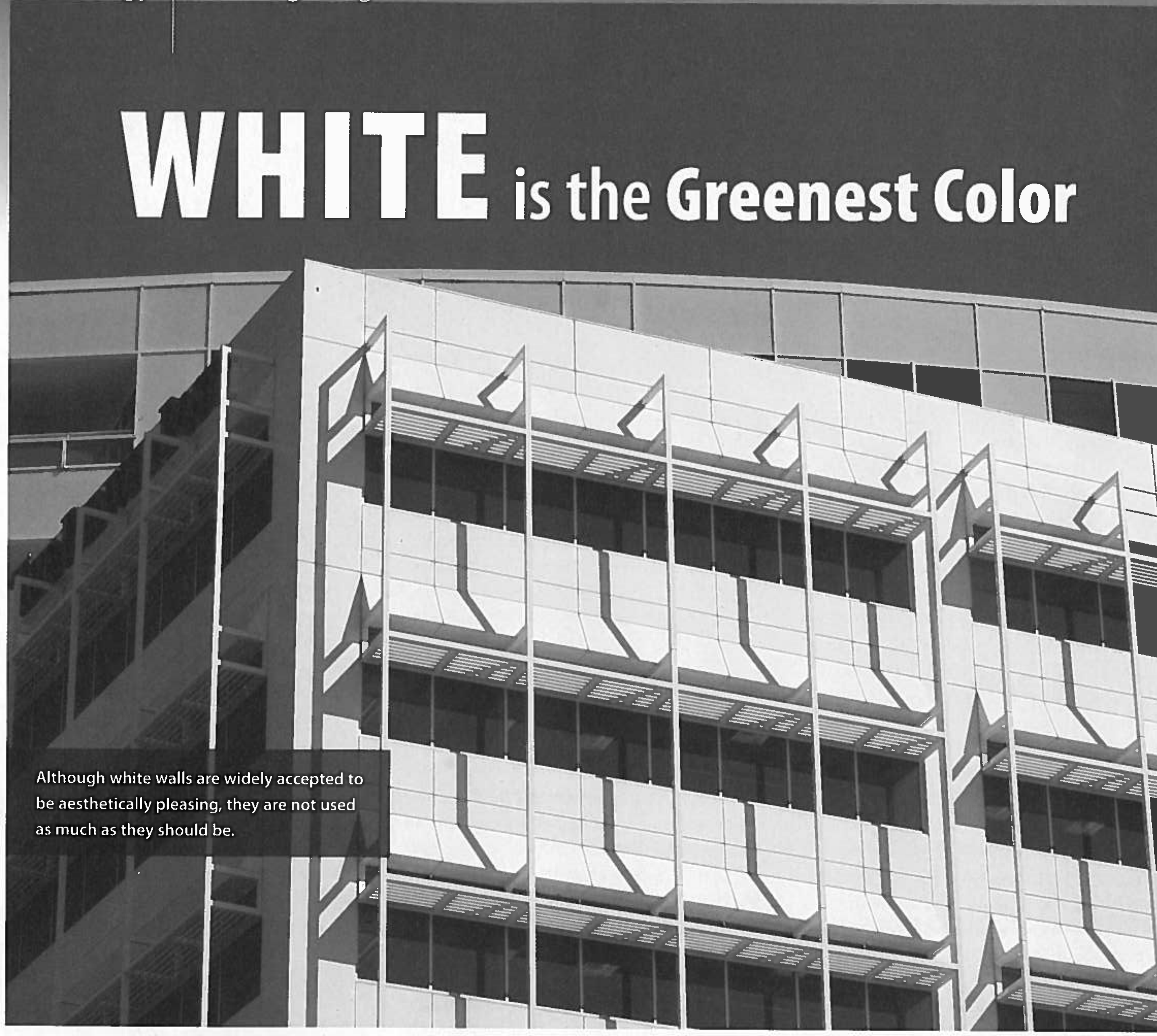
WHITE is the Greenest Color



Although white walls are widely accepted to be aesthetically pleasing, they are not used as much as they should be.

"Rapid deployment of cool materials [white surfaces] represents one of the largest and most cost-effective opportunities we have to counter global warming, improve health and strengthen security."

— U.S. SECRETARY OF ENERGY STEVEN CHU

When it comes to solar-responsive design, perhaps the lowest-hanging fruit is choosing white. Selecting white design elements can save much energy, thereby saving money and helping to save the planet.

White roofs dramatically reduce overheating in both buildings and cities. A white roof will reflect much of the sun's energy back into space, while a black roof absorbs most of the sunlight and turns it into heat. A black roof can get more than 60°F (33°C) hotter than a white roof, significantly heating both the building and the outdoor air. As a result, buildings get heated twice by their black roofs — once directly through the roofs, and secondly by the increased air temperature of the neighborhood. Cities can be as much as 16°F (9°C) warmer than the surrounding rural areas due to the extra absorption of dark roofs and pavements and the lack of trees. This "heat island effect" also increases pollution levels in cities.

White buildings can also reduce the energy required for lighting a building. White ceilings and interior walls make electric lighting more efficient, and white roofs and exterior walls can make daylighting more efficient in urban areas. Because daylight enters windows from the sky, most of the light ends up illuminating only the indoor spaces near the windows. On the other hand, much of the light reflected from white walls and the roofs of lower buildings enters windows from below, thereby illuminating the

Selecting light-colored roofs and walls is one of the easiest ways to save energy and money. So why don't we see more white roofs?

Text and photos by **NORBERT M. LECHNER**

ceiling, which generates better lighting and also sends it farther indoors. White exterior walls also improve nighttime lighting by reflecting, rather than absorbing, street and area lighting.

The heat gain through white roofs is 50 percent less than through black roofs, and the heat gain through white walls is about 35 percent less than through black walls. As a result, the use of white not only reduces the amount of energy required to cool buildings, it also reduces the peak electrical load, which occurs in most of the United States on hot, sunny afternoons. Even buildings without air conditioning benefit greatly, because a white roof will result in a ceiling temperature about 3°F (1.7°C) cooler. That's equivalent to reducing the indoor temperature about 5°F (2.8°C).

But shouldn't roofs be black in cold climates to collect solar radiation? The answer is definitely no in any cold climate that experiences overheating in the summer. Thus, white roofs are best in almost all parts of the United States, southern Canada and most of the world. The reason is the asymmetry of solar geometry. For example, at 40° northern latitude, the sun heats a roof for about 15 hours on June 21, but only about nine hours on Dec. 21 — the solar heater is on for six fewer hours per day in the winter. Also, the low winter sun lights only half of the roof, while the summer sun lights the whole roof most of the day. Furthermore, the wind usually blows more during winter than summer. Thus, a black roof loses most of the heat generated to the cold winter wind. Ironically, white roofs make sense even at higher latitudes, because the daylight hours increase in the summer and decrease in the winter. For example, at 50° northern latitude, there are 16 daylight hours for heating on June 21 and only eight hours on Dec. 21. Thus, white roofs are best in almost all climates.

Black Is Beautiful, But It Absorbs Too Much Heat

Figure 1 shows the solar reflection factor, also known as "albedo," for different surfaces/colors. Keep in mind that the reflectance factor and the absorption factor are two different ways to describe the same phenomenon. Either can tell us how much of the sunlight falling on a surface is absorbed and how much is reflected. Because white has a very high reflectance

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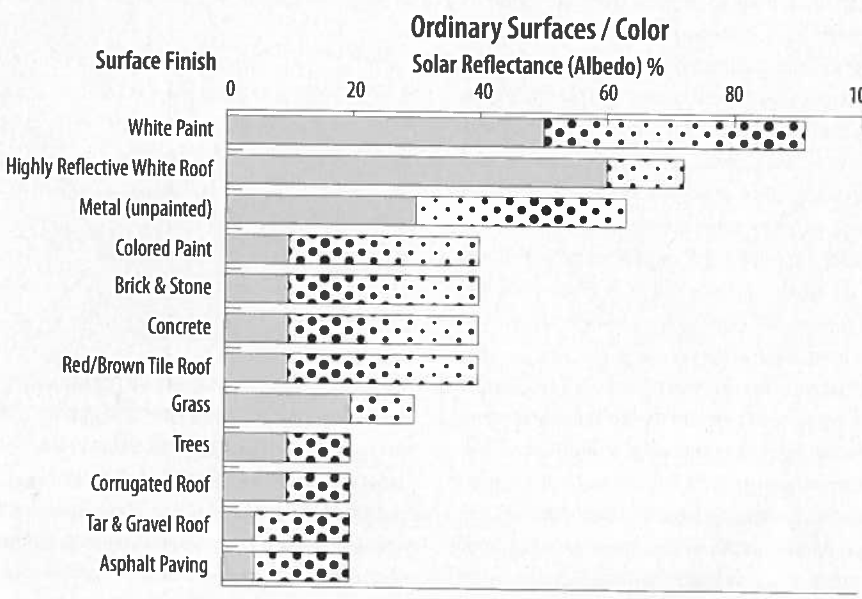
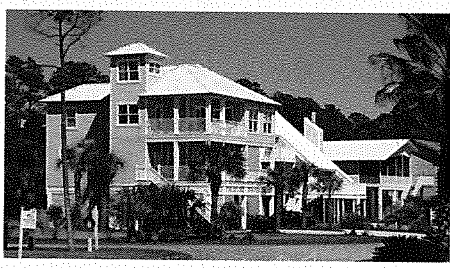


Figure 1. The percent of solar radiation reflected (not absorbed) by a surface or color is described by the solar reflectance factor, also known as albedo. The values are given as ranges because of variations in color and dirtiness. For example, the solar reflectance factor for white can vary from 50 percent to 90 percent.



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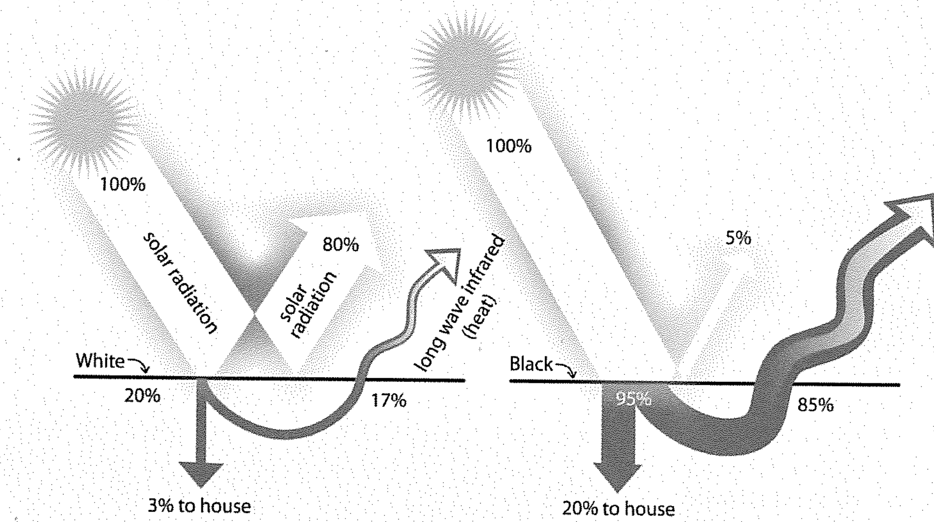


Figure 2. How hot a surface gets in the sun depends not only on its solar reflectance (albedo), but also on its ability to emit long-wave infrared (heat) radiation. A black surface in the sun would be even hotter if it were not able to emit a significant amount of the heat it absorbs.

A white roof can reduce air-conditioning load as much as 20 percent in one-story buildings. It can reduce both the initial and the operating costs of the air-conditioning system.

factor, the absorption factor must be very low, and with black it is the reverse.

Because all objects simultaneously absorb and emit radiant energy, their equilibrium temperatures (i.e., how hot they get when exposed to the sun) are a result of how much is absorbed compared to how much is emitted. Thus, any object exposed to the sun will simultaneously absorb solar radiation and emit long-wave infrared radiation, which our eyes cannot see but our skin can feel as heat. Consequently, an object's equilibrium temperature is not only a function of the solar reflectance factor, but also how well it emits heat radiation (figure 2, above). The rate at which heat is emitted from an object is a result of both its temperature and its physical ability to emit radiation, which is described by its emittance factor. All colors and surfaces have high emittance except for shiny metal surfaces, which have low emittance. Although shiny metal surfaces reflect most of the solar radiation just as white does, they cannot emit heat radiation as well and, therefore, get much hotter in the sun than do white surfaces. Thus, a white roof will have the lowest equilibrium temperature — a white roof is the coolest roof.

Although black is also a good emitter, it absorbs so much more solar radiation than other colors that it has a very high equilibrium temperature. So why are so many sloped roofs dark colored? I have yet to find a clear reason. However, there is a story going around to explain the popularity of black roofs in the U.S. South. Near the end of the Civil War, General Sherman marched his army through the South, burning as many buildings as possible. Believing that the South had not suffered enough, he decreed after the war that all roofs must be black. He wanted Southerners to continue to suffer from unnecessarily hot buildings. Because of tradition, they are still suffering — if not thermal discomfort, then financial discomfort from unnecessarily high summer energy bills. Whatever the reason for dark

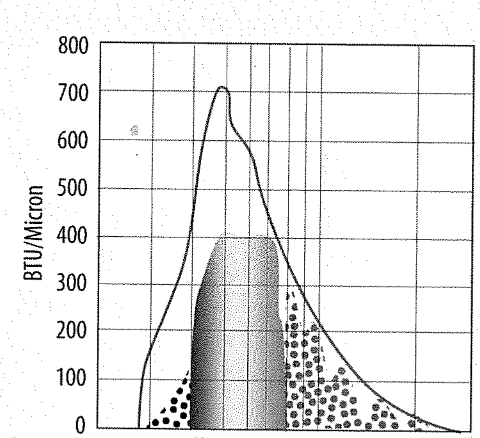
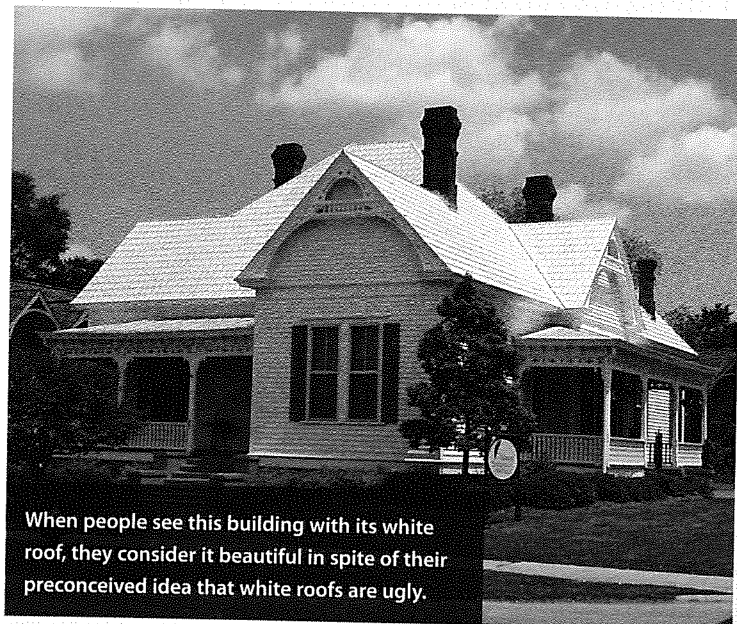


Figure 3. Only about 50 percent of the energy in solar radiation is visible. But surfaces exposed to the sun are heated by the full spectrum of solar radiation, which also consists of about 45 percent solar infrared (short-wave infrared) and about 5 percent ultraviolet, neither of which is visible to our eyes.

roofs, most people believe that black is beautiful and white is not (though when confronted with images like the one on this page, they admit that a white roof need not be ugly). Do people in Bermuda have bad taste, because all of their roofs are white? Should we waste money and energy and harm the planet because of widely held opinions in aesthetics?



When people see this building with its white roof, they consider it beautiful in spite of their preconceived idea that white roofs are ugly.

A black roof can get more than 60°F (33°C) hotter than a white roof, significantly heating both the building and the outdoor air.

What about white walls (see photo, page 48)? White walls are already popular, and we know of at least one reason for that. Starting with the Renaissance and reinforced by the neo-classical styles after that, white became popular because it was believed that buildings in ancient Greece and Rome were all white. We are now horrified to discover that parts of ancient Greek temples were painted in bright colors. One objection to the use of white walls is that they cause glare. However, the problem is exaggerated. When I visited the Moroccan city of Casablanca (which means "house white"), I did not suffer much from glare; my eyes adjusted to the brightness. We can control much of the potential glare of white walls by planting trees and green walls, which should be done anyway, because they are an important part of creating beautiful cool cities.

A Case of Faulty Values?

Because of resistance to the use of white or very light colors based on aesthetics, the industry has developed "cool colors," or "cool coatings." These high-tech color coatings allow the same dark colors to have higher solar reflectances. This apparent contradiction is possible due to the nature of solar radiation. About 50 percent of solar radiation is visible, about 45 percent is short-wave infrared, and about 5 percent is ultraviolet (see figure 3, facing page). The color of a surface is determined only by the visible part of the spectrum (i.e., light). Because the "cool coatings" version of a color reflects more of the non-visible part of the solar spectrum than the ordinary color, the equilibrium temperature is lower (figure 4).

Truth in advertising would require these "cool coatings" to be called "less-hot coatings." Although figure 5 (page 52) shows that the "cool coating" versions of various dark colors do reflect more solar radiation than the ordinary versions of those colors, these "cool coating" colors still reflect much less than white. Thus, they are not the great remedy we are led to believe. Ironically, it is therefore more expensive to get a mediocre

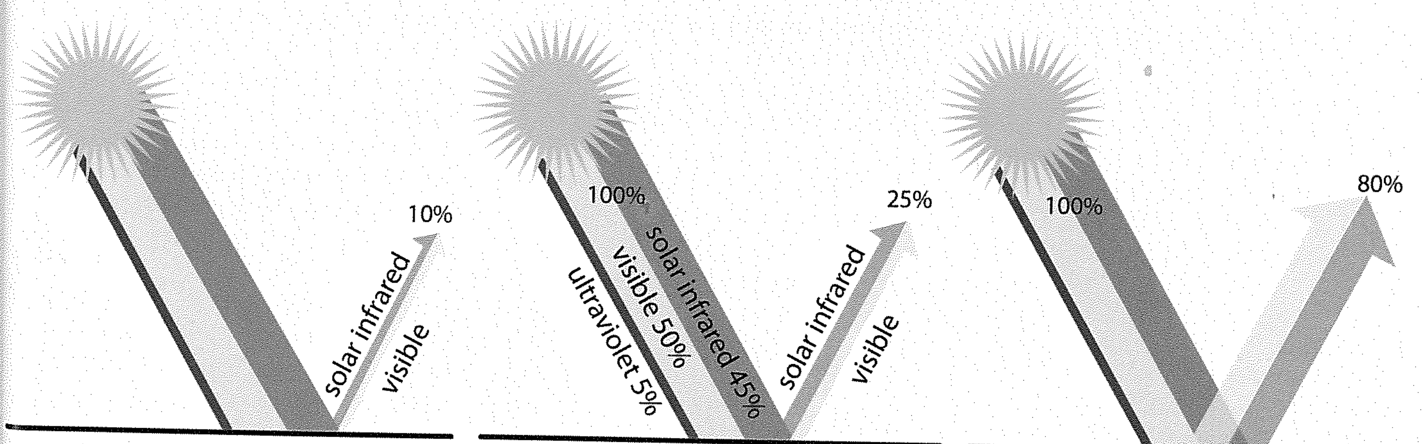


Figure 4. High-tech "cool" coatings and surfaces reflect more of the solar infrared than do ordinary materials of the same colors. It is important to understand, however, that dark or medium-dark "cool" surfaces reflect much less solar radiation than do ordinary white or very light colors.

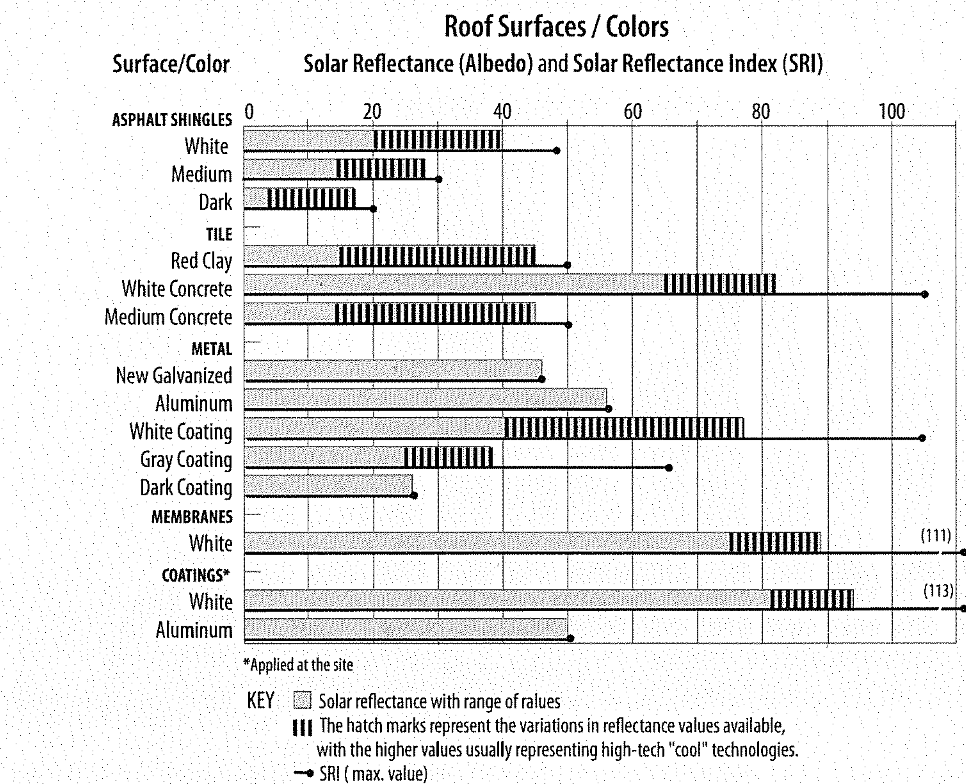


Figure 5. "Cool" versions are available for some roofing materials. Although they can significantly improve the solar reflectance for darker roofs, they do little, if anything, for light-colored roofs, which are nevertheless superior. For example, a "cool" gray metal roof is 150 percent better than the ordinary gray metal roof, but a white metal roof is still 310 percent better. Much of the data in this chart comes from the Cool Roof Rating Council: coolroofs.org/ products/search.php.

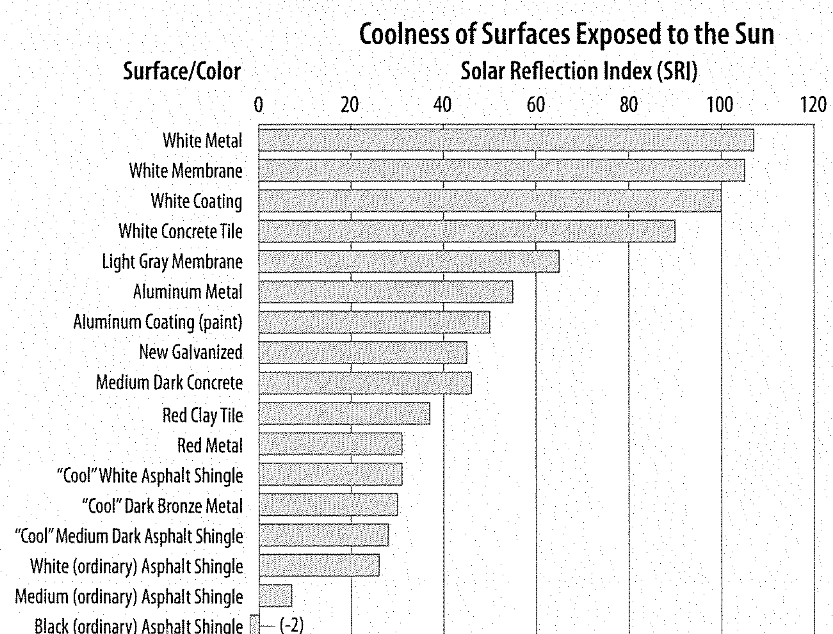


Figure 6. Because the coolness of a roof is a function of both the solar reflectance and its emittance characteristic, the solar reflection index is the best way to evaluate a roof's coolness.

benefit by using a "cool" color than a large benefit from using white or a very light color.

Because the coolness of a surface exposed to the sun is a function of both the solar reflectance and the emissivity of the surface, neither of which we can estimate with our eyes, the solar reflectance index (SRI) was developed to incorporate both. The higher the SRI number, the better. An SRI of 100 represents the performance of a clean white surface, while an SRI of 0 represents a clean black surface (see figure 6, below).

A white roof (an SRI near 100) can reduce air-conditioning load as much as 20 percent in one-story buildings. It can reduce both the initial and the operating costs of the air-conditioning system. Adding extra roof insulation in lieu of a white roof is more expensive and is only a partially successful alternative, since the dark roof still heats the neighborhood. In homes and other small buildings, the air-conditioning ducts are often placed in the attic, where it is common to have 50°F (28°C) air flowing in the ducts and 150°F (83°C) air in the attic. This 100°F (55°C) temperature difference pushes heat through the duct insulation, greatly increasing the air-conditioning load. Because they enable smaller, less-expensive air-conditioning systems, and because it will cost less to cool such buildings, white roofs are a "free lunch that you are paid to eat," to borrow from Amory Lovins of the Rocky Mountain Institute. You pay less for them initially to save money for the life of the building.

The prejudice against light-colored roofs is a case of how our values can hurt us and the planet. I compare it to the prohibition against solar clothes dryers. Do those who object believe that dirty laundry is hung out for all to see? Most people hang only their freshly cleaned clothing, so what is the problem — could it be faulty values? I believe that the preference for black over white roofs is another faulty value. **ST**

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