>
<tr>
<td>Average US House Emits</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Average US Car Emits</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Average Global Car Emits</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>Average CFL <strong>Saves</strong></td>
<td>.05=1/20</td>
<td>200</td>
</tr>
</tbody>
</table>
Effect of Solar Reflective Roofs and Pavements in Cooling the Globe
(Source: Akbari, Menon, Rosenfeld. *Climatic Change*, 2009)

<table>
<thead>
<tr>
<th></th>
<th>Δ Solar Reflectivity</th>
<th>CO₂ Offset by 100 m²</th>
<th>CO₂ Offset Globally</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Roof</td>
<td>0.40</td>
<td>10 tons**</td>
<td></td>
</tr>
<tr>
<td>Average Roof</td>
<td>0.25</td>
<td>6.3 tons</td>
<td>24 Gt ***</td>
</tr>
<tr>
<td>Cool Pavement</td>
<td>0.15</td>
<td>4 tons</td>
<td>20 Gt</td>
</tr>
<tr>
<td>Total Potential</td>
<td></td>
<td></td>
<td>44 Gt</td>
</tr>
</tbody>
</table>

Value of 44 Gt CO₂ at $25/t ~ $1 Trillion

*White Roof will be “diluted” by cool colored roofs of lower reflectivity, and roofs that can not be changed, because they are long-lived tile, or perhaps they are already white.

** Compare 10 tons with a family car, which emits ~4 tons/year.

*** 24 Gt CO₂ Offsets Global CO₂ emissions in 2009
• Comparison of CO2 offset directly by albedo vs. CO2 reduced by AB 32

• Albedo reduction based on a plausible 15-year program for white and cool roofs (Title 24 for new buildings and major retrofits) and a yet to be developed program for cool pavements
Cool Roof Technologies

Old

- flat, white
- pitched, white

New

- pitched, cool & colored
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
Cool is cool: From cool color roofs to cool color cars and jackets

Toyota experiment (surface temperature 10K cooler)
Ford is also working on the technology

Courtesy: BMW (http://www.ips-innovations.com/solar_reflective_clothing.htm)
Many cool colors to choose

- **Cool clay tile**
  - R ≥ 0.40
  - Courtesy MCA Clay Tile

- **Cool metal**
  - R ≥ 0.30
  - Courtesy BASF Industrial Coatings

- **Cool concrete tile**
  - R = 0.41
  - Standard concrete tile (same color)
    - Courtesy American Rooftile Coatings

- **Cool fiberglass asphalt shingle**
  - R ≥ 0.25
  - Courtesy Elk Corporation

**Solar reflectance gain:**

- cool clay tile: +0.37
- cool metal: +0.26
- cool concrete tile: +0.23
- standard concrete tile: +0.15
- cool fiberglass asphalt shingle: +0.29
Pavements can also be cool