COOL ROOFS COOL THE PLANET

There's an important, although little-known, advantage to cool roofs: They help cool the planet.

BY TINA KAARSBERG AND HASHEM AKBARI

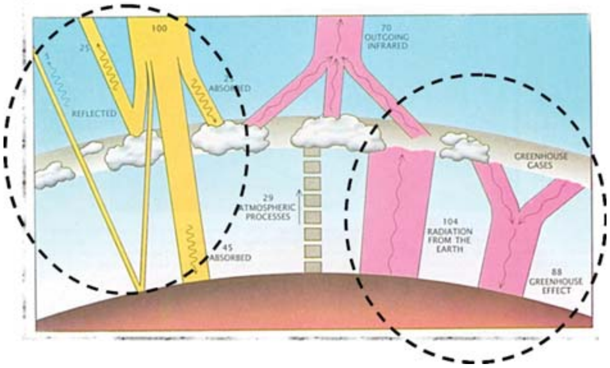
The Summer 2006 heat wave resulted in dramatic increases in both A/C electric bills and homeowners' interest in cool roofs. As *Home Energy* readers know, cool roofs can reduce A/C use by up to 20% and improve a home's comfort in the event of a power loss (see "Cool Colored Roofs," *HE* March/April '06, p. 12). This article focuses on a lesser known cool roof benefit—their contribution to the Earth's albedo or reflectivity. Approaches such as cool roofs that instantly reduce global warming may well turn out to be a critical tool in countering the risk of abrupt climate change.

Albedo Basics

Albedo—a term to make a climatologist's heart race—characterizes how a surface reflects light (see "The Physics of Cool-Colored Roofing Materials"). We define albedo as a number between 1 and 0 that indicates the fraction of incident radiation, including the invisible ultraviolet and near-infrared parts of the spectrum, that is reflected. Planet Earth now has an average albedo of 0.3—that is, it reflects about 30% of the sunlight that lands on it (see Figure 1). There is great potential in the United States and worldwide for cool roofs. Currently more than 90% of the roofs in the United States are dark colored, with an average albedo of approximately 0.15.

The higher albedo of a cool roof instantly reduces the amount of heat that can be trapped by the Earth's greenhouse gases (GHGs). This instant cooling contrasts with the cooling time frame of the prevailing climate technology strategy of reducing GHG emissions. The very best that a GHG emissions reduction strategy can achieve in a human lifetime is to flatten the rate of increase in global warming, as we explain below. Since the cooling caused by an increase in land surface albedo is immediate, it is more accurate to describe it as a delay in the GHG-caused warming than it is to describe it in terms of carbon equivalent—the more typical metric for climate technologies.

The Earth's Radiation Budget



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Figure 1. The Earth, on average, reflects 30% of incoming radiation (that is, it has an albedo of 0.3), and the Earth's surface absorbs 45% of incoming sunlight. The left oval shows the average reflection and absorption of sunlight that strikes the Earth. The Earth later reemits the radiation, but at a much longer wavelength. The right oval shows the Earth's emissions of this far infrared energy and the greenhouse gases' absorption, reemission, and partial trapping of the infrared radiation—the 'greenhouse effect'.

Greenhouse Gas 101

To fully appreciate the difference between GHG reduction and land surface albedo strategies to counter global warming, it helps to understand how GHGs cause global warming. GHGs are almost transparent to incoming radiation, which is mostly visible and near infrared (see Figure 1). But when the Earth absorbs radiation, it reemits it at a much lower frequency—the far infrared (see the pink arrows in Figure 1). Since reflected radiation from cool roofs is still in the visible spectrum and therefore doesn't get absorbed by GHGs, preventing the Earth's surface from absorbing sunlight prevents a portion of the greenhouse effect from taking place.

Increasing albedo counters human-caused (anthropogenic) global warming so much faster than GHG reduction because the root cause of GHG-induced global warming is not the gases themselves, but the radiative forcing that they cause. Forcing is defined as the amount by which the world's thermal radiation balance—in units of watts per square meter (W/m^2)—is imbalanced. Global warming is the positive forcing caused by CO_2 and other GHGs. But GHGs are not the only anthropogenic form of radiative forcing. Figure 2 shows three important anthropogenic radiative forcings and the uncertainty with which they are known. Leftmost and best measured is the positive forcing due to well-mixed greenhouse gases. The middle and the right bars show the more uncertain, but negative radiative forcing due to changes in the atmospheric and land-surface albedo. For simplicity, Figure 2 does not show all forcings or the effect of ocean heat storage on radiative forcing. If these are included, the net forcing—the amount by which the Earth's energy is imbalanced—is about 0.9 W/m².

The net cooling from anthropogenic land surface albedo changes is by far the smallest bar in Figure 2. It is caused by changes in land use, such as converting forest to cropland or deserts. If future human changes to the landscape—including pavement and roofs—were deliberately made with higher albedo, the potential impact would be proportionately greater. This is because the majority of the Earth's human population now lives in cities below 45° latitude, where the direct-cooling benefits of cool roofs are the greatest.

Latitude and Solar Intensity

Solar intensity varies with changes in latitude and the Earth's orbit over the course of a year (see Figure 3). While atmospheric absorption, clouds, surface albedo, and mountains also affect solar intensity, latitude and orbit have a large and relatively unchanging effect. Incoming sunlight is most intense at the equator (0° latitude). Everywhere else, the incoming sunlight strikes the Earth's surface at an angle, spreading the energy out over a larger surface area and reducing the intensity of the radiation. At the poles, averaged over the year, solar intensity is about half that at the midlatitudes. That's why polar snowmelt—a dangerous positive albedo feedback in the Earth's climate—has a lower-than-average impact on the Earth's albedo, although the local effects are quite dramatic. Earth's human population is centered at about 30° latitude, where albedo changes can have a proportionately greater-than-average impact on the Earth's overall albedo.

The Global Benefits

Recently Hashem Akbari and Art Rosenfeld, of the California Energy Commission, estimated the global cooling impact of cool roofs in just the largest cities (1% of land) on Earth. These urban areas consist of about 25% roof and 35% paved surfaces. Based on their experience in California, Akbari and his collaborators assume that the albedo of roofs and pavements can be cost-effectively increased by 0.25 and 0.15 respectively for a net urban area albedo change of at least 0.1. They estimated the effect of such an albedo change on global warming, using simplified climate models, published global climate model (GCM) simulations, and their own simulations. While the local cooling due to modest cost-effective changes is dramatic (approximately -5°F), the global cooling is less impressive, averaging only 0.02°F, or a three-month delay in the warming due to current world emissions. Even this small global temperature change is equivalent to a reduction in emissions of 10 billion metric tons of CO_2, or a little more than one year of today's U.S. carbon emissions.

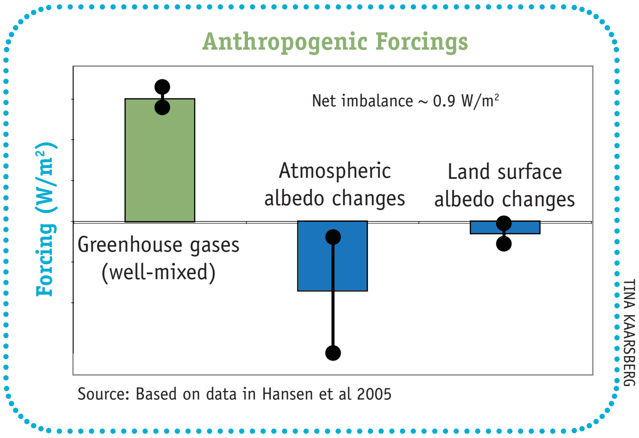


Figure 2. Forcing is defined as the amount by which the world's thermal radiation balance—in units of watts per square meter (W/m²)—is imbalanced. Global warming is the positive forcing caused by CO_2 and other GHGs.

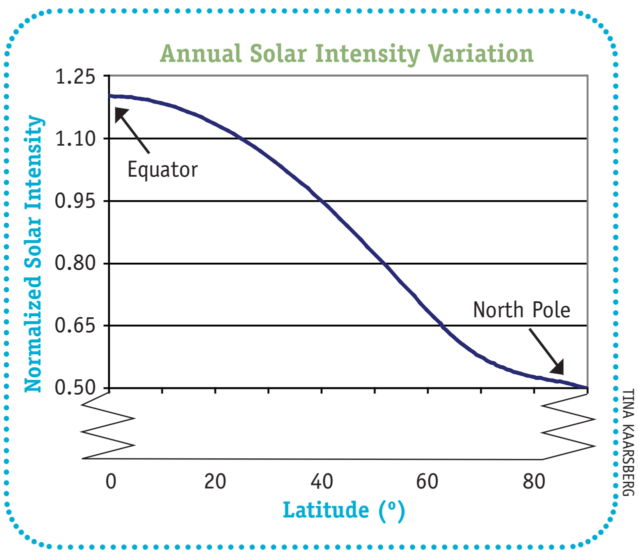


Figure 3. The average annual solar intensity varies with latitude (normalized to 90° = 0.5).

Robert Hamway of the Centre for Economic and Ecological Studies in Geneva, Switzerland, recently conducted another estimate of the impact of raising earth's surface albedo. His analysis differs from that described above in that he includes all human controlled surfaces, not just those in the largest cities, and he assumes a somewhat larger albedo increase in these areas (up to a = 0.3). His very preliminary estimates are derived using a static two-dimensional model without all the features of a full-blown GCM. He estimates a globally averaged change in radiative forcing of -0.17 W/m², or a delay of about six years in global warming. Note that the current total radiative imbalance of the Earth is approximately 0.9 W/m², so a decrease in forcing of this magnitude would decrease the net positive forcing by nearly 20%.

What Next?

So while cool roofs aren't the complete solution to global warming, they can buy us critical time if we are near a threshold of an abrupt climate change. And cool roofs can save money that can be applied to other climate solutions. In California, the electricity, environmental, health, comfort, and overall energy benefits were enough to result in a code requirement for roofs. The cool roofs criteria and standards are now incorporated into the most recent California Title 24 building code. But before we encourage codes requiring high albedo for *all* human controlled surfaces worldwide, we need

The Physics of Cool-Colored Roofing Materials

Most people understand why white roofs reflect sunlight, but how are dark-colored "cool" shingles able to reflect so much more than their uncool conventional counterparts? And why are shiny metal roofs so hot? The key to understanding these conundrums is to know that less than half of the solar power in the sunlight is in the visible part of the spectrum. The invisible near-infrared (NIR) part of the sunlight spectrum bears more than half of the power in sunlight (see Figure A).

Whereas conventional roofs (including metal roofs) tend to absorb this NIR, cool pigments reflect in the NIR. Because they absorb like conventional pigments in the visible, they look the same to us. Conversely, Figure B shows that a galvanized sheet-metal roof—something that you might expect to be shiny and therefore high albedo—actually has a low thermal emmittance and a temperature rise similar to that of a black roof!

Industry researchers have already developed complex inorganic color pigments that are dark in color but highly reflective in the NIR portion of the solar spectrum. Examples of commercially available cool pigments with high NIR reflectance include chromium oxide green, cobalt blue, phthalocyanine blue, and Hansa yellow. To lower cost and increase consumer options, the Cool Team, a U.S. consortium of Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory, and 16 companies that manufacture roofing materials—including shingles, roofing granules, clay tiles, concrete tiles, tile coatings, metal panels, metal coatings, and pigments—are collaborating on improving the manufacture of cool-colored roofing materials. The iterative development of cool-colored materials has included selection of cool pigments, choice of base coats for the two-layer applications, and identification of pigments to avoid. To date, the Cool Team has identified and characterized the optical properties of over 100 pigmented coatings; has created a database of pigment characteristics; and has developed a model to maximize the solar reflectance of roofing materials for a choice of visible color. The application of novel engineering techniques to include NIR-reflective pigments in the manufacture of cool colored roofing materials can lower the costs of producing these materials.

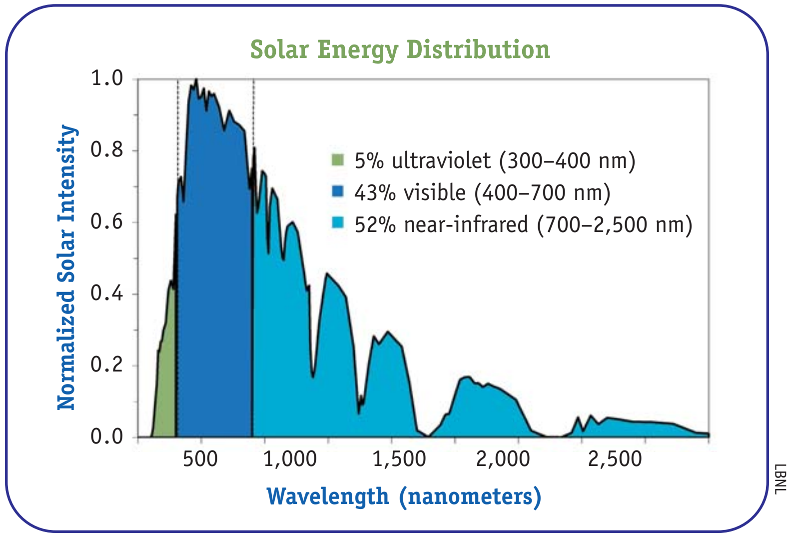


Figure A. The invisible near-infrared (NIR) part of the sunlight spectrum bears more than half of the power in sunlight.

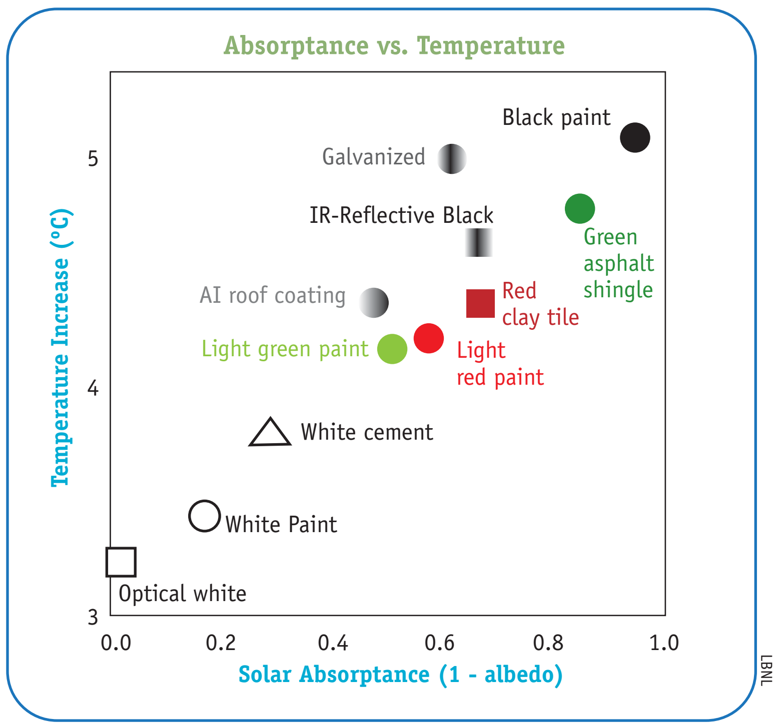


Figure B. Due to the invisible IR part of the solar spectrum shown in Figure A, the albedo of a white colored surface can range from 0.7 (white cement) to nearly 1 (optical white) with corresponding temperature changes. IR-reflective black has the same albedo and only a slightly higher temperature increase than red. And the temperature rise for galvanized steel is nearly as high as that for black paint.

to understand their climate impact—including any potential feedbacks.

In order to set priorities for government and other global warming policy responses, we need to do policy research on cool roof codes and other regulations versus incentives. And we need to better understand cool roof lifecycle costs and benefits, including reductions in peak electricity use, ground level ozone concentrations and related health costs, and the longer life spans of cool materials due to reduced diurnal temperature fluctuation and thus reduced expansion and contraction and degradation. For example, Rosenfeld has recently suggested setting up a fund for cool roof microloans or incentive programs in the rapidly growing megacities of the world and we are working to understand the potential cost and impact of this proposal.

Finally, the technology research needs to continue. Now that cool roof shingles are commercially available, DOE-sponsored research at Lawrence Berkeley National Laboratory and Oak Ridge National Laboratories is developing other cool materials including cooler tiles and panels and cooler paving materials.

Think Globally, Roof Locally

Cool roofs have benefits that extend far beyond the local energy and air pollution benefits. They can also help make most homes more comfortable as the anthropogenic global warming already in the pipeline takes hold. And in addition to the direct increase in albedo, they also reduce global warming risks by reducing fossil fuel use and thus GHG emissions. Homeowners worried about climate change don't need to wait for government action but can experience the benefits of cool roofs while reducing risk for the most vulnerable populations in developing countries and future generations. With such clear advantages and few downsides, increasing the use of cool roofs and pavements ought to be a worldwide initiative.

Tina Kaarsberg serves as senior staff with the Department of Energy's Policy and International Office in Washington, DC. Hashem Akbari is a staff scientist and leader of the Heat Island Group at the Lawrence Berkeley National Laboratory in Berkeley, California.

FOR MORE INFORMATION:

Both EPA and DOE have made efforts to educate consumers on the benefits of cool roofs. To learn more about these efforts, go to www.epa.gov/hiri/strategies/coolroofs.html and www.eere.energy.gov/buildings/news_detail.html/news_id=9926.

For more on cool roofs, go to http://heatisland.lbl.gov.