January 2012

A Practical Guide to Cool Roofs and Cool Pavements

Primer

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Primer

Cool Roofs and Pavements

Cool roofs have the ability to reflect and reject heat because the roofs are prepared with materials which have properties of high solar reflectance.

– New Delhi Chief Minister, Sheila Dikshit, India-Express.com, January 20, 2011

Introduction

World temperatures are rising at an unprecedented rate.

According to the Intergovernmental Panel on Climate Change, the Earth's average temperature is on track to increase by between 2 and 7 degrees Celsius (4 to 13 degrees Fahrenheit) this century. This dramatic change in temperature will produce a climate never before experienced by human civilization. Cities are often significantly warmer than the surrounding landscapes because urban surfaces absorb more sunlight than natural landscapes, cities lack vegetation, which cools landscapes by evaporating water, and urban areas release more heat from human activity including air conditioning, vehicles, and industry. The difference between outside air temperatures in a city and its surrounding rural areas can be 5 to 9 degrees Celsius (9 to 16 degrees Fahrenheit) or more in summer months.[1] This phenomenon is called the summer "urban heat island effect." Addressing this heating effect will only become more important because the world is rapidly urbanizing—**within 50 years an estimated 80 percent of the world's population will live in an urban area**.[2]

Higher temperatures adversely affect our health, our energy consumption, and our environment.

Rapidly increasing temperatures stress ecosystems, increase the frequency and duration of heat waves and exacerbate air pollution. Together, these factors are creating serious health risks to people around the world. In addition, increasing wealth in the developing world is spurring the rapid deployment of air conditioners that are taxing electrical grids with their energy demands.

Roofs and pavements cover about 60 percent of urban surfaces, and absorb more than 80 percent of the sunlight that contacts them. This energy is converted to heat, which results in hotter, more polluted cities, and higher energy costs.[4]

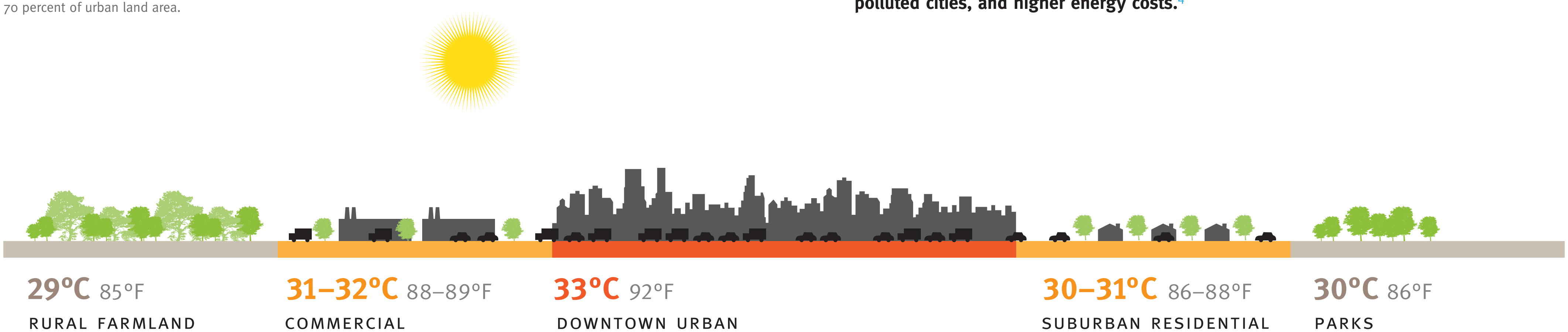
Cool roofs and pavements can help cool down buildings and cities.

Studies of a city's "urban fabric" indicate that about 60 percent of urban surfaces are covered by roofs or pavements. About 20 to 25 percent are roofs and 30 to 45 percent are pavements.[3] Because these surfaces are dark and typically absorb over 80 percent of sunlight that contacts them and convert that solar energy into heat, our built environment exacerbates the warming effects of climate change. Replacing and upgrading roofs and pavements with more reflective materials could reverse this warming, turning urban surfaces into assets instead of burdens. Vegetated roofs, permeable pavements, and shade trees are other cooling strategies that are complementary with cool roofs. Cool roofs paired with appropriate levels of roof insulation help keep buildings more thermally comfortable. Cool, reflective roofs and pavements should be a priority strategy because they are cost-effective, typically pay back within one year, and help cities both mitigate and adapt to climate change while making them more desirable and comfortable places to live.

The Summer Urban Heat Island Effect

Adapted from LBNL Heat Island Group.

Coverage percentages shown represent the most common ranges of urban land area by type but there is some variability by city. Some studies indicate that pavements can comprise up to approximately 70 percent of urban land area.



How it Works

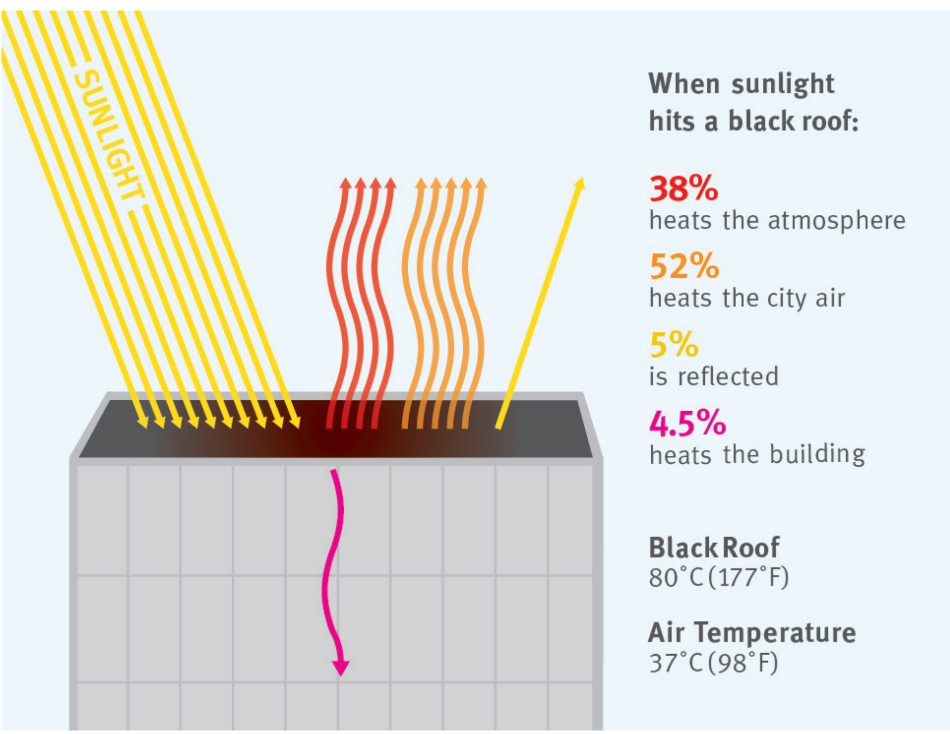
It's simple.

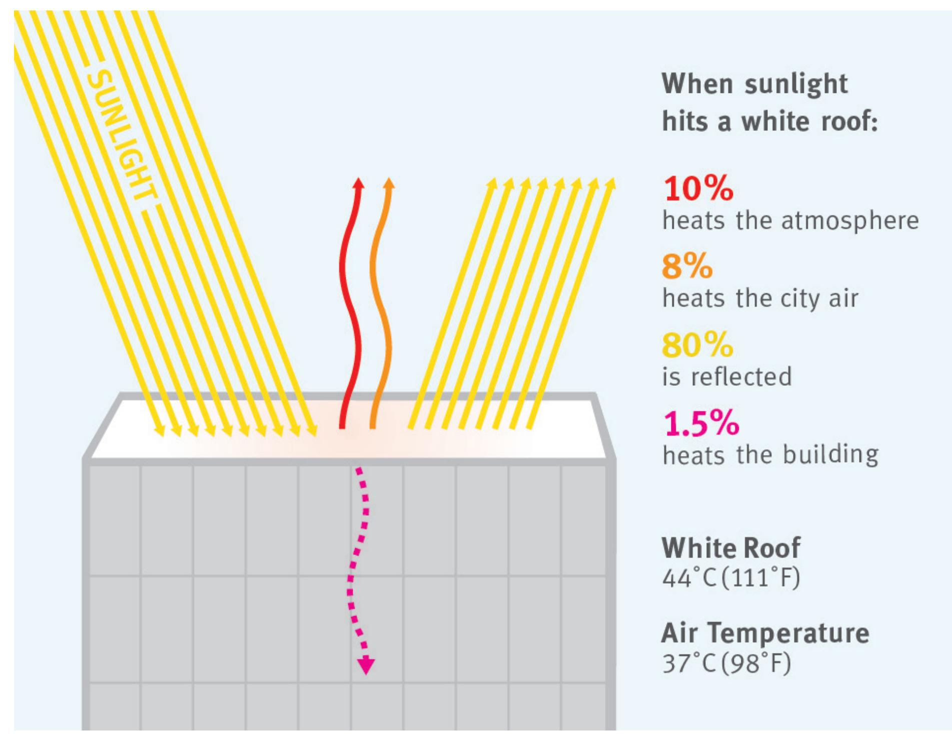
Cool surfaces are measured by how much light they reflect (solar reflectance or SR) and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive to minimize the amount of light converted into heat and to maximize the amount of heat that is radiated away. Every opaque surface reflects some incoming sunlight and absorbs the rest, turning it into heat. The fraction of sunlight that a surface reflects is called solar reflectance or albedo. White roofs reflect more sunlight than dark roofs, turning less of the sun's energy into heat. Increasing the reflectance of our buildings and paved surfaces—whether through white surfaces or reflective colored surfaces—can reduce the temperature of buildings, cities, and even the entire planet.

- Most roofs are dark and reflect no more than 20 percent of incoming sunlight (i.e., these surfaces have a reflectance of 0.2 or less); while a new white roof reflects about 70 to 80 percent of sunlight (i.e., these surfaces have a reflectance of 0.7 to 0.8).
- New white roofs are typically 28 to 36 degrees Celsius (50 to 65 degrees Fahrenheit) cooler than dark roofs in afternoon sunshine while aged white roofs are typically 20 to 28 degrees Celsius (35 to 50 degrees Fahrenheit) cooler.[5]

The Albedo Effect

Comparison of a black and a white flat roof on a summer afternoon with an air temperature of 37 degrees Celsius (98 degrees Fahrenheit).





Source: Adapted from data from LBNL Heat Island Group. Numbers do not sum to 100 percent due to rounding.

Key Cool Roofs Terminology

Solar Reflectance (SR or albedo)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is reflected from a surface. SR typically ranges from about 0.04 (or 4 percent) for charcoal to 0.9 (or 90 percent) for fresh snow. High solar reflectance is the most important property of a cool surface.

Solar Absorptance (SA)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is absorbed by a surface. Surfaces with high solar absorptance tend to get hot in the sun. If the surface is opaque, solar absorptance equals 1 minus solar reflectance.

Thermal Emittance (TE)

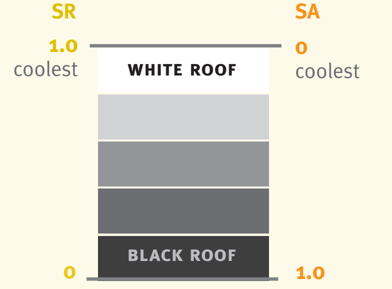
The efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance, which means it will stay warm. An uncoated metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation. TE is the second most important property of a cool surface.

Solar Reflective Index (SRI)

A coolness indicator that compares the surface temperature of a roof on a sunny summer afternoon to those of a clean black roof (SRI = 0) and a clean white roof (SRI = 100). SRI is computed from solar reflectance and thermal emittance, and can be less than 0 for an exceptionally hot surface (e.g., a solar collector) or greater than 100 for an exceptionally cool material (e.g., a very bright white roof). (See the graph on page 23 for a visual explanation.) An SRI calculator can be found at http://coolcolors.lbl.gov/assets/docs/SRI%20Calculator/SRI-calc10.xls.

Thermal Resistance (R-value)

A measure of a material or system's ability to prevent heat from flowing through it. The thermal resistance of a roof can be improved by adding insulation, a radiant barrier, or both.



Solar reflectance (SR) and absorptance (SA) have an inverse relationship. The more heat a surface reflects, the less heat it absorbs.

Uncoated metal
SRI = 68
SR = 0.75
TE = 0.08
R = LOW

Coated metal
SRI = 92
SR = 0.75
TE = 0.83
R = LOW

Metal that is painted and coated has a considerably higher thermal emittance than uncoated metal. This raises its SRI to 92, which is much cooler than uncoated metal, whose SRI is 68.

The values in the above examples are estimates.[6] Actual product values may vary. Please consult the Cool Roof Rating Council or a manufacturer for actual values.

The Benefits

Unless otherwise noted, all dollar values are USD.

Benefits to individual buildings

Energy savings potential Increasing the reflectance of a roof from 0.1-0.2 to 0.6 can cut net annual cooling energy use by 10 to 20 percent on the floor of the building immediately beneath the roof by reducing the need for air conditioning.[7]

Cost savings potential Retrofitting 80 percent of the 2.6 billion square meters of commercial building roof area in the U.S. would yield net annual energy cost savings (cooling energy savings minus heating energy penalty) of $735 million, and offer an annual CO_2e reduction of 6.2 million tonnes. Expanded to a global market, cool roofs could be an investment that saves billions of dollars.[8] In addition, cool coatings are treated as a maintenance product for tax purposes and are allowed to be written off in the year they are installed, rather than capitalized over 39 years like traditional roof materials.

Improved roof and equipment life Extreme changes in surface temperature can damage roofs and the expensive equipment on them. Cool roofs reduce temperature fluctuations and will likely lengthen the life of roof equipment and material. Extending roof life also helps reduce waste going to landfills. A cooler roof is also likely to improve the efficiency of solar PV panels.

Short payback period Cool roofs are typically low cost investments. If the roof needs to be replaced anyway, choosing a white colored material often costs the same as a dark colored alternative. (Please see page 36 for a full list of cost differentials by materials). Further, installing a cool roof is a retrofit that does not inconvenience the building occupants. The average annual energy cost saving (cooling energy saving minus heating energy penalty) for a white roof on a commercial building is $0.36 per square meter ($0.033 per square foot).[9]

Improved thermal comfort In a building that is not air conditioned, replacing a dark roof with a white roof can cool the top floor of the building by 1 to 2 degrees Celsius (2 to 3 degrees Fahrenheit),[10] enough to make these living spaces noticeably more comfortable and even save lives in extreme heat waves. Cooler roofs are more comfortable and functional for residents of regions where the roof is used as living space. Appropriate levels of insulation are also an important part of improving thermal comfort.

When it comes to energy savings, the power of one can become the power of many.

One cool roof saves its owner 10 to 20 percent on energy spent on air conditioning on the top floor of the building. If building owners installed cool roofs on 80 percent of U.S. commercial buildings, they'd save $735 million every year. Photo: Arlen

Benefits to pavements

Conventional paving materials can reach peak summertime temperatures of 50 to 65 degrees Celsius (120 to 150 degrees Fahrenheit), heating the air above them.[11] There are many kinds of paving options that are lighter in color and create more reflective paved surfaces. Additionally, many kinds of permeable pavements, including reinforced grass pavements, can also cool a pavement surface through the evaporation of moisture stored in the pavement. If pavements are too bright, they can cause undesirable glare, but there are many shades of gray that are reflective that do not cause too much glare.

There are a number of additional benefits to light colored pavements beyond cooling.

Improved durability Testing and research are underway to evaluate the durability and longevity of cool pavement materials in a variety of usage conditions. Asphaltic pavements that stay at lower temperatures may be less likely to rut.

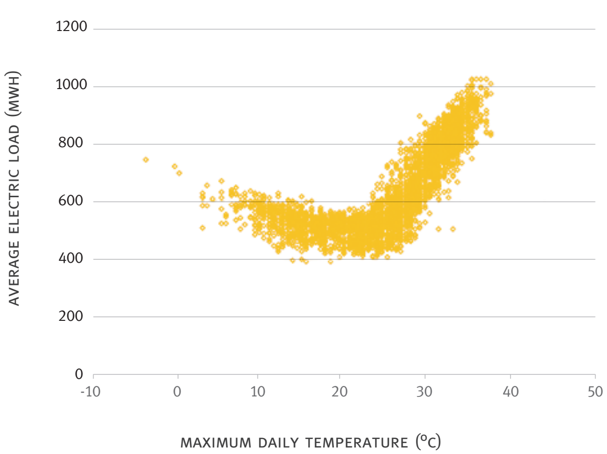
About 20 to 25 percent of urban surfaces are roofs and 30 to 45 percent are pavements. Photo: Eric Konon

Nighttime illumination Parking lots and streets that use light colored pavements will allow for better visibility and safer streets at night and may also reduce the need for street lighting.

Improved water quality Higher pavement temperatures can heat stormwater runoff which, in turn, can affect metabolism and reproduction of aquatic species. The U.S. Environmental Protection Agency classified elevated water temperature as a "pollutant of concern" in the Clean Water Act.

New Orleans Hot Weather Energy Demand

Demand for electricity can increase steadily once temperatures begin to exceed about 20 to 25 degrees Celsius (68 to 77 degrees Fahrenheit).



Source: Adapted from Sailor, D. J. 2002. Urban Heat Islands, Opportunities and Challenges for Mitigation and Adaptation. Sample Electric Load Data for New Orleans, LA (NOPSI, 1995). North American Urban Heat Island Summit. Toronto, Canada. 1–4 May 2002. Data courtesy Energy Corporation.

City-wide benefits

Reduced summer heat island effect

Simulations run for several cities in the U.S. have shown that city-wide installations of highly reflective roofs and pavements, along with planting shade trees will, on average, reduce a city's ambient air temperature by 2 to 4 degrees Celsius (4 to 9 degrees Fahrenheit) in summer months.[12] Reducing urban temperatures makes cities more comfortable and enjoyable to live in and promotes healthier populations.

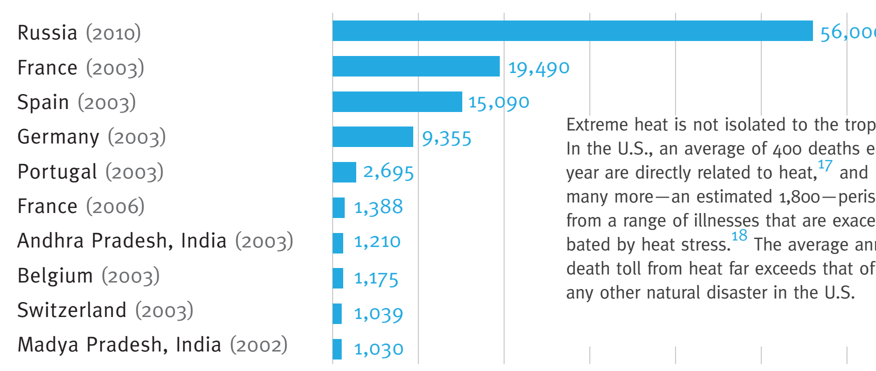
A hot summer day in Chicago. Photo: Zane Edwards

More resistant to heat related deaths Cool roofs can cool the areas in a building where the risk of death during heat waves is high. For example, there were 739 deaths in the Chicago heat wave of 1995. Virtually all of the deaths occurred in the top floors of buildings with dark roofs.[13] Subsequent heat waves have claimed thousands of lives in the U.S., France, Russia, and elsewhere.

Reduced peak electricity demand In climate zones where summer brings peak electricity demand from air conditioning, cool roofs are of great value to utilities and grid operators. They can improve utility capacity utilization and therefore profitability, reduce transmission line congestion, avoid congestion pricing, and forego the need for additional investments in peaking generation capacity. Approximately 5 to 10 percent of U.S. peak electricity demand for air conditioning is a result of the urban heat island effect.[14] Research indicates that peak electricity demand increases by 2 to 4 percent for every 0.5 degrees Celsius (1.8 degrees Fahrenheit) increase in temperature above a threshold of about 15 to 20 degrees Celsius.[15] Rosenfeld et al. (1996) estimated that eliminating the urban heat island effect in Los Angeles—a reduction of 3 degrees Celsius (5.4 degrees Fahrenheit)—could reduce peak power demand by 1.6 gigawatts resulting in a savings of about $175 million per year (at 1996 electricity prices).[16] Approximately $15 million

Ten Most Deadly Heat Events

Events are listed by country and year with the number of deaths shown in thousands.
Source: EM-DAT: The OFDA/CRED International Disaster Database. 2007. Available at em-dat.net, Université Catholique de Louvain, Brussels, Belgium. Data downloaded on 20 September 2007.



Extreme heat is not isolated to the tropics. In the U.S., an average of 400 deaths each year are directly related to heat,[17] and many more—an estimated 1,800—perish from a range of illnesses that are exacerbated by heat stress.[18] The average annual death toll from heat far exceeds that of any other natural disaster in the U.S.

Respiratory illness resulting from air pollution is a major global health problem. Photo: Kathmandu, Nepal by Michael Renner

of that amount was due to more reflective pavements. A 2004 analysis of New York City when electricity averaged 16.5 cents per kWh found that a one degree reduction in temperature would cut energy costs by $82 million per year. Electricity prices have subsequently increased by over 20 percent.[19]

Air quality benefits City-wide temperature reduction not only makes cities more comfortable, but also improves air quality because smog (ozone) forms more readily on hot days. Ozone pollution is a major contributing factor to respiratory illness, which the World Health Organization predicts will be the third leading cause of death by 2030.[20] Simulations of Los Angeles indicate that lighter surfaces and shade trees could cool temperatures and thus reduce smog in excess of EPA-defined safe concentrations by 10 percent.[21] Across the U.S., the potential energy and air quality savings resulting from increasing the solar reflectance of urban surfaces is estimated to be as high as $10 billion per year.[22]

Easy to monitor Compared to many climate change mitigation strategies, the area of cool roofs and pavements installed is relatively easy to measure and monitor with aerial and satellite imagery.

Unless otherwise noted, all dollar values are USD.

The role of shade trees Planting and maintaining an urban tree canopy is another way to cool cities while adding beauty and character to neighborhoods. Trees cool cities by shading the ground and structures around them but also through evapotranspiration—a process by which trees release water into the atmosphere through their leaves. These cooling effects can be significant. Studies indicate that tree groves can be 5 degrees Celsius (9 degrees Fahrenheit) cooler than open ground around them. In addition to saving energy, the use of trees and vegetation as a mitigation strategy can provide air quality and greenhouse gas benefits.[23] For more information on the costs and benefits of tree programs see *Reducing Urban Heat Islands: Compendium of Strategies: Trees and Vegetation* by the U.S. Environmental Protection Agency.

Air-conditioned vs. non air-conditioned buildings Cool roofs are valuable in both air-conditioned and non air-conditioned buildings. In air-conditioned buildings, the indoor air temperature is controlled, so installing a cool roof does not change the comfort of the building. However, a cool roof can reduce air conditioning costs by as much as 20 percent in a single story building.[24]

In non-air-conditioned buildings, particularly those that are poorly insulated, cool roofs can noticeably improve the comfort of the building by lowering the indoor air temperature of the top floor of the building by 1 to 2 degrees Celsius (2 to 3 degrees Fahrenheit).[25] This temperature reduction is enough to save lives in extreme heat waves and make non-conditioned work environments like barns and warehouses more usable and comfortable for employees. Air sealing and insulation are important investments for improving the comfort of poorly insulated, non-air conditioned buildings but require access to walls and attic spaces. Cool roofs can be deployed on almost any structure and, because they do not require wall or attic access, they typically have a lower install cost than air sealing and insulation.

Air conditioners in Hong Kong. Photo: Niall Kennedy

There is a growing global market for air conditioning as a first response to hot indoor temperatures, particularly in rapidly developing countries like India and China. Electric air conditioning is an expensive and energy intensive first choice for cooling. It further taxes electric grids that are already straining to meet new demand. Cool roofs and pavements are a cheaper alternative that could forestall the purchase of AC units, especially on the top floors of buildings.

Benefits to the planet

Global cooling potential Replacing the world's roofs and pavements with highly reflective materials could have a one-time cooling effect equivalent to removing 44 billion tonnes of CO_2 from the atmosphere, an amount roughly equal to one year of global man-made emissions.[26] Every 10 square meters (100 square feet) of white roofing will offset the climate warming effect of one tonne of CO_2. Assuming a 0.15 increase in reflectance is realized by switching to a lighter pavement option, cool pavements would "offset" approximately 0.5 tonnes of CO_2 per 10 square meters (100 square feet), or 300 tonnes of CO_2 per lane mile (1.6 kilometers) of highway. Assuming the average car emits 4 tonnes of CO_2 per year, the combined "offset" potential of replacing the world's roofs and pavements with highly reflective materials is equivalent to taking all of the world's approximately 600 million cars off the road for 20 years.

Case Study

The Greenhouses of Almería, Spain

The semi-arid Almería region of southern Spain has the most dense concentration of greenhouses in the world. In preparation for the hot summer months, farmers whitewash the roofs of the greenhouses to help lower inside temperatures. Researchers studying weather station data and satellite imagery have found that the cumulative effect of the increased reflectivity has also cooled outside temperatures. Over the last 20 years, temperatures in the Almería region have fallen by 0.3 degrees Celsius, in contrast to a 0.5 degree Celsius increase in temperatures in surrounding regions that do not have highly reflective greenhouses.[27]

Google satellite view of the whitewashed greenhouse roofs in Almería, Spain. The greenhouses cover approximately 350 square kilometers (135 square miles) of this region. Credit: Google

Ready to Learn

Primer
Choosing Cool Surfaces

White is the coolest, but not the only, color to choose. Building owners can choose almost any color they like.

Choosing a Cool Roof

The cool roof options available to a building owner depend in large part on the building and roof type they are working with. That said, there is a cool option for nearly every type of roof. Cool roofs are relatively easy to implement for commercial buildings. The roofs of most commercial and high-rise residential buildings are low-sloped (i.e., almost flat),[28] and are generally not visible from the street. As a consequence, there is little resistance or cost to changing the color of these roofs during routine retrofits or when waterproofing.

In contrast, residential buildings often have steep-sloped roofs that can be seen from the ground. In many parts of the world, white is not currently a popular color for residential roofs, and as a result there can be aesthetic concerns about using white materials. To address this, roofing manufacturers have developed "cool" materials in popular roof colors (e.g., red and gray) that strongly reflect the invisible heat component of sunlight and much of the sun's energy away from the building.[29]

The desirability of cool roofs depends on latitude, altitude, annual heating load, annual cooling load, peak energy demands, and sun blockage by trees, buildings, and hills for the particular building. Cool roofs on buildings in some far northern communities such as Anchorage, Alaska or in forested mountainous areas such as at Lake Tahoe, Nevada, may not be appropriate. That said, whether or not a cool roof is appropriate in any climate depends on the building, its energy usage pattern, existing needs, and costs.

Caution: Mind your surroundings

Cool roofs must be considered in the context of their surroundings. It is relatively easy to specify a cool roof and predict energy savings, but some thinking ahead can prevent other headaches. Ask this question before installing a cool roof: *Where will the reflected sunlight go?* A bright roof could reflect into the higher windows of taller neighboring buildings. In sunny conditions, this could cause uncomfortable glare and unwanted heat for you or your neighbors. In these cases, building owners can opt for a cool colored roof to provide some improvement in reflectance without significantly affecting neighboring buildings.

Common Building Types and Roofing Materials

Cool roofing options are available for all standard roofing materials. (See table on page 24).

A flat-roofed commercial building in Shenzhen. Photo: dcmaster

Red tile roofs in Dubrovnik. Photo: Marcel Oosterwijk

A steep-sloped single family home with asphalt roof shingles in the U.S. Photo: Eric Allix Rogers

Multi-story buildings with concrete or cement roofs are common in India. Photo: John Roberts

Corrugated metal roofs in Rio de Janeiro. Photo: whl.travel

Urban rooftops in Mexico City. Photo: Storkholm Photography

Cool colors

White is the "coolest" color, but there are cool versions of a wide variety of popular colors. Building owners have more choice than they realize. Highly reflective roofs can come in popular colors such as red, green, and gray. Cool colored materials are available for all types of steep-sloped (pitched) and low-sloped (nearly horizontal) roofs. These materials include asphalt shingles, metal, clay tiles, and concrete tiles. Highly reflective colored roofs typically have an initial solar reflectance 0.30 to 0.55, compared with around 0.10 for conventional dark steep-sloped roofs.

Cool colored metal roofs. Photo: Custom Bilt Metals

Cool roofs come in many colors.
Many roof materials in any color can be treated with a reflective coating, giving them a higher solar reflectance than the standard version of that material.

Standard Concrete Tiles (SR)	0.04	0.18	0.24	0.33	0.17	0.12
With Cool Coating Applied (SR)	0.41	0.44	0.44	0.48	0.46	0.41

Source: Adapted from data from American Rooftile Coatings.

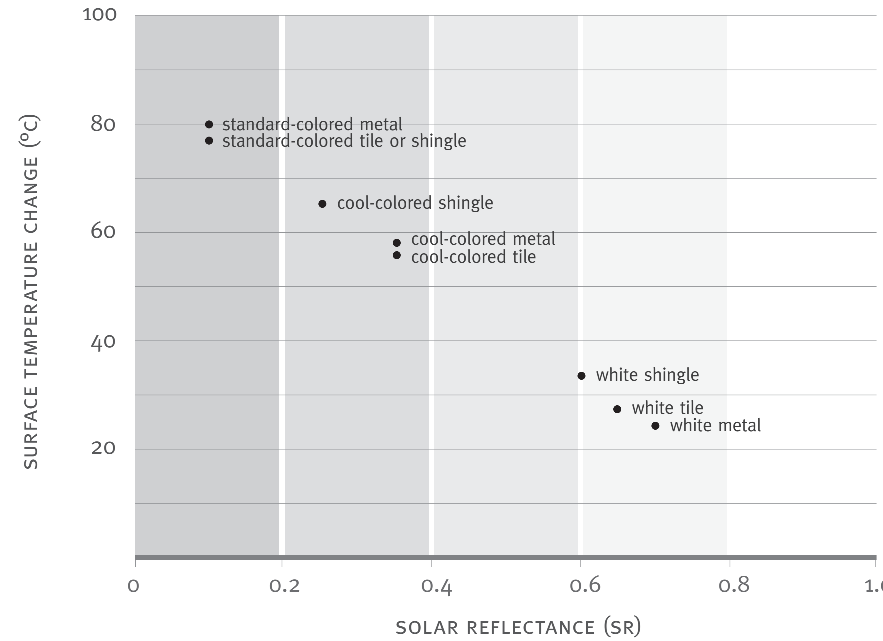
Beware of "paint"

Although many cool roof advocates call for building owners to "paint" their roofs white, using white house paint to coat any kind of roof is inappropriate and ill-advised. Some roof coatings are installed by using rollers like the ones used for indoor house paint, thus it may look like roofs are being "painted." In fact they are being "coated" with products made specifically for roofs. The major difference between paint and coatings are that paints are typically cosmetic in nature and significantly thinner applications than coatings. Also, coatings are more reliably weather resistant.

Some shingle manufacturers will not honor the warranty of their products if the roof has been painted or coated in any way. Be sure to check with your roof manufacturer before installing a cool roof on top of your existing roof.

In some countries, notably India and Greece, whitewashing homes to keep them cooler in summer months is a long-standing tradition. This is an advisable and appropriate practice for some building materials, depending on availability and cost of more permanent alternatives.

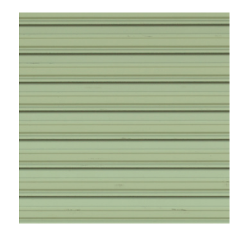
Solar Reflectance of Common Roofing Materials
Surfaces that are more reflective tend to remain cooler than those that are less reflective. Both solar reflectance and (surface) temperature rise should be considered when assessing a cool surface material. The graph shows solar reflectance and temperature rise of common steep-sloped roofing materials (Air temperature is 37 degrees Celsius / 13 degrees Fahrenheit). Source: Adapted from data from LBNL.



Photos: Creative Commons and LBNL

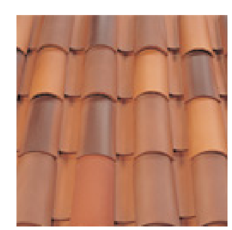
STANDARD | COOL-COLORED | WHITE

Uncoated metal

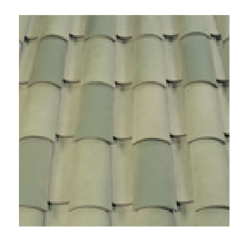


Cool-colored metal (coated)

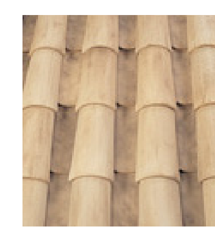
White metal (coated)



Ceramic tiles

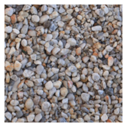
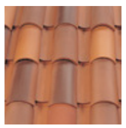
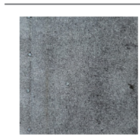
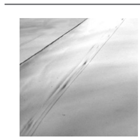


Cool-colored clay tiles



White coating

Common Roofing Materials and Cool Options*

	Roof Type	Life Expectancy (years)	Roof Slope	Non-Cool Roof Options	Non-Cool Roof Solar Reflectance	Cool Roof Options	Cool Roof Solar Reflectance
	**Asphalt Shingle**	15 to 30	steep-sloped	black or dark brown with conventional pigments	0.05–0.15	"white" (actually light gray) or cool color shingle	0.25
	**Built-Up Roof**	10 to 30	low-sloped	with dark gravel	0.10–0.15	with white gravel	0.30–0.50
				with aluminum coating**	0.25–0.60	white smooth coating	0.75–0.85
	**Clay Tile**	50+	steep-sloped	dark color with conventional pigments	0.20	terracotta (unglazed red tile)	0.40
						color with cool pigments	0.40–0.60
						white	0.70
	**Concrete Tile**	30 to 50+	steep-sloped	dark color with conventional pigments	0.05–0.35	color with cool pigments	0.30–0.50
						white	0.70
	**Liquid Applied Coating**	5 to 20	low- or steep-sloped	smooth black	0.05	smooth white	0.70–0.85
	**Metal Roof** Uncoated corrugated metal is typically less durable than coated metal	20 to 50+	low- or steep-sloped	unpainted, corrugated**	0.30–0.50	white painted	0.55–0.70
				dark-painted corrugated	0.05–0.10	color with cool pigments	0.40–0.70
	**Modified Bitumen**	10 to 30	low-sloped	with mineral surface capsheet (SBS, APP)	0.10–0.20	white coating over a mineral surface (SBS, APP)	0.60–0.75
	**Single-Ply Membrane**	10 to 20	low-sloped	black (polyvinyl chloride (PVC) or ethylene propylene diene monomer rubber [EPDM])	0.05	white (PVC or EPDM)	0.70–0.80
						color with cool pigments	0.40–0.60
	**Wood Shake**	15 to 30	steep-sloped	painted dark color with conventional pigments	0.35–0.50	bare	0.40–0.55

Source: Adapted from coolcalifornia.org roofing options table. Photos: Creative Commons and LBNL

* Spray polyurethane foam is not included in this chart because it is typically coated by a reflective liquid applied coating to minimize ultraviolet damage to the foam. ** Aluminum and metal have high solar reflectance but their low thermal emittances reduces their ability to stay cool.

What happens as the surface ages?

Over time, white roofs get dirty; they collect soot, dust, salt, and, in some climates, biological growth. As a result, their reflectance decreases. The aged solar reflectance of a white roof is typically 0.55 to 0.65. Replacing a dark roof with an aged white roof still reduces the amount of sunlight absorbed by around 40 to 50 percent. Codes and standards typically use the aged SR value of white roofs.

The reflectivity of pavements also changes as they age. Concrete pavement tends to be initially more reflective and get darker with age and use. Dark asphalt pavement tends to lighten to a gray color over time. Despite this convergence in reflectivity, concrete typically remains more reflective than asphalt pavements.

Rating products

Most countries have enacted some voluntary or mandatory codes and standards for buildings and energy use. Some of these include language covering cool roofs and pavements. In order for codes to be effective, there must be a broadly accepted rating and labeling system for materials.

Determining both the initial and aged solar reflectance of a given material or roofing product requires testing. In the U.S., the Cool Roof Rating Council (CRRC) has been established as an independent, non-profit organization that maintains a third-party rating program, which rates and publishes a roof product's solar reflectance and thermal emittance. The CRRC allows standardized test methods as agreed to under the American Society for Testing and

Applying white coating to a roof in China. Photo: United Coatings

Materials (ASTM). Once a product is rated the results are published on CRRC's online Rated Products Directory and given a label with the results (see sample below). Manufacturers are encouraged to list their roofing products in the CRRC Rated Product Directory; in order to do so, they must follow the CRRC Product Rating Program Manual (CRRC-1) testing method. Since all roofing products can be rated by CRRC, consumers and builders should use the CRRC label to identify which roof products meet their purchasing objectives (e.g., qualifying for ENERGY STAR certification, meeting building code requirements, and/or qualifying for utility rebates).

All products that have been tested by the CRRC are listed in their online directory, which can be found at coolroofs.org/products/search.php.

A product's inclusion in the Directory does not mean that the product is "cool" as defined by any particular code body or program.

A European Cool Roofs Council was established recently to begin to establish testing infrastructure for cool roofs in Europe. Their website is coolroofs-eu-crc.eu. Similar initiatives are underway in India, China, Japan, Brazil, Thailand, and Australia.

An example of a CRRC label. Source: CRRC.

How cool is cool?

Any shift along the solar reflectance continuum towards more reflective materials will create benefits from an energy savings, local cooling, and global cooling perspective. However, for codes and standards to be effective and useful, they need to establish a threshold value for compliance. Cool roof requirements have been included in a number of mandatory and voluntary standards. See the Building Codes and Standards Table on page 72 for further information.

Choosing Cool Pavements

A range of materials are available for standard paving needs. Pavement criteria can vary greatly depending on the use. Highways, highway shoulders, municipal streets, parking lots, sidewalks, playgrounds, driveways, bridge decks, and plazas all have specific functionality requirements that can be met by a range of cool pavement options. Many kinds of permeable pavements, including pervious concrete, porous asphalt, and reinforced grass pavements, are also considered cool because they can cool a pavement surface through the evaporation of moisture stored in the pavement. Permeable pavements have the added benefit of providing storm-water management. Some common pavement types are described in the table on the facing page.

In Chicago there are 1,900 miles of alleyways, only part of the total 3,500 acres of impermeable surfaces in the city. Photo: City of Chicago

Cool Pavement Materials

Pavement type	Solar Reflectance (SR)	Uses	Pavement surface life
Clear Resin Binders	Depends on aggregate	New construction & maintenance for streets, sidewalks, parking lots, etc.	20 years
Coatings (e.g., cementitious coating, elastomeric coating)	New: 35–55%	Coatings for preventive maintenance for streets, driveways, parking lots, etc.	1 to 5
Light-Colored Aggregates (e.g., chip seal)	Depends on aggregate	Overlay for preventive maintenance for highways, streets, parking lots	2 to 5 years
Light-Colored Cement (e.g., slag, white cement)	New: 70–80%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years
Porous Asphalt Cement (AC), Pervious Portland Cement Concrete (PCC), & Reinforced Grass Pavements	Depends on pavement type	New construction, to aid with stormwater management	varies
Portland Cement Concrete (PCC)	New (gray cement): 35–50% Aged (gray cement): 20–35%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years

Source: Adapted from LBNL common pavement types table.

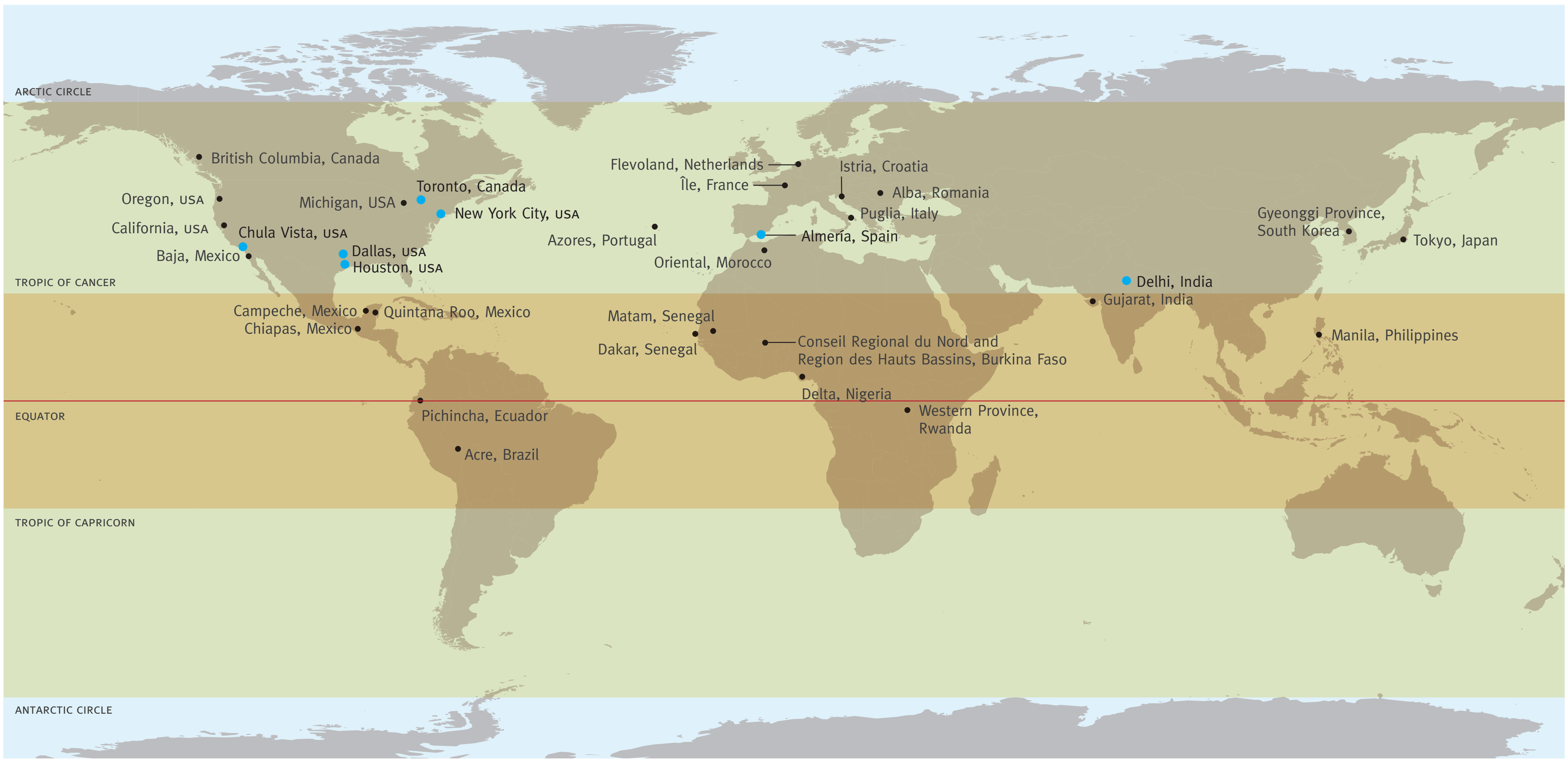
Climate Factors

Cool roofs and cool pavements are beneficial for most buildings and road surfaces almost everywhere in the world, although their cost-effectiveness can vary significantly, depending on climate and local factors. The specific benefits that accrue to individual buildings, individual cities, and the planet can also vary greatly depending on building type, climate zone, topography, and weather patterns of the region. Simulations with local conditions can identify the benefits of deploying cool roofs in a particular location. The map below shows global climate zones. Cities and regions in tropical zones have long hot seasons where the benefits of cool roofs and pavements are clear. Cool surfaces deployed in temperate climate zones, characterized by shorter hot seasons, will very often result in net benefits as well—even when evaluating only the net energy cost savings.

World map showing R20 member cities and regions, as well as the locations of case studies throughout this guide. The temperate and tropical regions of the world as commonly defined are indicated. Please note that not all temperate regions will be favorable for cool roof and pavement deployments. Sources: Adapted from NASA Surface Meteorology and Solar Energy maps.

- R20 member cities and regions
- Case Studies in this guide

- Arctic zones
- Temperate zone
- Tropical zone



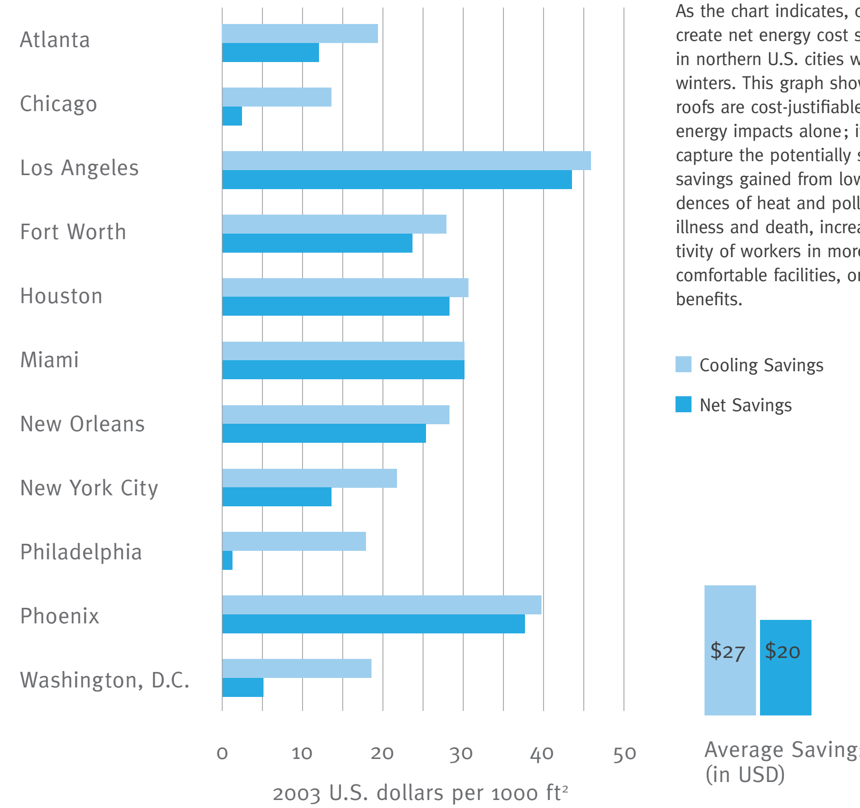
Winter heating penalty

The value that cool roofs bring to buildings is their ability to lessen the cooling demands of a building thanks to their higher SRI. In some cases in cooler climates, though, cool roofs may increase the heating requirements for buildings. A number of factors help to minimize the so-called “winter heating penalty” in many cases. The sun is generally at a lower angle in winter months than it is in summer months, which means that the sun has a reduced impact on roof conditions during the winter. In some areas, snow cover makes the underlying roof color irrelevant. Finally, heating loads and expenditures are typically more pronounced in evenings, (especially in residential buildings) but the benefit of a darker roof in winter is mostly realized during daylight hours.

The winter heating penalty occurs in most temperate areas, but in almost every case it is less than the cooling energy savings. Even some northern climates experience high peak temperatures in the summer and are therefore potentially good candidates for cool roofs. In addition to choosing a cool material, adding a reasonable amount of roof insulation (e.g., the amounts prescribed by the American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE] Standard 189.1–2009) when installing a new roof or replacing a roof membrane can enhance building energy savings and comfort. Over the life of the roof, this practice could save billions of dollars in energy costs for commercial buildings in the U.S. alone.

Pittsburgh in winter. Photo: Marcus Eubanks

Annual Net Energy Cost Savings in Various U.S. Cities from Widespread Use of Cool Roofing



As the chart indicates, cool roofs create net energy cost savings even in northern U.S. cities with long, cold winters. This graph shows that cool roofs are cost-justifiable based on energy impacts alone; it does not capture the potentially significant cost savings gained from lowering incidences of heat and pollution-related illness and death, increased productivity of workers in more thermally comfortable facilities, or other societal benefits.

Source: Adapted from Dallas Urban Heat Island, Houston Advanced Research Center, 2009. sciencedirect.com/science/article/pii/S0360544298001054

Cool Roof Economics [30]

In many cases, cool roofs are cost competitive with traditional roofing options and pay back in a year or less based on energy savings alone. Building owners and others should evaluate the full costs and benefits of their roofing choices. There are, of course, some societal benefits (e.g., health) that building owners will not typically factor into their buying decisions. However, policymakers should consider these quantitative and qualitative benefits when considering incentives and regulatory actions.

Roof cost should be evaluated using a lifecycle approach that accounts for the upfront costs as well as the ongoing savings and expenses incurred throughout the roof's service life. Roof lifetime, expected maintenance (regular roof inspections, repairs, and recoatings), disposal, and replacement costs should be evaluated for each viable roof option. Cool roofs may degrade more slowly and last longer than similar non-cool roofs, but more data are needed to establish this benefit. Conversely, some cool roofs in hot, humid environments may be susceptible to mold or algae growth which needs to be cleaned off regularly for the roof to maintain its reflective properties.

Additionally, non-cost benefits should be considered, most notably indoor comfort. In unconditioned spaces like warehouses, cool roofs can maintain cooler indoor temperatures.

While cool roofs may save more units of energy in the hottest climate zones, climate zones are not necessarily the best indicator of the relative value of cool roofs. For example, the savings might be more valuable in New York City than Atlanta because electricity is three times more expensive in New York.

Lifecycle of Cool Roofs and Pavements

Upfront and Ongoing Costs:

Materials and Labor

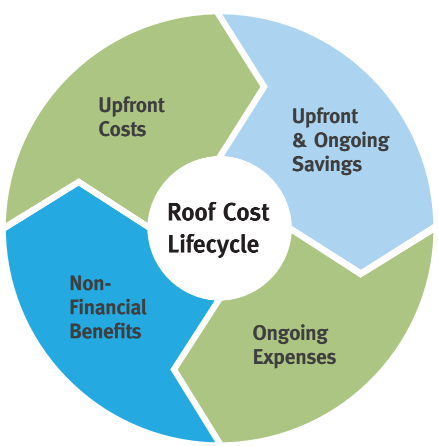
Disposal and Replacement

Maintenance (Varies)

Non-Financial Benefits:

Indoor Comfort (Cooler Temperatures)

Quality of life improvements from reduced air pollution and cooler ambient temperatures



Upfront and Ongoing Savings:

Energy Savings

Rebates and Incentives

HVAC Equipment Savings

Extended Roof Lifetime

Maintenance (Varies)

Water Management (Pavements)

Lifecycle analysis

Cool roofs can incur additional costs over the lifetime of the roof:

Materials and labor

The installed costs of a roof can vary depending on several factors, including its type, size, complexity, method of attachment, and building location.

1. **If the roof needs to be replaced anyway**
   In cases where new roof surfaces need to be installed, cool roof options are usually similar in cost or slightly more expensive than similar non-cool alternatives. Slightly higher upfront costs occur mostly in colored roofs that require specialty reflective pigments. But the labor required to install or coat cool roofs is about the same as for non-cool roofs.
2. **For a roof that is in good condition**
   Converting a roof that is in good condition into a cool roof has a higher incremental cost than if the roof needs to be replaced anyway. For instance, if you want to coat your new dark roof just to make it a cool roof, the additional cost can be significant. The cost of coating a roof cool depends on the existing roof's surface. Rough surfaced roofs, like those covered in granules, have more surface area, and require slightly more coating material to achieve the desired thickness.

Workers install a white roof on a museum building at University of Central Arkansas. Photo: UCentralArkansas

Typical, approximate installed roof cost premiums for different cool roof options are given in the tables on the following pages. The premiums equal the additional cost you can expect to pay for a cool product. For example, if you are planning to install a mineral-surfaced modified bitumen roof, the table indicates you might expect to pay $0.50 per square foot more for a cool roof with the same kind of surface. Since costs vary widely by location, check with your roofing contractor or estimator for more accurate cost comparisons.

Price Premiums for Roofing Upgrades

These prices are based on the U.S. market. Local pricing may vary.

Roof Type	Cool Alternative	Premium to Coat a Functioning Roof (USD/ft^2) *	Premium to Include Coatings as part of Roof Replacement (USD/ft^2) **
Smooth Dark Surface	Cool Coating	1.25–2.40	0.00–1.70†
Rough Dark Surface	Cool Coating	1.25–2.75	0.00–1.90†
Old Light or Cool Surface	Renewed Cool Coating	0.80–2.00	0.00–1.45†

Source: DOE Guidelines for Selecting Cool Roofs

* If the roof does not need any maintenance, but you want to install a cool roof anyway, you will incur the full cost of applying a cool coating.

** If, instead, your roof is in need of repair or replacement anyway, you would already be incurring the cost of a new coating. In this case, there may or may not be a price premium for installing a cool coating instead.

† This data is based on a small U.S. sample. Cost data will vary widely by location.

Price Premiums for Cool Roofs on New Roofs (Premiums are the extra cost of installing the cool alternative)

Roof Materials	Typical Non-Cool Surface	Cool Alternative	Price Premium (US$ per ft²)
Built-Up Roof	Mineral aggregate embedded in flood coat	Light-colored aggregate, like marble chips, gray stag	0.00
	Asphaltic emulsion	Field-applied coating on top of emulsion	0.80–1.50
	Mineral surfaced cap sheet	White mineral granules	0.50
Metal	Unpainted metal	May already be cool	0.00
		Factory-applied white paint	0.20
	Painted metal	Cool-colored paint	0.00–1.00+
Modified Bitumen	Mineral surface cap sheet	Factory-applied coating, white mineral granules	0.50
	Gravel surface in bitumen	Light colored gravel	0.00
	Metallic foil	May already be cool	0.00
		Field-applied coating	0.80–1.50
	Asphalt coating	Field-applied coating on top of asphaltic coating	0.80–1.50
Shingles	Mineral granules	White granules	0.00
		Cool-colored granules	0.35–0.75
Sprayed Polyurethane Foam	Liquid applied coating	Most coatings are already cool to protect the foam	0.00
	Aggregate	Light colored aggregate	0.00
Thermoplastic Membranes	White, colored, or dark surface	Choose a white or light colored surface	0.00
Thermoset Membranes	Dark membrane, not ballasted (adhered or mechanically attached)	Cool EPDM formulation	0.10–0.15
		Factory cool ply or coating on dark EPDM	0.50
Tiles	Non-reflective colors	Clay, slate (naturally cool)	0.00
		Cool colored coatings	0.00

Source: Adapted from DOE Guidelines for Selecting Cool Roofs.

Maintenance

The cost of maintaining a cool roof is similar to non-cool roofs. Soiling of roofs reduces solar reflectance. Although annual cleaning can restore up to 90 percent of initial reflectance, the energy cost savings alone may not warrant the cost. If you do clean your roof, be sure to follow the manufacturer's cleaning recommendations, since improper cleaning (e.g., power washing, harsh chemicals) could damage your roof.

Biological growth such as mold and mildew can occur on roofs in warm, moist locations. This is not a major problem, but it can look bad and reduce the roof's reflectance. Some roof coatings include special chemicals that prevent mold or algae growth, and these can last for a few years.

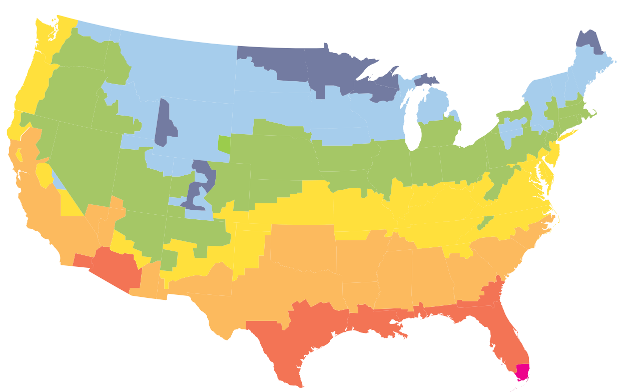
In cold climates, attics can accumulate moisture through condensation, and this may eventually lead to material degradation. Moisture control in cold climates is an important part of any roof's design. It is possible, though not yet proven, that cool roofs might be more susceptible to accumulating moisture than dark roofs of the same design.

Condensation, Moisture, and Ice

Designing a roof that can withstand and control moisture is essential since uncontrolled moisture could cause damage to the roof or the building. Moisture from the indoor air can condense within roof materials. If allowed to accumulate over months or years, moisture could damage those materials. Ordinarily, heat from the sun dries out building materials during the daytime and throughout the summer. In consistently hot and dry climates, there is little risk of this moisture buildup. In colder climates there is less heat available to dry out the roof and opportunities for condensation to occur. Without proper design, both dark and cool roofs can accumulate moisture in colder climates. Cool roofs maintain lower temperatures than dark roofs, and so they may provide less heat to dry out moisture. Potentially, this could make a cool roof more susceptible to moisture accumulation when used in colder climates. While this issue has been observed in both cool and dark roofs in cold climates, we are not aware of any data that clearly demonstrate a higher occurrence in cool roofs. The issue is the subject of ongoing research.

ASHRAE Climate Zones

American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is a professional association that creates voluntary standards covering many building systems and components. ASHRAE standards are often used by local regulators to set mandatory building codes. ASHRAE defined eight distinct climate zones for the U.S. as part of their standards.



Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7

Source: Adapted from map by AIA. Not shown on this map are Hawaii (Zone 1) and Alaska (Zones 7 and 8).

Benefits

Cool roofs can also save money in several ways, including energy savings, rebates and incentives, HVAC equipment downsizing, and extended roof lifetime.

Energy savings Energy savings generated by cool roofs are achieved each year, reducing building operating costs. Climate, roof reflectance, insulation levels, utility rates, and HVAC equipment efficiency all affect the expected savings. Web-based calculation tools make it easier for building owners to predict the yearly energy and cost savings associated with cool roofs. (See *Helpful Calculators* below.)

Rebates and incentives Some utilities and agencies offer rebates and incentives for cool roofs. To find out if there are any programs in your location, visit the CRRC website or DSIRE website and check with your roofing contractor. Nonresidential building rebate programs can be more complicated, and may also include other efficiency measures besides cool roofs. Contact your utility or the agency offering the rebate to determine the value of the rebate.

HVAC equipment savings If a cool roof reduces peak cooling loads significantly enough to reduce the air conditioning capacity needed, HVAC equipment savings may be achieved. At best, the associated savings are modest ($0.03 to 0.07 per square foot of cool roof area)[31] and can only be realized when HVAC equipment is being installed or replaced at the same time as the roof. Be aware that downsizing HVAC equipment could lead to insufficient cooling capacity if the cool roof becomes excessively dirty or is later replaced with a dark roof.

Extended roof lifetime One possible advantage of using cool roofs is extended roof lifetime. Roofs wear out and fail for many reasons, and some are linked to temperature. For example, higher temperatures can speed up material degradation. Cool roofs maintain a lower average temperature, so, in principle, this could slow heat-related degradation. A coated cool metal roof could be more durable and outlast a similar coated dark metal roof. Furthermore, several metal roof manufacturers believe that cooler roof temperatures slow color fading. In cases where heat-related degradation is the main reason for roof failure, it is plausible that a cool roof could be more durable and outlast a similar dark roof. More study is required to quantify these effects. Damage caused by other sources, like mechanical impacts, will not be avoided by using a cool roof. Today, manufacturers offer similar warranties for both cool and non-cool roofs.

Roof savings calculator

The Roof Savings Calculator is a simple and free online tool that allows users to calculate annual energy savings associated with choosing a cool roof instead of a dark roof.

To use this tool, you will need to answer a few basic questions about your building. The results will show you how much energy savings you can expect to achieve by choosing a cool roof versus a dark or less-cool roof, or by converting your existing roof to a cool roof.

Helpful calculators

- Roof Savings Calculator
- EPA Mitigation Impact Screening Tool (MIST)
- Cool California cool roof selection tool

Cool Roofs, Vegetated Roofs, Solar, and Insulation

There are a number of ways to use roofs to decrease the environmental toll of our built environment and to begin to use urban infrastructure as an agent of adaptation and environmental services. Installing white roofs, cool roofs, vegetated roofs, solar hot water, or photovoltaic panels can all be effective ways to improve the energy and environmental performance of roofs.

Cool roofs

Cool roofs are highly reflective roof surfaces that are minimally heated by the sun. By reducing the fraction of incident sunlight that is converted to heat by the roof, cool roofs can help cool buildings, cities, and the planet. They can reduce electricity use in air-conditioned buildings, increase thermal comfort in unconditioned buildings, reduce the urban heat island effect, and can mitigate global climate change. The most popular type of cool roof is a bright white roof. In recent years, however, cool colored roofing materials have become available for steep-sloped roofs (mostly residential). Cool colored roofing products are conventional residential roofing materials such as tile, asphalt shingle, and steel, whose pigments have a higher solar reflectivity. Compared to white roofs, cool colored roofs are less solar reflective and a bit more expensive. A cool colored asphalt shingle has a solar reflectance that is comparable to that of a vegetated roof. Cool roofs are an order of magnitude cheaper to install and pay back faster than vegetated roofs.

Vegetated roofs

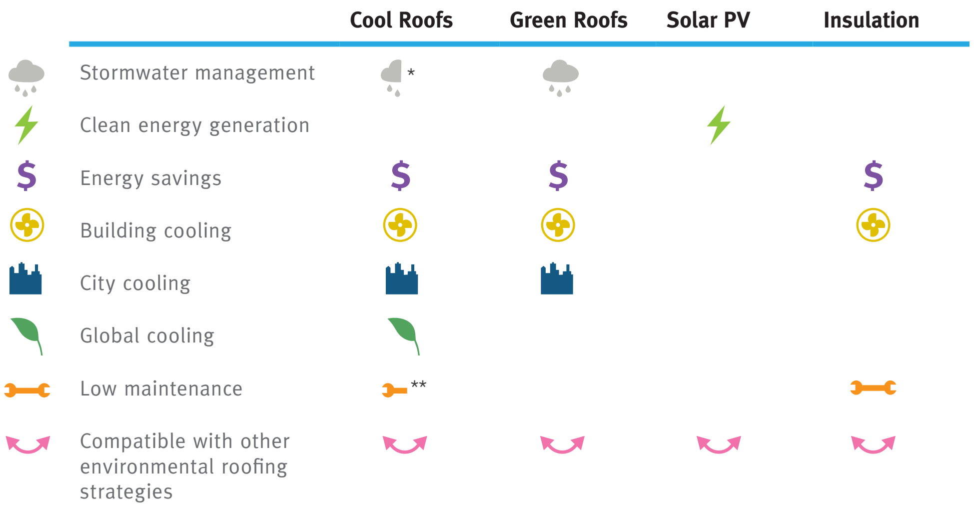
Vegetated roofs refer to roof surfaces that have been designed to incorporate large areas of vegetation. They retain and reduce peak stormwater runoff, extend the roof's service life, provide space for some urban agriculture, and improve air quality in cities. Vegetated roofs help mitigate the urban heat island effect by cooling the urban spaces around them through evapotranspiration. Vegetated roofs do not, however, provide enhanced reflectance compared to a white roof and thus would have a negligible effect on global temperature even if they were to be widely implemented.

A cool roof in Hawaii. Photo: Mikenan1

The vegetated roof at Walter Reed Community Center in Arlington, Virginia. Photo: Arlington County

Comparing Cool Roof Technologies

Source: Adapted from GCCA data. The chart below compares the properties of cool roof technologies. The icons in the chart indicate what characteristics each technology has.



* Roofs with stormwater management improvements can mitigate 100% of their stormwater runoff.
** White roofs may need periodic cleaning depending on location.

A solar PV roof in Australia. Photo: Neal Jennings

White, black, and green roof cost data

Many years ago, asphalt and labor were both cheap, and hot-mopped, black asphalt coatings were the preferred roof protection technology for flat-roof buildings in the United States. Recently, however, factory produced roof coatings and membranes, which increase roof longevity and are cheaper to install, have taken over the U.S. roofing market. Fortunately, all of these products can be finished in white. Accordingly, the cost premium of white over black has virtually disappeared, and all of these technologies run from $1 to $3 per square foot. In addition to factory produced goods, a huge driver in the adoption of white roofs has been the 2008 California Title 24 Energy Efficient Building Standard that requires flat, new, and replacement roofs to be white.

Green, vegetated roofs, however, still have a distinct cost premium over black or white roofs. According to RS Means 2012 Green Building Cost Data the least expensive type of green roof, an extensive, low-maintenance sedum system with roof access for work crews and little to no foot traffic, costs at least $20 per square foot more than a black or white roof. A cool roof with a stormwater management system is often cheaper than a vegetated roof.

Solar PV

A modern flat roof can accommodate HVAC equipment and solar applications such as solar hot water and photovoltaics (PV). Solar PV panels have a low solar reflectivity and run hotter than white or even cool-colored roofs, and they do not have the stormwater management benefits of a green roof. However, PV panels generate clean electricity, an important benefit in our global effort to transition to a low-carbon economy. PV installations also shade the underlying roof, thus helping to keep the surface cooler. Per square foot, solar hot water and PV (installed) costs roughly an order of magnitude more than cool roofs.

Most solar PV installations do not cover the entire roof surface, so the remaining uncovered sections can be cool. PV and cool roofs may be complementary technologies because PV may operate more efficiently when cooled by the wind which has just blown over the cool roof. Reduced thermal expansion and cooler wires and inverters also help make PV more efficient. Cool roofs, vegetated roofs, solar hot water, and PV are all excellent options for improving the environmental performance of a building. Which system or combination of systems is most appropriate for an individual roof will need to be evaluated on a case-by-case basis. We strongly believe that each of these options has an important role to play in reducing the environmental impact of our cities and we see plenty of room for each solution to thrive.

Roof insulation

Insulation provides thermal resistance and plays an important role in building efficiency, indoor comfort, and reducing greenhouse gas emissions. Cool roofs and insulation are complementary investments that together make up a "high-performance roofing system." Building owners considering a new or replacement roof have an opportunity to maximize the performance of their roofs by pairing cool surface materials with appropriate levels of roof insulation. Since roofs are one of the more frequently replaced building systems, there are many opportunities to add insulation to roofs and improve building performance.

Learn more about how cool roofs and insulation work together from the Center for Environmental Innovation in Roofing (ceir.org) or the Polyiso Manufacturers Association (pima.org).

Advanced research

While cool roofs are a well-developed and globally available technology. Research and development continues to advance in a number of important areas:

- **Keeping roofs cleaner, longer** White roofs soil as they age, resulting in reduced reflectance. To help improve the performance of aged roofs, researchers are developing materials that resist dirt pickup and/or chemically alter and remove deposited dirt. Dirt pickup can be reduced by using materials that are smooth and by reducing the use of plasticizers that can leach to the roof surface. Dirt can be chemically altered and removed by incorporating photocatalytic compounds such as titanium dioxide (TiO_2). Another potential benefit of using photocatalytic materials is the reduction of ground-level ozone precursors

- **More color options** White is not the only reflective color. Researchers have discovered or developed pigments and compounds that produce colors that appear identical to standard colors but are more reflective. Such colors can be significantly cooler as a result. Research efforts continue to identify new cool colors and to increase the reflectivity of cool colors.

- **Directional reflectivity** New products are also under development that would allow more precise control of how light reflects off of a surface. Such surfaces allow for pitched roofs to be reflective while appearing dark from ground level.

- **Color-shifting materials** Researchers are developing materials capable of shifting color based on temperature (thermochromic) and electrical stimuli (electrochromic). Such materials could potentially be used to mitigate the winter heating penalty or to provide aesthetic options for visible roofs. Initial research has focused on color-shifting for window applications.

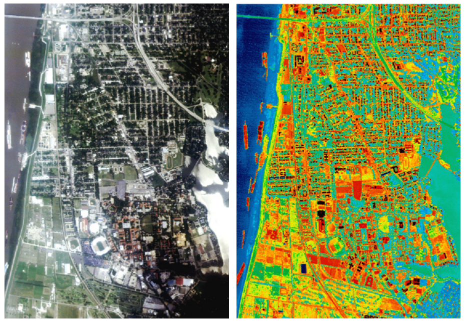
- **Clear coatings** In cases where a roof is visible and a white surface is not desired, a reflective coating that is visually clear could help increase reflectivity without causing aesthetic problems for the building owner. Clear coatings are under initial development for asphalt shingles—the predominant residential roofing material used in North America.

- **Advances in testing** The Cool Roof Rating Council tests the reflectivity and emissivity of roofing products sold in the United States. The current testing protocol requires that product samples be exposed to the elements for 3 years to determine an aged rating. Efforts are underway to simulate the 3-year aging process in a matter of days or weeks in the laboratory. In the short term, simulations would help companies reduce the cost of innovation by sending only promising materials to be formally age-tested. In the long run, the laboratory aging could replace the physical aging requirement and vastly accelerate product availability and innovation.

- **Cool pavements** Researchers are conducting field tests of permeable and reflective pavement materials and coatings to evaluate their performance and durability in a variety of usage scenarios.

- **Other** Broader geographic diversity of field testing and data sampling is necessary to better understand the benefits of cool roofs and pavements to individual communities. Field testing of widescale climate and air quality impacts of lowered urban heat island effects is needed, as is a more comprehensive accounting of lifecycle benefits and costs (e.g., roof life span, peak electricity benefits).

Dr. Ronnen Levinson taking reflectance measurements in San Jose. Photo: Lawrence Berkeley National Lab



Thermal image of Baton Rouge, Louisiana.
Source: Lawrence Berkeley National Lab

Ready to learn more:

- Environmental Protection Agency Heat Island Effect
- Global Cool Cities Alliance
- Lawrence Berkeley National Laboratory Heat Island Group
- Oak Ridge National Laboratory Building Technologies Research and Integration Center
- U.S. Department of Energy Building Envelope and Windows R&D Program Blog
- Center for Environmental Innovation in Roofing
- Polyiso Manufacturers Association

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5 Comparing a dark roof with a solar reflectance of 0.2 with a new white roof with a solar reflectance of 0.8 and an aged white roof with a solar reflectance of 0.55.

Page 12:

6 Based on Ronnen Levinson's Q&A for California Air Resources Board. Accessible here: http://heatisland.lbl.gov/sites/heatisland.lbl.gov/files/Cool-roof-Q+A.pdf

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7 Akbari et al. (2009); In some regions of the U.S., replacing a conventional roof with a cool roof will increase the need for heating energy. However, a cool roof almost always reduces the cooling load more than it increases the heating load; *see* Levinson, R., & Akbari, H. (2010). Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. *Energy Efficiency*, *3*(1), 53-109 for more information. See more under Winter heating penalty on page 32 of this guide.

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28 All roofs have some slope to them so that rain water will drain off. Low sloped roofs are typically defined as roofs with a ratio of rise to run not greater than 2:12. These roofs appear flat to most viewers.

29 Cool colored roofs strongly reflect the invisible "near-infrared" radiation that makes up nearly half of sunlight. White roofs strongly reflect both visible and near-infrared sunlight, and thus perform even better than cool colored roofs.

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30 This section draws heavily from U.S. Department of Energy. Guidelines for selecting cool roofs. Retrieved in October 2011 at http://www1.eere.energy.gov/femp/features/cool_roof_resources.html.

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Building Materials

American Institute of Architects
aia.org

Center for Environmental Innovation in Roofing
roofingcenter.org

Cool California cool roof selection tool
coolcalifornia.org/finding-a-product

Cool Roof Rating Council
coolroofs.org

ENERGY STAR Reflective Roof Products
energystar.gov/index.cfm?fuse action=find_a_product.showProduct Group&pgw_code=RO

National Roofing Contractors Association
nrca.net

Polyisocyanurate Insulation Manufacturers Association
pima.org

Reflective Roof Coating Institute
therrci.org

Codes, Standards, and Ordinances

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
ashrae.org

Building Codes Assistance Project
bcap-energy.org

California Title 24
energy.ca.gov/title24/coolroofs/

DOE Building Energy Codes Program
energycodes.gov

Energy Efficient Codes Coalition
ase.org/programs/energy-efficient-codes-coalition

IECC
iccsafe.org

IgCC
iccsafe.org

USGBC LEED Standards
usgbc.org/LEED

Cool Cities

NYC °CoolRoofs
nyc.gov/html/coolroofs

Cool Roofs Economics and Financial Incentives

Cool Roof Calculator
roofcalc.com

Database of State Incentives for Renewables & Efficiency
dsireusa.org

Partners & Stakeholder Organizations

Business Council for Sustainable Energy
bcse.org

C40
live.c40cities.org/about-us

California Energy Commission
energy.ca.gov

Global Cool Cities Alliance
globalcoolcities.org

GLOBE Alliance
globealliance.org

ICLEI Local Governments for Sustainability
iclei.org

National Association of Clean Air Agencies
4cleanair.org

R20 Regions of Climate Action
regions20.org

The Foundation Center
foundationcenter.org

US Green Building Council
usgbc.org

World Green Building Council
worldgbc.org

Technical Resources and Information Hubs

California Energy Commission
energy.ca.gov

Clean Air World
cleanairworld.org

DOE Building Envelope and Windows R&D Program Blogeere
blogs.energy.gov/buildingenvelope

ENERGY STAR
energystar.gov

EPA Heat Island Effect
epa.gov/heatisld

EPA Mitigation Impact Screening Tool (MIST)
heatislandmitigationtool.com

EU Cool Roofs Council
coolroofs.univ-lr.fr

Federal Energy Management Program Cool Roof Resources
www1.eere.energy.gov/femp/features/cool_roof_resources.html

Global Eco-Cities Survey
2009.westminster.ac.uk/schools/humanities/politics-and-international-relations/eco-cities

Human Relations Area Files
yale.edu/hraf

Institute for Market Transformation
imt.org

Lawrence Berkeley National Laboratory Heat Island Group
heatisland.lbl.gov

NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
asterweb.jpl.nasa.gov

National Association of Clean Air Agencies
4cleanair.org

National Association of State Energy Officials
naseo.org

NOAA National Climatic Data Center
ncdc.noaa.gov/oa/ncdc.html

Oakridge National Laboratory Building Technologies Research and Integration Center
ornl.gov/sci/ees/etsd/btric

World Meteorological Organization
wmo.int

* This list of resources was developed in January 2012. Check www.coolrooftoolkit.org for an up-to-date list.

Get updates at

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