January 2012

A Practical Guide to Cool Roofs and Cool Pavements

Global Cool Cities Alliance (GCCA) works with cities, regions, and other stakeholders to accelerate a worldwide transition to highly reflective, cooler, healthier cities. Its mission is to advance policies and programs that increase the solar reflectance of our buildings and paved surfaces to promote cool buildings and cool cities, and to mitigate the effects of climate change through global cooling. GCCA pursues this mission through program areas that, together, are designed to ensure that a range of mechanisms, from municipal action to advancements in research and development, act in concert to accelerate the adoption of cool surfaces.
globalcoolcities.org

R20 Regions of Climate Action
The mission of the R20 is to help states, provinces, regions, and other subnational governments around the world develop, implement, and communicate low-carbon and climate-resilient economic development projects, policies, and best practices.

The R20's low-carbon projects will produce global environmental benefits as well as local economic benefits in the form of reduced energy consumption and greenhouse gas emissions, enhanced local economies, new green jobs, improved public health, and increased climate resilience. The R20's projects will be developed and implemented by a diverse coalition of subnational governments and partners (non-profit organizations, corporations, academic institutions, intergovernmental organizations, financial institutions, United Nations programmes, and national governments.)

GCCA is a non-profit partner to the R20 and is the technical advisor on its cool roof and pavement initiative.
regions20.org

Get updates at
coolrooftoolkit.org

Be cooler.
We'll help you.

Rapid deployment of cool materials 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

Who should use this Guide

This guide was developed for a range of audiences to help speed a transition to cool roofs and pavements. Some of the information included in this guide is fairly technical and will be most useful to building operators, facilities managers, transportation engineers, developers, and roofing contractors. Some of this information is designed with city leaders and policymakers in mind and focuses on decision tools, city wide costs and benefits, and case studies. We hope that you will find this information useful and that it helps your city, region or organization reap the benefits of adopting cool materials.

There are important roles for many groups of people in making cool roofs and pavements a reality. If you are a scientist, a non-profit leader, a funder, a student, a home-owner, or a concerned citizen, we hope you will find this guide useful to your efforts as well. Regardless of your background, please share this guide with people in your city, region, organization, or corporation who will be able to use it to its fullest potential.

Acknowledgements

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We'd like to especially thank Dr. Arthur Rosenfeld, Dr. Ronnen Levinson, Haley Gilbert, Benjamin Mandel, and Julian Sproul of the Lawrence Berkeley National Laboratory Heat Island Group for their technical review of the Primer sections. We also thank Marc LaFrance of the U.S. Department of Energy for his support.

Additional Resources Online

coolrooftoolkit.org

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Ready to Learn: Primer

Build your own knowledge or use this as a tool to educate your colleagues.

Ready to Act: Implementation Guide

Use these tools and best practices to start or grow your own cool surfaces program.

Ready to Learn

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]

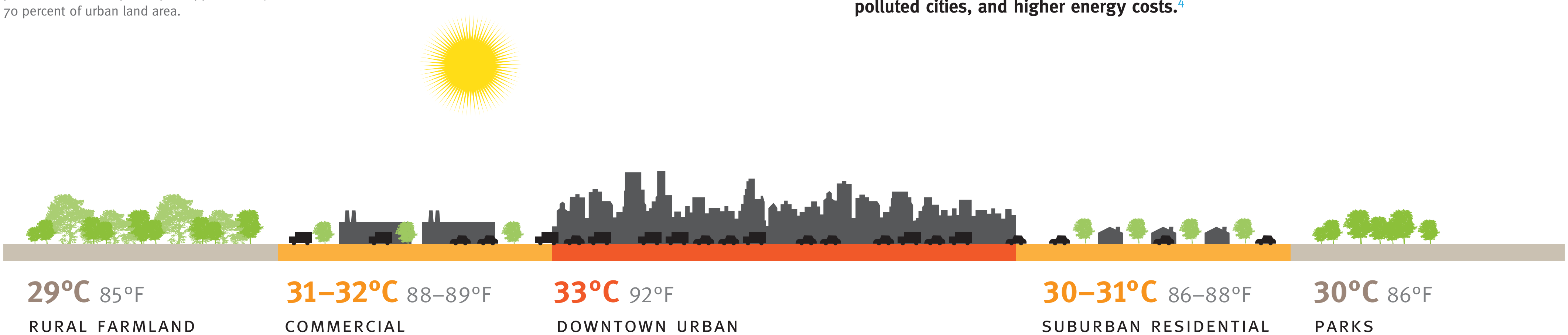
Cool roofs and pavements can help cool down buildings and cities.

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

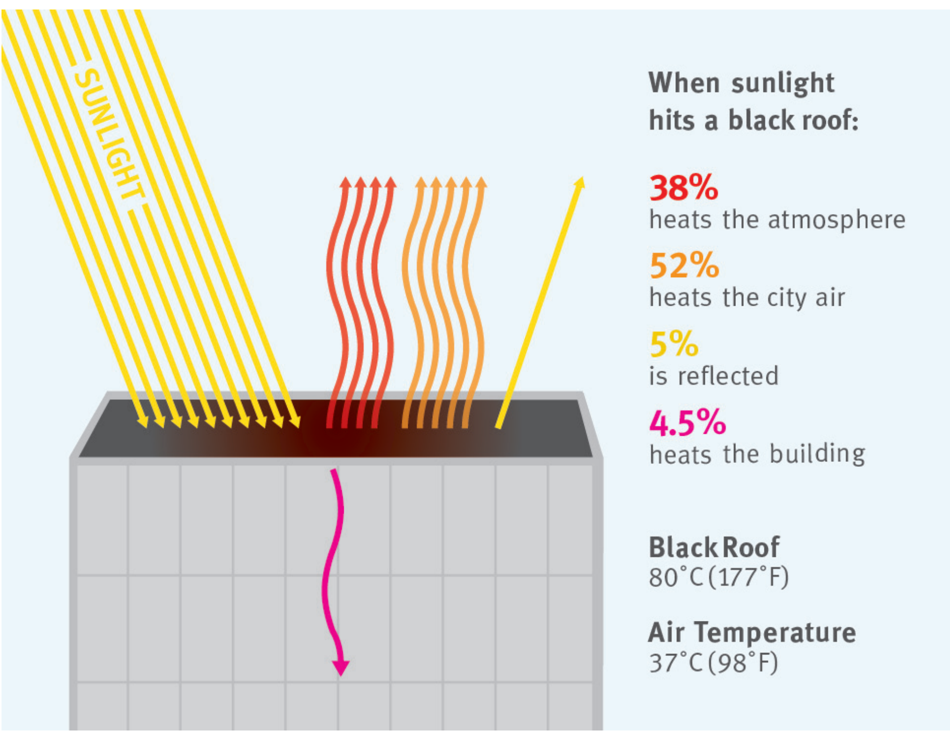
It's simple.

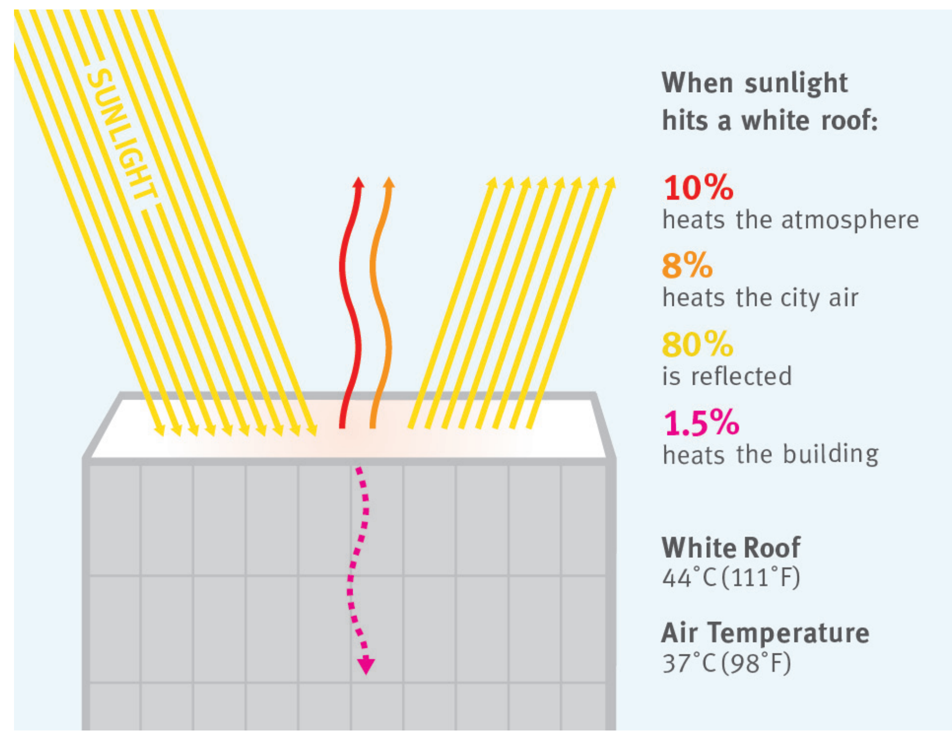
Cool surfaces are measured by how much light they reflect (solar reflectance or SR) and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive 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)

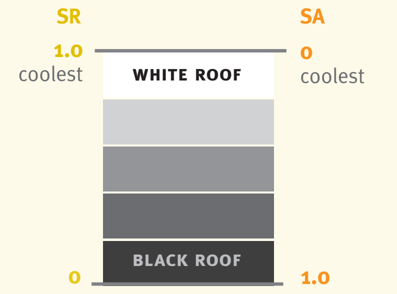
The efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance, which means it 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.

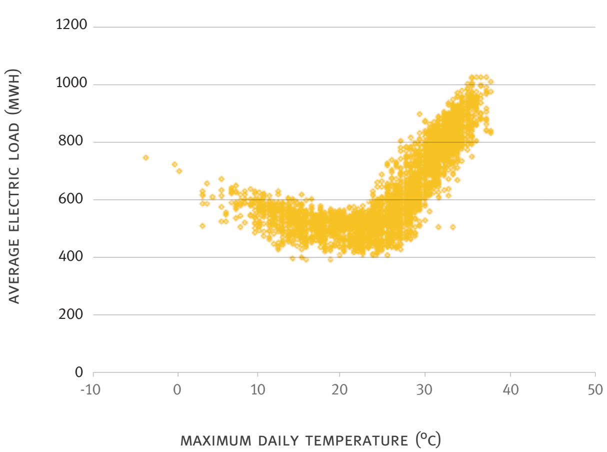
About 20 to 25 percent of urban surfaces are roofs and 30 to 45 percent are pavements. Photo: Eric Konon

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.

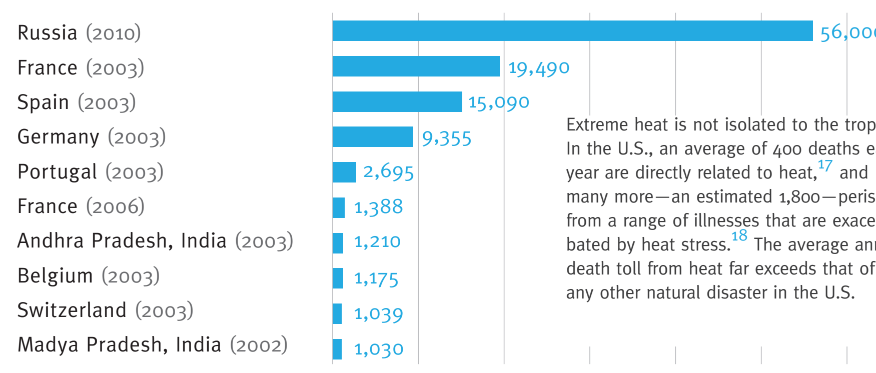
A hot summer day in Chicago. Photo: Zane Edwards

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.

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]

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.

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

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.

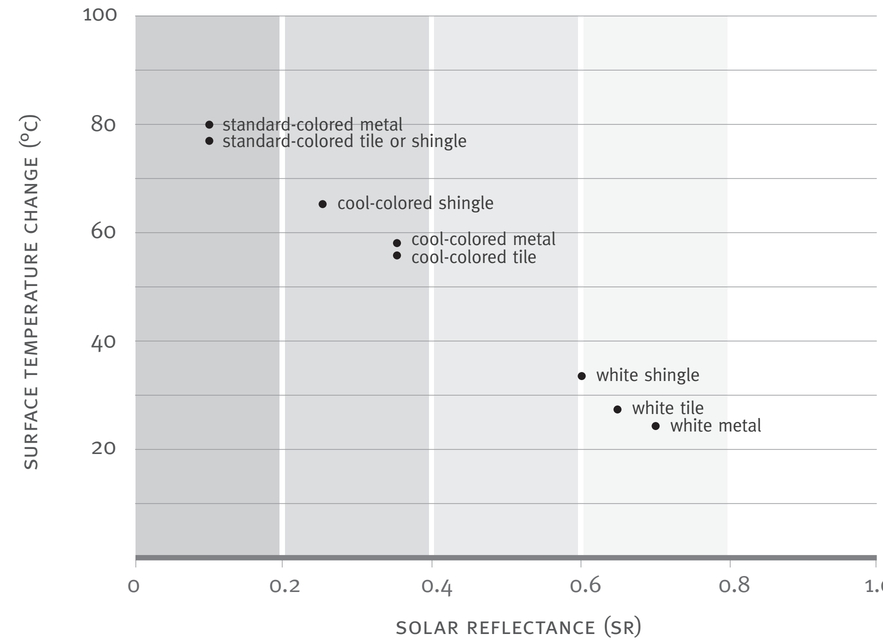
Beware of "paint"

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.

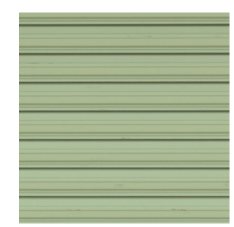
Solar Reflectance of Common Roofing Materials
Surfaces that are more reflective tend to remain cooler than those that are less reflective. Both solar reflectance and (surface) temperature rise should be considered when assessing a cool surface material. The graph shows solar reflectance and temperature 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

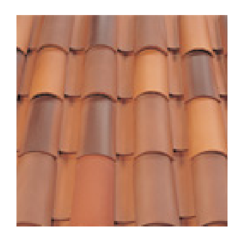
STANDARD | COOL-COLORED | WHITE

Uncoated metal

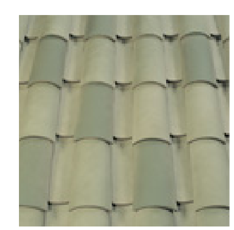


Cool-colored metal (coated)

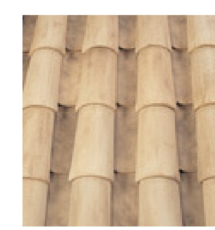
White metal (coated)



Ceramic tiles

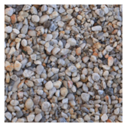
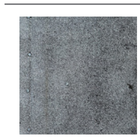
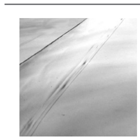


Cool-colored clay tiles



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 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.

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

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.

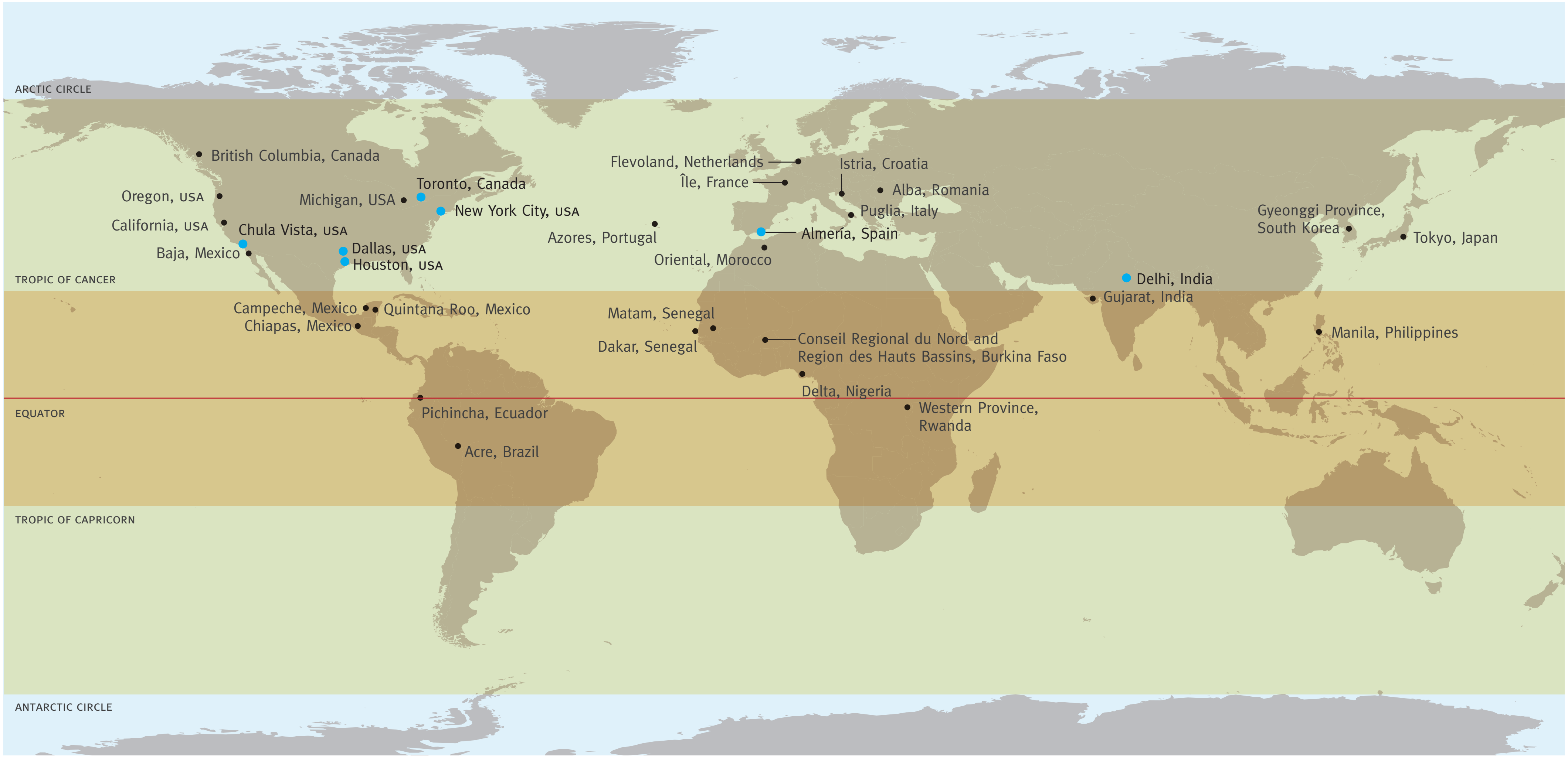
Climate Factors

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



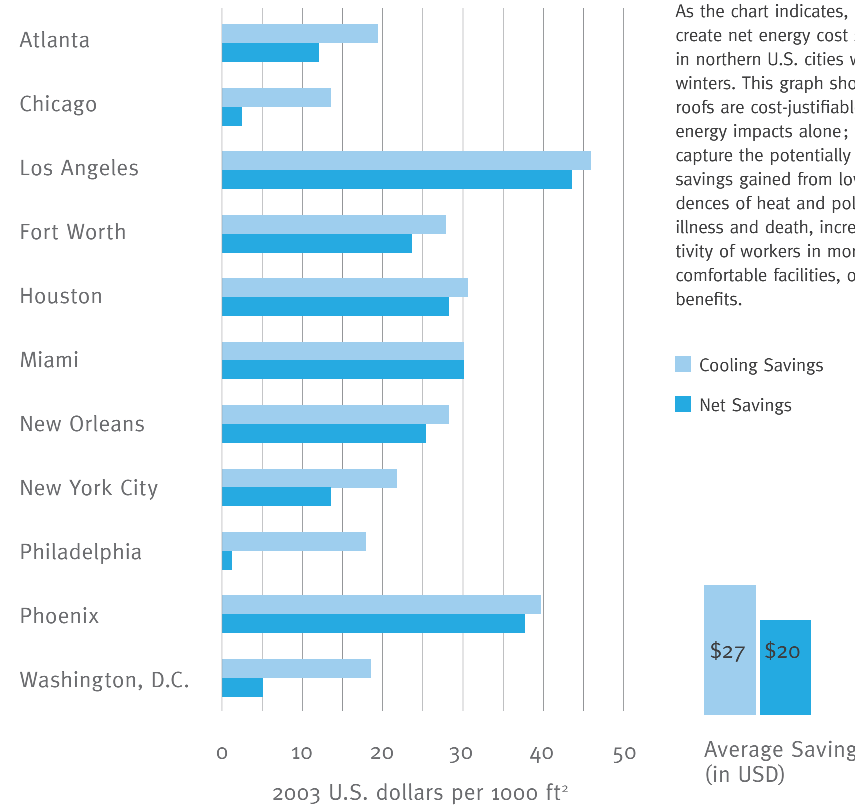
Winter heating penalty

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

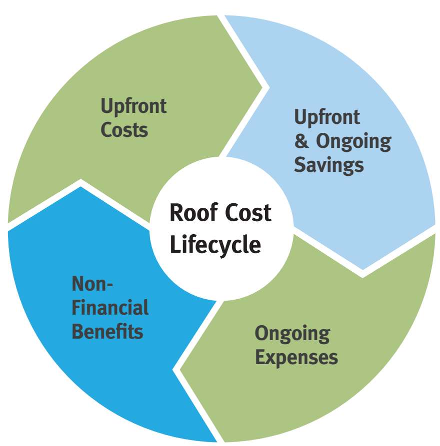
Disposal and Replacement

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/ft²) *	Premium to Include Coatings as part of Roof Replacement (USD/ft²) **
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.

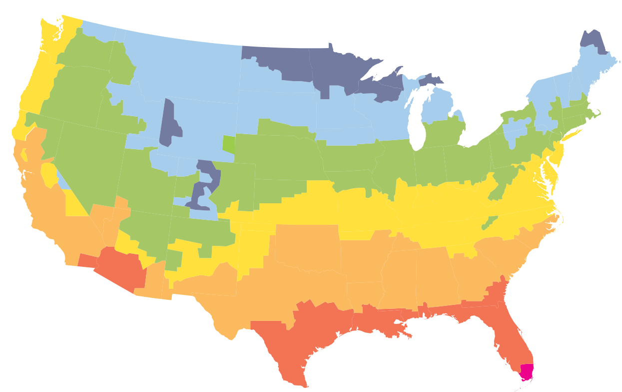
In cold climates, attics can accumulate moisture through condensation, and this may eventually lead to material degradation. Moisture control in cold climates is an important part of any roof's design. It is possible, though not yet proven, that cool roofs might be more susceptible to accumulating moisture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

	Cool Roofs	Green Roofs	Solar PV	Insulation
Stormwater management	✓ *	✓		
Clean energy generation			✓	
Energy savings	$	$		$
Building cooling	✓	✓		✓
City cooling	✓	✓		
Global cooling	✓			
Low maintenance	✓ **			✓
Compatible with other environmental roofing strategies	✓	✓	✓	✓

* 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.

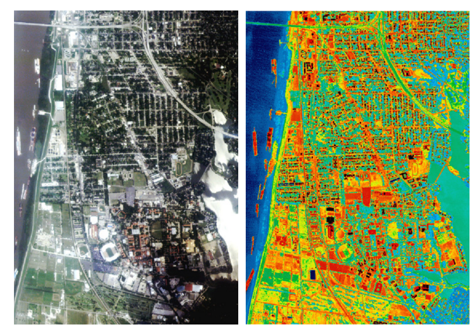
Dr. Ronnen Levinson taking reflectance measurements in San Jose. Photo: Lawrence Berkeley National Lab

- **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).



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

Ready to Act

Spreading the best practices and successes of existing initiatives

This guide is organized around two basic categories of activities to simplify the process of building and launching a successful cool roof and pavement effort: Foundational Activities and Implementation Activities.

Foundational Activities are important preparatory steps to building a solid base for launching programs, projects, and policies and should be conducted in advance of beginning Implementation Activities.

Implementation Activities offer best practices, case studies, and guidance for a variety of different cool roof and pavement program strategies. Implementation Activities are roughly broken into programs and policies. Implementation Activities can be undertaken in any order, or conducted in parallel since many are designed to be mutually supportive.

Implementation Guide

Foundational Activities

> It is quite amazing—the payback on these kinds of [cool roof] investments really are very quick and make an enormous difference.
>
> —New York Mayor Michael Bloomberg

Associated Press, "Bloomberg Hypes Energy Efficient Rooftop Painting." NYPost.com, September 24, 2009.

Foundational Activities

Good programs, like buildings, may look very different from one another but all must be built on solid foundations. The Foundational Activities described below cover some of the basic requirements to launching a successful cool program including

- Identifying existing activities
- Assessing local potential
- Building local support and capacity

These steps can be taken in any order, but each is an important part of developing a popular, measurable, and successful cool roofs and pavements program.

Foundational activities should be conducted in advance of beginning Implementation Activities. Use this checklist to get started.

Identify Existing Activities

Key questions:

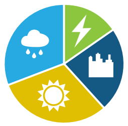
- Are cool surfaces a part of existing strategic plans, codes, laws, or incentives?
- To what extent have cool materials been widely deployed in my region to date?
- Are any high profile buildings already cool?

Key actions:

- ☐ Identify existing climate/sustainability plans for your city, state, or region.
- ☐ Research existing building and energy codes, laws, and incentives.
- ☐ Review aerial and satellite imagery to determine penetration of cool surfaces.
- ☐ Review thermal maps to identify urban heat centers.

Resources:

- Capital E
- Cool Roof Rating Council
- Dallas and Houston, TX case studies
- Database of State Incentives for Renewable Energy
- Energy Coordinating Agency of Philadelphia
- EU Cool Roofs Council
- Global Eco-Cities Survey
- Weatherization Assistance Project
- The White Roof Project



Assess Local Potential

Key questions:

- What types of buildings and pavements are in my area?
- What climate zone am I in and what are common weather patterns?
- What is the cost and demand for energy (electricity and gas) in my area?
- What is the market availability of cool products locally?

Key actions:

- ☐ Identify weather and air quality data files as well as building construction and pavement characteristics.
- ☐ Work with utilities/grid operators to secure energy use and pricing data and compare to temperature data.
- ☐ Engage local contractors, distributors, and manufacturers to determine availability of cool products.
- ☐ Develop the economic case for cool surfaces.

Resources:

- Center of Environmental Innovation in Roofing
- ENERGY STAR
- Human Relations Area Files
- NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
- NOAA National Climatic Data Center
- National Roofing Contractors Associations
- World Meteorological Organization

Build Local Support and Capacity

Key questions:

- How can cool roofs and pavements champions and stakeholders be identified and organized?
- How can we fund activities and programs?
- What existing resources and networks are available for technical support, training, and best practices?

Key actions:

- ☐ Find supporters and attract funding. (Start early!)
- ☐ Identify technical resources locally and globally.
- ☐ Join or leverage existing memberships in city/regional organizations.
- ☐ Develop local training and education programs.

Resources:

- The Business Council for Sustainable Energy
- The Foundation Center
- GLOBE Alliance
- National Association of Clean Air Agencies and Clean Air World
- Organizations of governments such as R20, ICLEI Local Governments for Sustainability, and C40
- World Green Building Council
- US Green Building Council

Identifying Existing Activities

Are cool surfaces a part of existing strategic plans, codes, laws, or incentives?

The first step in any effort to promote cool roofs and pavements in your city or region is to understand what has been done to date to support their adoption, and what plans are in place to further their adoption in the future. Start by determining if cool roofs and pavements are already a part of strategic plans or covered in existing ordinances or building and energy codes.

Ask: *Is there a "visioning" process in place? If so, does it include a building efficiency or city cooling effort? If not, what is the process for adding to or amending the plans to include cool roofs and pavements?*

Strategic plans

The most likely place to find support for cool roofs and pavements is in your city or region's existing strategic plans (e.g., climate action plans, regional sustainability plans, etc.). First, determine whether or not there is a "visioning" process underway in your city or region (most cities and regions have these already developed or underway). These documents are often available on a city's official website. If such a process or document has been developed, check to see if it includes a building efficiency effort or a city cooling effort. These may be identified as "urban heat island mitigation" initiatives.

Strategic plans to research:

- ☐ Climate action plan
- ☐ Regional sustainability plan
- ☐ Adaptation plan
- ☐ Urban heat island mitigation initiatives

Ask: *Are cool roofs included? What about cool pavements? Have they been considered? How are they included? What does the plan stipulate? If not, what is the process for getting them included?*

If cool surfaces are not already a part of your city or region's sustainability, climate action, or adaptation plans, or you feel that the plan's attention to cool surfaces could be strengthened, learn what the process is for adding to or amending these plans and begin to advocate for the inclusion of cool surfaces. It is important that any program set three, five, and ten year goals and include both pavements and roofs.

Codes and ordinances

The next place to look to understand what kind of support your city or region currently provides to cool roofs and pavements is in existing codes and laws. Check your city or region's building codes or pavement specifications to see if they include cool roofs or cool pavements. If they are included, what are the specifics?

Policies to research:

- ☐ City/region building codes
- ☐ City/region pavement specifications

Incentive plans including:

- ☐ Tax credits
- ☐ Utility rebates
- ☐ Loan programs

Learn more about building codes and incentives:

- Cool Roof Rating Council's website
- Database of State Incentives for Renewables & Efficiency

Ask: *Does the code make cool surfaces mandatory? Are they included in a prescriptive code and therefore encouraged but not required? If the code sets whole building performance standards, do cool roofs and pavements count towards achieving the results?*

In some cases, cities will adopt a national standard. A list of popular national standards and their treatment of cool surfaces is on pages 72–73. Performing a local search is still important in places that have adopted national standards because there may be modifications made locally that strengthen or weaken the language on cool surfaces. One easy way to check codes and ordinances in your region is to review the Cool Roof Rating Council's list of cities/states with cool roof building codes.

Rebates and Incentives

Your city, region, and/or local utility may have incentives for cool roofs or cool pavements. Common incentives include tax credits, utility rebates, and dedicated loan programs. Note that most loan programs are designed to support energy efficiency upgrades in general, and include cool roofs in some instances. The Cool Roof Rating Council and the Database of State Incentives for Renewables & Efficiency (DSIRE) are both good resources for incentive programs, as well as codes and ordinances, for cool roofs and pavements.

For information on codes, ordinances, and incentives outside of the U.S., try the European Cool Roofs Council or local building technology research institutions.

Case Study

Walmart: An Early Corporate Leader

Walmart has been an early corporate leader in deploying cool roofs on its stores. The retail giant began to install cool roofs on its facilities approximately a decade ago, and subsequently included cool roofing in their prototype store design. Now, approximately 75 percent of its nearly 4300 stores have white roofs. Internal studies found that, in most locations, having a reflective roof was a cost-effective investment that helped cut the energy budgets of individual stores.

How cool is my area already?

As a next step in understanding to what extent your city or region is "cool" already, identify the existing market penetration for cool surfaces in your region. A good place to start is by reviewing aerial or satellite imagery (such as those publicly available via Google Earth) to get an approximate sense of how light your roofs and pavements are already. Identify any high-profile buildings that have installed cool surfaces. University buildings, schools, government offices, and other landmark buildings can be used to build broader interest in cool surfaces. For example, the Department of Energy's Forrestal Building is being retrofitted with a cool roof, the University of California–Davis has installed cool roofs across its campus, Walmart has adopted a cool roof policy for its stores, and the City of Phoenix has installed a cool parking lot in its downtown area.

The Walmart and Sam's Club in Chino, CA, are both equipped with white roofs and solar panels to help Walmart reach its goal of being supplied by 100 percent renewable energy. Photo: Walmart Stores

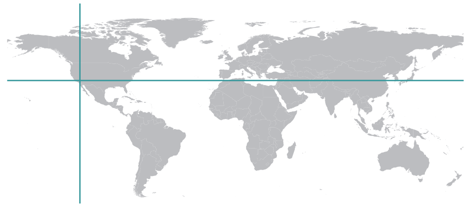
Walmart sustainability website

Case Study

Chula Vista, California: A Cool Roof Initiative within a Climate Adaptation Plan

City of Chula Vista

Chula Vista, California, U.S.A.
Mayor: Cheryl Cox
Population: 243,916
Coordinates: 32°37'N, 117°2'W



Background

In 2000, Chula Vista adopted a Carbon Dioxide (CO_2) Reduction Plan, which outlined steps for the City to reduce energy and fuel use as a means of achieving its commitment of reducing its greenhouse gas (GHG) emissions 20 percent below 1990 levels. The City's climate protection programs and policies have been a great success, helping Chula Vista reduce GHG emissions from municipal operations by 47 percent and community per capita emissions by 27 percent compared to 1990 levels. As a result, the City has been recognized for its climate-related accomplishments by multiple external organizations including the U.S. Environmental Protection Agency, ICLEI – Local Governments for Sustainability, California Sustainability Alliance, and the Sierra Club.

To complement these climate mitigation efforts, the Chula Vista City Council directed city staff in October 2009 to reconvene a Climate Change Working Group (CCWG)—comprising of residents, businesses, and community representatives—to develop a list of recommended strategies to reduce Chula Vista's vulnerability to expected local climate change impacts (i.e., a climate adaptation plan). Expected impacts include hotter and drier weather, diminished imported water supplies, more poor air quality/heat wave days, and increased rates of sea level rise. Stakeholders participating in the CCWG included representatives from development companies, business associations, energy and water utilities, environmental organizations, and education institutions.

The group held 11 public-noticed meetings between December 2009 and August 2010 to review potential impacts and identify over 180 opportunities to reduce these risks. In addition, the CCWG held two public workshops on climate adaptation planning to solicit additional feedback. The CCWG was further supported by regional experts, climate scientists, and staff from multiple municipal departments.

In October 2010, the Climate Change Working Group presented their 11 recommended Climate Adaptation Strategies to the City Council to address climate change vulnerabilities and solutions related to energy and water supplies, public health, wildfires, biodiversity, coastal resources, and the local economy. As a result, City Council directed city staff to develop more detailed implementation plans for the 11 recommendations, which would outline implementation steps, timelines, and costs.

Highlight

The recognition that average annual temperatures in Chula Vista are expected to increase up to 2.5 degrees Celsius (4.5 degrees Fahrenheit) by 2050 with summer temperatures increasing even higher, and that these rising temperatures, in tandem with a growing population, would cause peak electricity demand to grow by over 70 percent, led the Climate Change Working Group to carefully consider adaptation strategies that would help reduce the urban heat island effect. Cool paving and cool roofs are both recommended strategies.

Cool pavements

The CCWG recommended that the City develop an ordinance incorporating cool pavements into all municipal projects (parking lots and streets) and new private parking lot projects over a specific size. The City has committed to the following actions:

Chula Vista, California. Photo: Port of San Diego

Chula Vista residents. Photo: City of Chula Vista

Cool paving study and test area
The Public Works Department (Operations & Engineering) will perform a pilot project to evaluate multiple reflective or cool pavement strategies to help inform creation of new policies for municipal paving capital improvement projects and private parking lot projects.

Cool paving study results and standards options
Based on the study results, city staff will develop options for incorporating reflective pavement into all municipal projects and private parking lot projects over a specific size. The options will be presented to City Council for review and consideration.

Cool roofs

The CCWG recommended that the City require and provide incentives for new residential developments with air-conditioning systems to install ENERGY STAR cool roof technology. The City has committed to the following actions:

Municipal building code update
The Building Division will further evaluate cool roofing options and propose amendments to the City's Green Building Standards to require cool roofs on new residential developments with air conditioning. Chula Vista Municipal Code Chapter 15.12 adopts and amends the 2010 California Green Building Standards Code (CalGreen). Currently, cool roofing is a voluntary measure in CalGreen, and staff will be proposing to make these measures mandatory. Staff will also evaluate the cost and benefit of requiring cool roofs on new residential developments without AC systems. Even though city staff is not proposing amending the California Energy Code to require cool roofs, the California Energy Commission will have to approve any cool roof ordinance before it can take effect.

Shade trees

Planting shade trees, another effective cooling measure, is also one of the 11 recommended strategies included in Chula Vista's Climate Adaptation Plan.

All of the recommended Climate Adaptation Strategies include performance metrics and discrete timelines and budgets. The expected budget for the initial implementation of both the Cool Pavements and Cool Roofs programs is $144,000 and ongoing annual expenses are estimated at $8,500.

Note: All of the content included in this case study is pulled from Chula Vista's Climate Adaptation Strategies DRAFT Implementation Plans, February 2011.

Unless otherwise noted, all dollars refer to USD.

chulavistaca.gov/clean/conservation/Climate/documents/ClimateAdaptationStrategiesPlans_FINAL_000.pdf

Assess Local Potential

Though it is clear that cool roofs and pavements are a net benefit almost everywhere, the exact benefits and costs of cool surfaces will depend on a variety of locally specific conditions. Measuring the many aspects of a cool initiative is critical to tracking progress, identifying successes and areas for improvement and raising awareness within the community and beyond. The first step is establishing a baseline of basic data and performance.

Building and pavement characteristics

Building type and age play a major role in determining the energy savings and indoor comfort benefits of cool roofs and pavements. Building data can be captured through tax records, permits, aerial imagery, and other sources. It can be very helpful to engage the local utility early in this process. There may also be existing files gathered for research projects, so checking with scientific institutions, universities, state energy agencies, or code bodies may be helpful. Anthropologists collect a great deal of useful building and behavioral data that could be helpful for your analysis. Local universities will often have access to the Human Relations Area Files that contain this information. Google Earth is a user-friendly and public resource for rough aerial imagery. Space agencies may have more advanced aerial visual or thermal imagery (e.g., NASA's ASTER satellite imagery) for locations around the world.

The data points in the boxes below will help you characterize your local built environment.

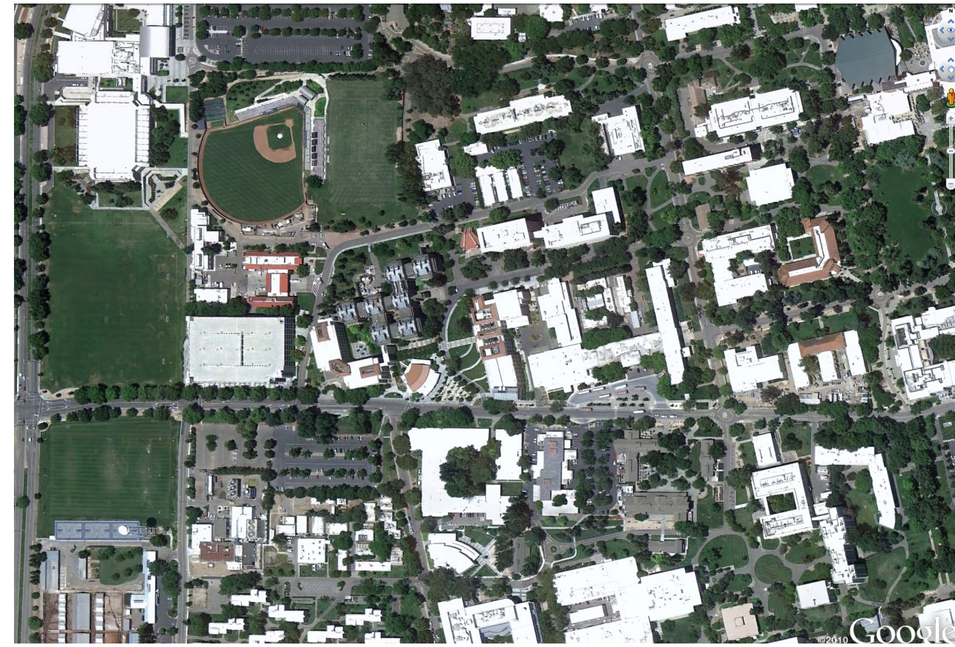
Data points to collect: Roofs

- ☐ Urban fabric: Estimates of percentage of surface area covered by roofs, pavements, and other surfaces
- ☐ Total roof area: Commercial roof space (or percentage), residential roof space (or percentage), flat versus sloped roofs
- ☐ Estimated average building age (broad categories)
- ☐ Existing building codes for roof and roof insulation requirements
- ☐ Estimated roof life
- ☐ Market share of local roof types and materials

Data points to collect: Pavements

Research local/regional transportation agencies or gather from aerial imagery.

- ☐ Total amount of pavement area (often described as lane miles)
- ☐ Percentage of land area paved
- ☐ Pavement area by ownership/responsible party (City roads, county roads, private roads, parking lots, and highways could be administered by city, county, state, national, or private stakeholders)
- ☐ Frequency of repair or repavement (Typically, parking lots are most frequently replaced, followed by city/county roads, then highways.)
- ☐ Materials used by road type



Google Earth view of UC Davis in Davis, California. Photo: Google Earth

Weather, climate, and air quality

Weather and climate data is equally as important as building data for an evaluation of the local benefits of cool surfaces. Weather data is often available from public sources or through local meteorologists or researchers. The NASA Atmospheric Science Data Center and the World Meteorological Organization offer access to key climate statistics for regions around the world. Air quality measurements can be obtained from local universities, health departments, environmental ministries, or other researchers. Having estimates for the characteristics in the list to the right is helpful.

Weather data points:

- ☐ Average annual solar insolation (the amount of solar radiation energy received on a given surface area in a given time, usually given in watts per meter squared (W/m^2))
- ☐ Average wind speed
- ☐ Maximum and minimum daily temperatures, degree days cooling and heating or average temperature by day for several years
- ☐ Air quality (pollutant types and frequency)
- ☐ Frequency of extreme heat events

Energy use and pricing

Utilities and electric grid operators have access to important data such as source energy mix, energy pricing, and usage statistics. These data sets can often be shared at an aggregated level. Both New York City and New Orleans created a helpful chart by combining energy use data with average daily temperatures to determine how much cooling costs rise per degree of maximum daily temperature. This kind of analysis creates a simple methodology for valuing incremental drops in temperature. (see New Orleans Hot Weather Energy Demand on page 14).

Local roofing market

The roofing industry will have the most locally specific market information and should be engaged early in the scoping process. Talk with large local contractors, distributors, and manufacturers to evaluate the market availability of various cool roofing and pavement products and to understand the cost differences (if any) between cool and uncool products.

☞ Ask: *Are major roofing players marketing cool products? Is there demand for these products and, if so, from what types of building owners? What questions are consumers asking about cool products? Have contractors required additional training to install cool surfaces? What benefits and challenges have consumers raised?*

Making the case for white roofs in Chula Vista.
Photo: City of Chula Vista

Making the case

An evaluation of the impacts to your city or region from cooler roofs and pavements will be very useful in helping build support and momentum for policies and programs. Start by reviewing detailed feasibility studies conducted by other cities and regions that helped inform their cool roof policy and code-making initiatives. While these won't be as accurate as a custom local study of your region, it is worthwhile to review existing analyses before undertaking a new one. Existing studies provide insights into good methodologies to include in your own study. In cases where a city/region has a similar built environment and climate to yours, the results can be a good starting point for your own analysis. Examples of existing studies and initiatives can be found at the Global Cool Cities Alliance website.

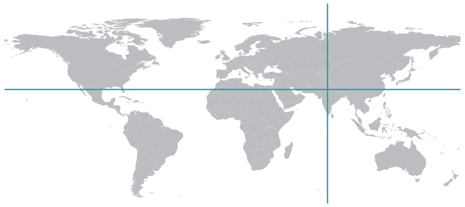
If no current study exists and your city or region is ready to engage in a customized analysis of the potential impacts of going cool, the first steps are to scope out the study, develop a request for proposals, and identify an individual researcher, or organizations that can take on the work. Local research facilities or consulting groups can be ideal partners for such a study. The study would use the data collected (see page 52 and 53) to evaluate the energy, health, and other benefits of a cooler city/region as well as offer some suggestions for a deployment strategy. The cities of Houston and Dallas both worked with the Houston Advanced Research Center to develop detailed analyses of the potential for various urban heat island mitigation technologies in their metro-regions. You can read about these efforts in the case study on page 69. Local universities could be a valuable source of analytical support and technical assistance. In some cases, graduate students can provide free or low-cost support.

Case Study

Delhi, India: Cool Roofs on High-Profile Buildings

Delhi Department of Environment

Delhi, India
Chief Minister: Sheila Dikshit
Population: 19.8 million
Coordinates: 28°36'N, 77°13'E



A new program in Delhi offers a good illustration of the best practice of using government buildings as test sites, the benefits of having a strong local champion, and how to maximize the value of pilot projects.

In January 2011, the Chief Minister of the City of Delhi announced a pilot project to install cool roofs on some government buildings in the city. Delhi will start with high profile sites like the Delhi Secretariat (shown below) as well as all government schools and some hospitals. A number of different cool roof materials will be used, including elastomeric coatings, lime coatings and tiles. Technical experts will measure the demonstrations to generate locally relevant cool roof performance data. The choice of schools and hospitals has the added advantage of using sites that are accessible to the public. Visibility of these demonstration projects to the public will help raise awareness of the energy saving and thermal comfort benefits of cool roofs.

The pilot comes amid a severe power shortage in the region. The highest levels of the Delhi government have embraced cool roofs as an important step to take to save energy and reduce peak demand. The involvement of city leaders in championing the project helps to maintain the momentum of the initiative.

The goal of the program is to grow in phases. Ultimately, the Chief Minister envisions a longer-term pilot program that would include a neighborhood sized sample area to demonstrate the citywide benefits of cool materials. Such an approach allows for growth in the size of the project (and in the breadth of the information gathered) by leveraging earlier work.

Delhi Secretariat building. Photo: Laurie Jones

Buildings in Old Delhi. Photo: gwgs

Build Local Support and Capacity

As beneficial as cool surfaces are, there will always be competition for local resources, time, and effort amongst worthy policy objectives. Building local awareness of and support for cool surfaces is a critical task to start early. There are a wide variety of important stakeholders that should be a part of the planning process. One way to bring these disparate groups together and to build momentum and catalyze action for cool roofs and cool surfaces is to develop a steering or leadership committee of key agencies and private stakeholders to oversee implementation and provide a point of contact for decision-makers.

Best practices for official buy-in:

- ☐ Identify and approach other key entities that can organize across agencies (e.g., regional managers, finance agencies, school districts, planning offices), and other regional organizations like air and water quality agencies which may become important partners.
- ☐ Strive to inform and include representatives from local departments of energy, environment, transportation, public works, housing, and health.
- ☐ Regional planning agencies may already include a robust stakeholder mix and should be approached early in the process.
- ☐ Departments with a large portfolio of buildings, such as school districts, universities, and corporate campuses should be brought into the early stages of the process.

Local officials

A city or region-wide transition to cool materials will be accelerated in those cities or regions where the leadership prioritizes and actively promotes the concept of going cool. A focused effort to garner the buy-in and support of top officials and key stakeholders is an important component to any cool surfaces campaign. Support from top officials (governor or mayor, if possible) will help secure buy-in across relevant governmental departments, and help raise awareness and visibility for cool roofs as an effective mitigation and adaptation strategy.

Building owners

Ensuring widespread installation of cool roofs and cool pavements requires that the people responsible for selecting roof and pavement materials are well informed about cool surface options, benefits, and costs. A high level of education is especially important for those who make decisions about surfaces that are repaved or reroofed frequently. An information campaign targeted at key decision-makers is an important element of developing support and momentum for cool surfaces. Key decision-makers include policymakers, but also building owners and industry professionals such as local contractors and architects. Converting major commercial building owners into cool roof champions can be an effective way to quickly catalyze the transition to cool materials because they often own both a significant amount of roof area and some of the most high profile buildings. Furthermore, they are often politically influential and can typically move more quickly than governments. To engage local building owners, start by creating an inventory of major commercial building and/or parking lot owners (e.g., industrial/manufacturing complexes, large retailers, major residential developers) and identify high profile buildings that might be a good fit for cool roofs (e.g., stadiums, conference centers, large hotels, university campuses). Help

A white roof on the Phoenix Civic Center, a focal point of activity in downtown Phoenix, AZ. Photo: United Coatings

building owners run the modeling necessary to determine whether or not cool roofs will be a profitable investment for them. These tools are publicly available online. For example, The Roof Savings Calculator is a good starting place: roofcalc.com.

Other champions

It is important that early on in the development of your cool city campaign you identify existing or potential champions who will be able to drive cool roofs implementation to the next level in your city or region. These champions may include manufacturers, building owners, roofing contractors, and/or utility program officers or executives. Share this guide with them! If no strong existing or potential champions exist, consider becoming a champion yourself. To do this, use this guide to become a cool roof and pavement expert.

General public

Eventually, everyone in your city or region will have a role to play in transitioning to cool surfaces. By the time your campaign requires public outreach, it should have specific programs developed that members of the public can opt into (e.g., tax incentives, utility rebates, corporate sponsorship opportunities).

Attracting funding

One of the major challenges of any new initiative is finding ample funding. There are a variety of funding options and combinations to consider (see checklists on page 59).

When building a local stakeholder group, consider what kind of funding each partner has access to and expertise in securing.

Landscape architect Ruth Fox discusses the green roof at Water Tower Place with residents in Cedar Rapids, Iowa.
Photo: 350.org

Develop local training and education programs
Demonstration projects, code changes, new incentives, and other policies are opportunities to raise awareness about cool surfaces. Each can be a useful channel around which to build cool roof training. Target initial training sessions with local building trades, architects/designers, and other construction stakeholders. The American Institute of Architects already runs a periodic training for architects on cool roofs and coatings, and may be a good distribution partner. In addition, local contractor, labor, and roofing consultant networks can identify existing curriculum or help design new training materials. Training materials should include a discussion of the interaction between roof insulation and cooler surfaces, as well as other building system impacts. Training methods include web-based information, informational videos, and in-person workshops. These training programs can be developed in coordination with local building and roofing organizations to ensure that information is consistent.

California's cool roof requirements have included a wide range of outreach and education activities including online training and training videos for code enforcement staff and building trades. You can view some of their training documents here: energy.ca.gov/title24/

Some cities have developed volunteer programs to coat roofs. Volunteers supplement the work of contractors and typically work on different buildings than those serviced by most contractors (e.g., public buildings, lower income dwellings, buildings owned by non-profit organizations). For example, New York City has coated almost 2 million square feet of rooftop during its two-year old cool roof volunteer program. The city pays for about 50 percent of the cost of materials and organizes the volunteers. Such programs help raise public awareness of cool surfaces, complement the work of the private sector, and deliver a steady stream of good press about cool surfaces.

Identify technical resources locally and globally
Building relationships with local and international experts will be extremely valuable as you develop a cool surfaces program. These experts—researchers, academics, manufacturers, consultants, and more—have a wealth of knowledge and experience. Identify building or energy research centers in your area. These groups often have cool roof and pavement expertise and a deep understanding of the local market.

The University of California Energy Institute maintains a comprehensive list of regional energy institutes. You can search their list here: ucei.berkeley.edu/ucei/nrgorgs.html

The Global Cool Cities Alliance, Lawrence Berkeley National Laboratory's Heat Island Group, Oak Ridge National Laboratory's Building Envelopes Group, and Environmental Protection Agency Heat Island Group should all be able to assist you directly or help identify resources in your area. These officials are often involved with research and experts in the cool roof and pavement space. Another avenue is to connect with your country's energy or environmental ministry.

Scientists and educators from the Smithsonian Conservation Biology Institute and George Mason University attend a groundbreaking ceremony for a new green design conserbation complex in Virginia
Photo: Smithsonian's National Zoo

Join or leverage existing memberships in city/regional organizations
Groups like GCCA, R20, ICLEI, National Governor's Association, C40, and others have networks to connect you to program managers and decision-makers in other regions. Attend workshops, meetings, and conferences.

Funding ideas:

- ☐ Secure funding from local, state, or federal government grants. Apply for grants from national agencies.
- ☐ Identify funding opportunities from multilateral sources.
- ☐ Seek out philanthropic support.
- ☐ Require contributions from building owners.
- ☐ Partner with corporations.

In-kind support ideas:
Cities can also seek in-kind support that will offset an expense they would normally incur running programs. For example

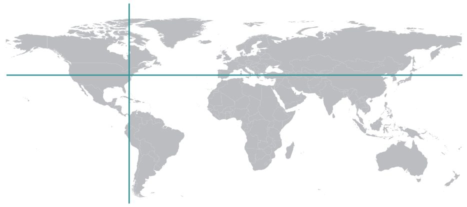
- ☐ Volunteer programs
- ☐ Bulk material discounts
- ☐ Technical support and training
- ☐ Program marketing assistance

Case Study

NYC °CoolRoofs: A Successful Volunteer Initiative

NYC °CoolRoofs

New York City, New York, U.S.A.
Mayor: Michael Bloomberg
Population: 21.3 million
Coordinates: 40°43'N, 74°00'W



Background

In 2007, New York City's Department of Design and Construction conducted a study on cool roofs and green roofs to better understand the applicability, technicalities, costs, and benefits of both roofing strategies. (Download the study here.) One driver of this study was the finding that New York City was 13 to 14 degrees Celsius (5.4 to 7.2 degrees Fahrenheit) hotter than nearby rural areas.[1] In doing this analysis, department staff were struck by the cost effectiveness of cool roofs; they are at least an order of magnitude less expensive to install than green roofs.

The City's Office of Long Term Planning and Sustainability also conducted an analysis of the benefits of transitioning the city's roof stock to cool roofs, from both a building owner and city-wide perspective. Their analysis indicated that the city could achieve one degree of cooling if cool roofs were installed across the city and further found that for each degree (Fahrenheit) of temperature rise, the city consumes an average of 3,300 megawatt hours more energy on days when cooling is required. Since cooling is required on approximately 150 days annually, the annual energy savings for each degree of temperature reduction (Fahrenheit) would be roughly 495 million kilowatt hours. At an average cost of 16.5 cents per kilowatt hour, the annual cost savings resulting from one degree decrease in NYC's temperature during warm months would be roughly $82 million.[2]

In 2009, Mayor Bloomberg and former Vice President Al Gore helped the Department of Buildings and Sustainability and NYC Service kick off a pilot program for cool roofs. They selected a "hot pocket" (an area that had been subject to blackouts and was a peak load demand area) in Queens for the pilot. Because of the potential of the program to reduce electricity demand, ConEdison became the lead sponsor of the pilot. During the three week pilot, more than 100,000 square feet (just over 9,000 square meters) of cool roofs were installed through the use of volunteer labor and donated materials. In 2010, the City launched a dedicated cool roof program, which passed its initial annual goal of 1 million square feet (just over 90,000 square meters) of cool roofs installed by October 2010.

Volunteers in Queens, New York. Photo: Community Environmental Center

Former U.S. Vice President Al Gore and New York Mayor Michael Bloomberg kick off the pilot program. Photo: Edward Reed, NYC.gov

Launch of the NYC °CoolRoofs program at LaGuardia Community College in Queens, New York. Photo: Community Environmental Center

Highlight

New York City's cool roofs program has done an exemplary job of securing the participation of volunteers to help speed the City's transition to cool roofs. The NYC °CoolRoofs program is run as a joint effort between NYC Department of Buildings and NYC Service, the agency responsible for coordinating city-wide volunteer efforts. °CoolRoofs is NYC Service's largest environmental initiative. The program targets corporate sponsors who provide volunteers and funding to cover the cost of materials. The City identifies buildings and coordinates the logistics of the "coating days." The City partners with two local non-profit organizations, Green City Force and Community Environmental Center. These non-profits assume liability for the events, coordinate inspections, which ensure volunteer safety and the appropriateness of cool roofs for the individual buildings, and provide staffing for the "coating days." Green City Force provides workforce development to underserved youth (ages 18 to 24). In 2010, its 34 Corp Members coated 500,000 square feet of roofs. Without the support of these non-profits, the City would not be able to run the program.

Performance

In 2010, NYC °CoolRoofs coated 1,168,369 square feet (108,545 square meters) of rooftops across 135 buildings. Sixteen-hundred volunteers participated in these coating efforts.[3] Seventeen companies participated and almost all of them have repeated the program in 2011. The program has continued to expand in 2011 and the City recently passed two million square feet (18,500 million square meters) cooled.

One million square feet (just over 90,000 square meters) of cool roofs should reduce New York City's carbon emissions by 27 tonnes or 500,000 pounds. This reduction is equal to removing 50 cars from the road or having 300 New Yorkers not drive for an entire year.[4]

1. NYC Cool and Green Roof Manual

2. Reducing New York City's Urban Heat Island Effect, Laurie Kerr, Office of Sustainable Design, 2004.

3. NYC Cool Roofs Annual Review, 2010.

4. NYC Cool Roofs Annual Review, 2010.

Unless otherwise noted, all dollar amounts are in USD.

Ready to Act

Use these tools and best practices to start or grow your own cool surfaces program.

Implementation Activities offer best practices, case studies, and guidance for a variety of different cool roof and pavement program strategies. Implementation Activities are roughly broken into Programs and Policies. Implementation Activities can be undertaken in any order, or conducted in parallel since many are designed to be mutually supportive.

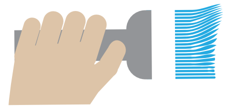
Implementation Guide

Implementation Activities

Implementation Activities

If you have made your way through the activities in Foundational Activities, you are now in a strong position to undertake a wide variety of implementation initiatives. This guide lays out a number of options that have worked well in cities or regions around the world. Implementation Activities is broken into two basic approaches: policies and programs. There is no magic starting place, but the most successful cases have launched both policies and programs that are mutually reinforcing. Of course, there is always room for new, creative approaches that speed the deployment of cool roofs and pavements.

The items in the overview checklist on this page can be undertaken in any order, or conducted in parallel since many are designed to be mutually supportive.



Design and launch programs

Such as:

- ☐ Awareness raising/marketing campaigns
- ☐ Education and training programs
- ☐ Demonstration projects
- ☐ Volunteer programs
- ☐ Contests

Best practices:

- ☐ Design demonstration projects that build local performance data and engage the public.
- ☐ Work with industry to encourage program sponsorship or the donation of in-kind support.
- ☐ Use volunteer installation programs to raise public awareness and target buildings underserved by the market.
- ☐ Measure the success of programs both quantitatively and qualitatively.

Case studies & resources:

- American Institute of Architects
- California Energy Commission
- Case Studies: Toronto (page 75), Chula Vista (page 50), New York City (page 60), Walmart (page 49), Delhi (page 55).
- Global Cool Cities Alliance
- Global Eco-Cities Survey
- NYC °CoolRoofs

Enact cool policies

Such as:

- ☐ Code and ordinance adoption
- ☐ Support for code enforcement
- ☐ Incentives (rebates, volume discounts, loans)
- ☐ Government procurement policies

Best practices:

- ☐ Assess local applicability of existing cool roof standards, codes, and laws.
- ☐ Understand the code-making process and identify partner agencies.
- ☐ Build the case for change and secure broad support.
- ☐ Ensure monitoring and enforcement
- ☐ Work with officials and utilities to develop incentives.
- ☐ Include cool surface requirements in procurement specifications.

Resources:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- Building Codes Assistance Project
- California Title 24
- DOE Building Energy Codes Program
- Energy Efficient Codes Coalition
- International Energy Conservation Code (IECC) and International Green Construction Code (IgCC)
- Lawrence Berkeley National Lab
- New York City Cool Roof Ordinance
- USGBC LEED standards

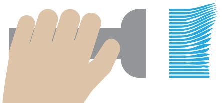
Share your experience

Such as:

- Help others by sharing your experience along the way.
- Partner with scientists, NGOs, or utility companies to spread the word or build your program.

Share your experience with us at:

- Cool Roof Toolkit
- Email Kurt Shickman at kurt@globalcoolcities.org



Design and launch programs

Programs are a tangible way to demonstrate the value of cool roofs and surfaces. Cities often pair programs with incentives to help drive attention and interest. With any program, it is a good idea to engage a variety of government agencies and to identify partners who can run the day-to-day operations. Appropriate stakeholders will differ by program type but could include weatherization groups, green worker training organizations, industry partners, or local research institutions.

Training for contractors:

A more efficient way to reach contractors —beyond developing and offering training programs directly—may be through organizations that already provide training to them and to other building professionals, for example:

- ☐ Architecture organizations, such as the American Institute of Architects, that offer training programs for practitioners (e.g., contractors, designers, architects).
- ☐ Manufacturers of cool coatings and materials that offer training resources. (As noted earlier, work through distributors to identify manufacturers serving your area and approach them directly.)
- ☐ Many contractors or their trade associations have well-designed worker training programs. Coordinate with them to ensure a strong flow of new local labor to meet new roofing project demand.

Awareness raising

Several activities in Foundational Activities help build communication channels to raise public awareness of cool roofs. Use those channels, supplemented by broader communication efforts (e.g., advertisements, public statements, flyers) to describe the reasons for pursuing local cool surface efforts, provide details of new programs, and explain how to participate.

Education and training

Good education and training programs are critical to the success of any policy or initiative. Training contractors allows them to respond to new codes or ordinances and leverages their marketing activities to spread the word about new programs or policies. There are a number of different ways—beyond developing and offering training programs directly—to provide training for contractors (see checklist to the left).

Demonstration projects

Demonstrations of cool roof and pavement technology can provide important local performance data and, if in a high-profile location, can help to raise interest and awareness. Since one of the primary goals of demonstration projects is to refine local simulation results with real data, it is a good idea to partner with a research institution to fully monitor and measure the impact of cool installations. It is best to bring these partners into the design stages of the project to ensure that a good baseline of data is available before the project begins and to minimize other changes to the pilot site so that comparisons are useful and relevant.

The first step in developing a demonstration project is to identify neighborhoods or regions where the impact of cool surfaces would be the greatest. A good demonstration project site can be difficult to quickly identify so start the process as early as possible. Consult with community leaders, researchers, and other important stakeholders at this stage and build a process to help them share their thoughts and opinions (see checklist below).

Engage the community to help garner resources for the effort and build momentum. Partner with local NGOs, businesses, and other sustainability efforts to empower individual action and generate donated resources (volunteers, materials, etc). Identifying local iconic, high-profile buildings to incorporate into the pilot will help raise awareness.

Identify a building, location, neighborhood, or region for a demonstration project:

A number of factors will drive the selection process but some combination of the following characteristics is optimal:

- Enthusiasm on the part of the neighborhood and willingness of the property owner to test new materials or to be a proof of concept for a city new to cool surfaces
- A site sufficiently large and contiguous so as to allow the study of both the building and neighborhood effects of cool roofs and pavements (Ideally, the pilot site would be a couple of square kilometers.)
- A good mix of building types and uses
- A high percentage of non air-conditioned buildings (and, thus, residents who are more exposed during heat waves)
- Areas with particularly poor air quality
- A site with only a small number of building owners so as to speed the approval process and offer the ability to control occupant behavior during the pilot (College campuses and military bases are examples of sites with many buildings but only one “owner”.)
- An area with a particularly hot microclimate or high seasonal energy use

Pilot projects can be expensive. Be creative in developing financial support and develop partners who can access a wide variety of funding sources including grants from government agencies, corporate contributions, in-kind support, philanthropic giving, or multilateral development bank funding.

A number of cool city projects demonstrate not only good research practice but also an impressive mix of partners.

Volunteer programs

Engaging citizens and local corporations in volunteer programs that apply cool coatings has proven effective in places like New York City. As with most efforts, finding good partners early is a key step. New York City, for example, partnered with Google and Consolidated Edison, the local utility. If you plan to use volunteers to help coat roofs, it is important to identify a portfolio of buildings that would be appropriate for unskilled volunteers to work on. Typically, these should be lower buildings with low-sloped (i.e., basically flat) roofs, easy roof access, and robust safety equipment (e.g., guardrails etc.). A good place to start is with local schools, public buildings and lower-income multi-unit housing. Engineers should inspect the roofs of candidate buildings

Mayor Bloomberg of New York City announces the NYC °CoolRoofs Program. Community Environmental Center president Richard Cherry is at the left, and Kevin Burke, the president of Con Edison, is at the right. Source: Community Environmental Center to ensure they are sound and ready for a cool coating. Coating manufacturers may be able to help train volunteers on the appropriate way to apply the coating. Pairing volunteer groups with buildings can be a challenge as volunteer groups will have specific needs, primarily location and an appropriately sized roof for their group. Successful volunteer programs are fun for the participants. Providing food and interesting speakers is one way to ensure that participants have an enjoyable experience. It will be important to publicize completed projects to maintain a steady flow of good press to keep the public engaged. Running such a volunteer program is a significant amount of work. Coordinating multiple roof coating events per week, or per day, will require at least one dedicated staff member. Finding the staff resources can be difficult. If your city or region has a service department, they may be able to take on the program. Alternatively, a service oriented non-profit organization may be able to take on the coordinating role. Insurance is another requirement for these kinds of programs that city governments will typically not be able to cover. Insurance may need to be provided by a non-profit partner.

Contests

Another way to raise awareness of cool roofs and pavements while spurring deployment is to create public competitions to earn cool roofs or pavements. For example, the Philadelphia, Pennsylvania Coolest Block Contest was a collaboration between the mayor's Office of Sustainability, a non-profit implementing agent (Energy Coordinating Agency), and a cool material manufacturer (The Dow Chemical Company). Residential blocks organized by "block captain" applied for the prize of having free cool roofs installed. A short list of eligible blocks was determined by which had the highest sign-up rate of block residents. Renters were required to get sign-off from landlords to participate. A selection committee then evaluated essays each block submitted with their applications and chose a winner. Mayor Michael Nutter announced the winning block during a rooftop signing ceremony for a city ordinance requiring cool roofs on new low-slope roofs. The cool roof installations were performed by the Energy Coordinating Agency with materials donated by the Dow Chemical Company. The kick-off featured a block party that was free to residents, and provided a high-profile and press-worthy opportunity for local politicians to reaffirm their commitment to sustainable communities.

Measuring success

Once the pilot project has been successfully implemented, it is important that the research partners reengage and assess the performance of the cool roof and/or pavement installation. Technical monitoring ideally would include: electricity savings (for air-conditioned buildings), indoor air temperature reductions (for non air-conditioned buildings), above pavement temperatures, and ambient air temperature and quality. As cool roof and pavement pilots crop up around the world, it will be important that researchers use standard monitoring protocols so that data can be easily aggregated.

Philadelphia, the Energy Coordinating Agency, and the Dow Chemical Company ran a contest for the "coolest" block in the city. Photo: RetroFIT Philly program. © Nigel Maynard

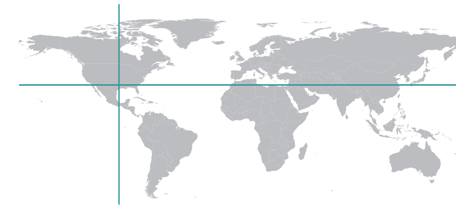
Case Study

Dallas and Houston, Texas: Urban Heat Island Assessment in Partnership with a Third Party Research Organization

Houston Advanced Research Center, Houston Urban Heat Island Effect

Dallas Urban Heat Island Study

Dallas and Houston, Texas, U.S.A.
Mayors: Mike Rawlings (Dallas) and Annise Parker (Houston)
Populations: 1.2 million (Dallas), and 2.1 million (Houston)
Coordinates: 32°46'N, 96°48'W (Dallas) and 25°45'N, 95°22'W (Houston)



Some cities have undertaken comprehensive evaluation of the urban heat island effect impact on their communities and identified strategies to mitigate it. Working with initial funding from the U.S. Environmental Protection Agency and foundation support, a regional research organization called Houston Advanced Research Center (HARC) worked in partnership with city officials to undertake an analysis of the urban heat island effect in Houston and Dallas, Texas. HARC set out to determine where the hotspots were in each city and how hot they were, and to identify strategies for cooling them down. The reports also provided background on the urban heat island effect to help educate policymakers.

The HARC team began by evaluating available thermal and aerial imagery of both cities to help characterize their urban fabric. For Dallas, a local community college agreed to process imagery from NASA's ASTER satellite imagery. The college used the analysis as a learning tool for their students and performed the work free of charge. In Houston, analysis from NASA and a DOE national lab was available. This type of analysis was integral to shaping heat island mitigation strategies. For example, the thermal analysis of Dallas revealed that industrial warehouse areas were the hottest, not the downtown zone as had been expected.

In addition to a characterization of the urban heat island, HARC's report also included three strategies for cooling the city: cool roofs, cool pavements, and shade trees. HARC provided a basic description of each technology and a cost/benefit analysis and suggested policy interventions to help speed implementation.

HARC presented the findings to both cities and, in Houston, facilitated a series of working groups to develop the actual implementation plan. The working groups included representatives of the roofing industry, local government (including the policy, public works, stormwater management, and parks and recreation departments), the local university, environmental groups, business organizations, and developers. This process took about a year in Dallas and about two and a half years in Houston, where the scope of the exercise was broader. Under the leadership of Mayor Bill White, Houston subsequently adopted cool roof provisions as part of its building code, and has continued to pursue its million tree plus campaign.

Thermal image of central Houston. Photo: NASA Marshall Space Center, September 1999

Implement policy

There are two basic policy interventions: regulations and incentives. Regulations take the form of building codes, energy codes, ordinances, and/or pavement specifications. Incentives come in a variety of financial and non-financial forms from rebates and tax breaks to priority permitting and relaxed code standards in other areas. Whether you are considering regulations, incentives, or both, policies are most successful when targeted at building owners' decision points; in this case, reroofing, new or replacement roof installation, or repaving.

Building codes, energy codes and pavement specifications

One of the highest impact ways to support the rapid implementation of cool roofs and cool pavements is to include them in your region or city's building codes or pavement specifications. That said, making changes to the codes can be a long and time-consuming process.

Researching the existing status of cool roofs and pavements in local building and energy codes and ordinances is an important first step, and is described in the Foundational Activities section. A good second step is to identify model language to use as a basis for local cool codes (see below).

Look up codes and specifications:

Cities and regions have used a number of sources to inform changes to their codes and specifications. These include the following:

- New York City Cool Roof Ordinance
- ASHRAE 90.1, 90.2, 189 standards
- International Energy Conservation Code (IECC)
- International Green Construction Code (IgCC)
- Energy Efficient Codes Coalition
- USGBC LEED standards

See the table on the following page for more codes and specifications.

Model language for cool codes:

- California offers a great case study not only because of the robust cool roof standards that were enacted, but also because of the process used and the diversity of the climates covered by the new code. In 2005, California prescribed white surfaces for low-sloped commercial roofs as part of its Title 24 energy efficiency codes. In 2008, the state prescribed cool colored surfaces on steep roofed residential buildings in its five hottest climate zones. (California recognizes 16 climate zones in its energy and building codes.) Cool roof standards were the result of utility Pacific Gas and Electric working with technical experts at the Lawrence Berkeley National Laboratory to make a strong quantitative case for cool roofs across nearly all of California's diverse climate zones.
- New York City built on California's approach and developed an equally stringent code that reflected its many roof types and uses. Their code went into effect in January 2012.

Once you have identified good code language and modified it (if necessary) to meet local needs, the work of getting the language officially adopted begins. As demonstrated by the California case, building a coalition of stakeholders that can help lead and participate in this campaign is critical. Changing building codes requires considerable time, effort, and support from community leaders. In addition, it is crucial to have the support of stakeholders in the building trades and the business community. Such changes should only be considered after there is sufficient understanding and support among community leaders and stakeholders.

Once codes are enacted, they must be monitored and enforced. If cool roofs and pavements are already included in your city or region's codes, but the codes are not getting enforced, focus on working with enforcement officials to improve their oversight. One good way to start is to use publicly available aerial imagery like Google Earth to identify whether buildings that recently received permits to install new or replacement roofs are in fact in compliance. While this visual test is not sufficient for code enforcement purposes, it will help prioritize the field of buildings to inspect and give building owners and contractors the sense that their activities will be reviewed. That said, Google Earth and public imagery tools are a good first step but may include older images. Enforcement should be based on new images or visual inspections.

Case Study

India's Cool Roof Building Codes

Cool roofs and pavements feature in a number of India's building codes and standards. In 2007, India's Bureau of Energy Efficiency incorporated cool roofs into its Energy Conservation Building Code (ECBC-2007). Projects qualify either under a prescriptive approach (where materials and technologies are specified) or a whole-building performance approach. Buildings attempting to qualify via the prescriptive method must have roofs with a reflectivity of at least 0.70 as determined by widely accepted testing standards (ASTM E903-96). For a building taking the performance approach, designers may include highly reflective roof assumptions in the modeling required to qualify. The ECBC is currently voluntary but will become mandatory in 2012 for commercial buildings in eight states, including Delhi and Maharashtra.

- India Bureau of Energy Efficiency

The Bank of India in Mumbai, Maharashtra. India's Conservation Building Code of 2007 is currently voluntary, but will become mandatory for commercial buildings in eight states, including Maharashtra, in 2012. It requires an initial SR of greater than 0.7 and initial TE of greater than 0.75. Photo: United Coatings

U.S. Code	Description	Cool Roof Requirement
ASHRAE 90.1	U.S. national, model code for commercial and high-rise residential buildings	Allows reduced roof insulation if a cool roof of SR >0.55 and TE >0.75, or SRI >64 is used. This allowance is permitted in climate zones 1–3 only. Several exclusions.
ASHRAE 90.2	U.S. national, model code for low-rise residential buildings	Allows reduced roof insulation if a cool roof of SR >0.65 and TE >0.75, or SRI >75 is used. This allowance is permitted in climate zones 1–3.
ASHRAE 189.1	Voluntary, "advanced," national model code for commercial and high-rise residential buildings.	Requires that 75% of the roof surface of a building and parking lot covering be a cool roof. The Standard defines a cool roof as having an SRI of 78 for low-sloped and 29 for steep-sloped roofs, or as a roof material that complies with ENERGY STAR.
California Title 24	Residential and non-residential energy efficiency standards. Cool roof requirements vary by region.	Low-sloped roofs: aged SR >0.55 and TE >0.75, or SRI >64 Steep-sloped, weight <5 lbs/ft^2: aged SR >0.20 and TE >0.75, or SRI >16 Steep-sloped, weight >5 lbs/ft^2: aged SR >0.15 and TE >0.75, or SRI >10
Chicago Energy Conservation Code		Low-sloped roofs: initial SR >0.65, aged SR >0.50, TE >0.90 Medium-sloped roofs: initial and aged SR >0.15, TE >0.90
Florida Building Code	The 2007 Code includes a credit for cool roofs in their performance-based requirements for residential buildings.	SR >0.7 TE >0.75
Hawaii	Prescriptive requirement for low-slope residential roofs that includes cool roofs as one of four ways to meet the standard.	SR >0.7 TE >0.75
IECC Chapter 5 (proposed 2012)	U.S. national, model code for commercial and high-rise residential buildings	Required for low-sloped roofs above air-conditioned space only in climate zones 1–3. Four ways to qualify: • aged SR >0.55, aged TE >0.75 • initial SR >0.7, initial TE >0.75 • aged SRI >64 • initial SRI >82 Exceptions are roof area that is shaded, covered by equipment, vegetated, or ballasted.
LEED Green Building Rating System	Leading voluntary green building standard in the U.S.	Cool roofs (for flat roofs with an SRI >78 and sloped roofs with an SRI >29) = 1 point Cool materials used on other impermeable surfaces = 1 point
New York City Local Law 21	Cool roof requirements for low-sloped roofs. Includes modifications for a variety of roof types and uses.	Initial SR >0.7 and TE >0.75, or SRI >78
U.S. EPA ENERGY STAR	ENERGY STAR is EPA's energy efficiency product label. It includes labels for roofing products.	Low-sloped roofs: initial SR >0.65, aged SR >0.50 Steep-sloped roofs: initial SR >0.25, aged SR >0.15
Washington D.C.	Building code for commercial and residential buildings.	Low-sloped roofs: SRI >78. Green roofs and other exceptions apply.

Source: CRRC and Akbari et. al. "Evolution of Cool Roof Standards in the U.S.", 2008

A brief note on the types of codes

There are a variety of ways that cool roofs and pavements may be incorporated into building and energy codes. Below are descriptions of some common examples:

- **Mandatory measures** All buildings must comply with mandatory measures regardless of compliance path.
- **Prescriptive compliance** Compliance through prescriptive packages that vary with climate zones—no trade-offs allowed.
- **Performance compliance** Use an approved compliance software to demonstrate compliance for the entire building—allows trade-offs.
- **Compliance options** Measures that are not required prescriptively but can result in a compliance credit if installed, such as high Energy Efficiency Ratio (EER) air conditioning and buried ducts.
- **Cool surfaces procurement specifications** Before codes or ordinances are adopted broadly, governments can lead by example by incorporating cool surfaces into their own procurement policies and lease requirements. Governments are often major building owners or tenants, so cooler procurement may help spur market development. It can also build a database of energy savings and other benefits that could be used by local authorities to justify new ordinances and codes for cool surfaces. For example, U.S. Secretary of Energy Dr. Steven Chu directed all Department of Energy offices requiring a new or replacement roof to install cool roofs if they are cost effective over its lifetime.

Incentives

Financial Incentives may help sway building owners towards cool roofs or encourage them to install roofs and pavements that exceed performance required by code. Financial incentives typically take the form of rebates, tax incentives, or cooperative/volume purchasing. To develop such programs, start by conducting a careful analysis of price premiums and savings potential, then work with the city, region, or utility to establish criteria for eligible buildings and eligible reroofing or repaving materials and create the funding mechanism. One rule of thumb is to target incentive levels so they are 50 percent of the incremental cost of choosing cooler options. Incentives will be particularly important in promoting cool pavements because they do not generate direct energy savings for their owners but are important for mitigating the urban heat island effect. While some cool pavements generate positive return on investment by increasing durability or reducing lighting costs, rebates will likely be needed to make the economic case for most owners. Incentives will also be important for steep-sloped roofs because the cost premium for cool-colored roofing materials is typically higher than for flat roofs, and the air-conditioning savings are lower because the solar reflectance is lower, thus the pay back is longer. This cost premium means that it will take longer for building codes to require cool roofs for steep-sloped roofs. Therefore, incentives will be the primary tool for catalyzing adoption.

Rebates can be established by the local utility or government and are typically awarded on a per square meter or per square foot basis. In California, rebates were used before codes were enacted to encourage the installation of cool roofs. Once codes were enacted, the qualifications for the rebates were increased to encourage building owners to install roofs above code requirements. Toronto's Eco-Roof Incentive Program, for example, offers a $2 per square meter incentive for a coating over an existing roof or a $5 per square meter for a new roof membrane to a total possible incentive of US $50,000. Cool roofs must be installed on an existing building in order to be eligible for funding. The program is funded in part through cash payments made by building owners who wish to opt out of Toronto's green roof requirements.

Tax Incentives can be structured similarly to rebates, but provide small tax advantages instead of direct payments. Local taxing jurisdictions should be a part of the development process and could be reimbursed for the incentives offered. There are a number of ways to organize tax programs. Property tax incentives could be offered for new or replaced roofs or resurfaced parking lots. Sales taxes could be waived on the purchase of cool roofing and pavement materials. Water taxes could be reduced if permeable pavements or roof water management systems are installed.

Volume Purchasing Regions and cities could develop a bulk-purchasing program so that building owners can take advantage of volume discounts. Officials should carefully review product options in a transparent and open process to avoid "picking winners."

Non-Financial Incentives Incentives do not necessarily have to involve direct payments. Other methods can rely on building requirements as an incentive basis. For example, The City of Portland has implemented a Floor Area Ratio (FAR) bonus option to encourage vegetated roof development for the purposes of water runoff control. The FAR bonus allows the total area of a building to be larger than it might be otherwise if certain vegetated roof criteria are met. This incentive structure could also be used to support cool roofs.

Cities and regions may also offer priority or preferential permitting for buildings or development projects designed with a cool roof or pavements. Preferential permitting can be very valuable because it can shave considerable time off of the construction or retrofitting process.

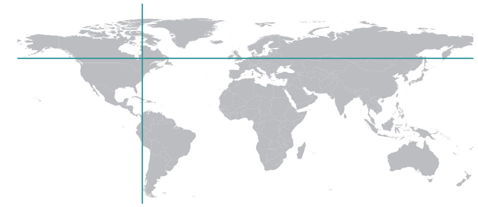
Case Study

Toronto, Canada: Eco-Roof Incentive Program

Dollar values in this case study are CAN.

Toronto Eco-Roof Incentive Program

Toronto, Canada
Mayor: Rob Ford
Population: 2.5 million (5.1 million metro area)
Coordinates: 28°36'N, 77°13'E



The Eco-Roof Incentive Program provides incentives for green and cool roofs to commercial, industrial and institutional property owners so that Toronto's building stock becomes more sustainable and better adapted to climate change. It was adopted by the Toronto City Council on December 1, 2008.

In May 2009, the City Council adopted the Green Roof By-Law and authorized a cash-in-lieu option for property owners that wished to opt out of building a required green roof on a new building. The cash-in-lieu is directed to the Eco-Roof Incentive Program to be used for green roof projects on existing buildings.

The Eco-Roof Incentive Program offers a $50 per square meter incentive, to a total of $100,000 for green roof projects on existing buildings, or a green roof on a new industrial building with a gross floor area (GFA) of 2,000 square meters or greater, or a green roof on a new institutional or commercial building with a GFA of less than 2,000 square meters. The incentive covers green roof projects on either existing buildings or new buildings that are not affected by the Green Roof By-Law.

Cricket Club, Toronto. Photo: Steve Pataki

The Eco-Roof Incentive Program also offers a $2 per square meter incentive for a cool coating over an existing roof or a $5 per square meter for a new cool roof membrane to a total possible incentive of $50,000. Cool roofs must be installed on an existing building in order to be eligible for funding. Funding for the cool roof portion of the Eco-Roof Incentive Program ended on December 31, 2011.

Since the program began in 2009, 92 Eco-Roof applications were received, 82 of which were approved for funding. There were eight approved applications where the project was ultimately not pursued. A total of 144,767 square meters of green and cool roofs have been approved with a total funding allocation of over $1.1 million. Of the approved eco-roof applications it is estimated that

- Green roofs reduced energy consumption on average by 11 kWh per square meter a year, helping to avoid on average 31 tonnes of greenhouse gas emissions annually.
- The combined green roofs divert between 7 and 8 million liters of stormwater from storm sewers annually.
- Cool roof installations reduced energy consumption on average by 1.72 kWh per square meter a year, helping avoid on average 38 tonnes of greenhouse gas emissions annually.

Toronto Sample Documents:

Link to a copy of the initial report online

Revisions to the program were made in February 2010. Link to updates online.

A copy of the report detailing the Green Roof By-Law

Share your experience

Building a global movement to transition our urban environments to cool surfaces will require that leaders document and share their experiences. If your experience is typical, you will have built relationships and received advice throughout the process of developing a cool program for your area. Be a part of that community by sharing your own successes. Contributing your experiences will help those that are just beginning their own programs and raise awareness about your program.

While your city or region is in the process of designing and launching your cool surfaces program, be sure to document all of your decisions and activities. Start documenting as soon as the process is underway. There are best practices and challenges at every stage; don't wait until the end to recap your success. This level of documentation can be streamlined by identifying a person or group responsible for tracking, developing, and disseminating case studies, presentations, and other materials. All materials developed should funnel through that office.

Volunteers in New York paint the roof of a charter school in Harlem to promote energy efficiiency as a solution to climate change. Photo: 350.org

As mentioned above, an important element of your cool surfaces program should be working with local researchers to instrument and monitor pilot projects, using standard monitoring protocols if possible, and to publish the resulting data. It is important that performance data is shared openly. If demonstration participants have privacy concerns, aggregate the data as needed.

Continuing education

This document has everything you need to get started, but we encourage you to continue to educate yourself, your colleagues, and your partners on the broad range of topics relating to cool roofs, cool pavements, and cool cities. Some of the information in this document is dynamic and will be updated periodically. Because we will not be able to update this document regularly, please visit CoolRoofToolkit.org to find updated material including building codes, incentives, active partners, and new resources.

The remaining pages of this document provide a list of case studies, a catalog of the links cited throughout the document, and references and notes. These resources are also available at CoolRoofToolkit.org, and will be maintained and updated there.

We look forward to working with you to help your city or region transition to cool surfaces and to hearing about your progress!

References and notes

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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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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.

Page 38:

31 Ibid.

Review all the case studies:

Resources*

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?fuseaction=find_a_product.showProductGroup&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.

Glossary

albedo: Another word for solar reflectivity or solar reflectance of the surface of a material.

aluminum roof coating: A cool roof technology. The material is an asphalt-type resin containing "leafing" aluminum flakes, meaning flakes tend to accumulate at the upper portion of the coating exposed to solar radiation. The aluminum flakes increase the solar reflectance of asphalt from a few percent to above 50 percent.

anthropogenic heat: Manmade heat generated by buildings, people, or machinery. Anthropogenic heat is considered a climate change contributor by almost the whole scientific community.

ASHRAE: The American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE produces energy efficiency standards for buildings, which include cool roof requirements or performance criteria, with respect to the overall energy performance of the building envelope.

asphalt cement concrete: A construction material, usually called asphalt, used for paving roads but sometimes roofs as well. It is a hardened mixture mainly composed of an asphalt binder (material produced by petroleum refineries that glues loose material together and accounts for less than 8 percent of the total pavement weight) and aggregate (mixture of various sized stones, dust and sand, accounting for not less than 92 percent of the total pavement weight). Cool roof materials and technologies improve the thermal performance of asphalt-made roofs under solar radiation.

asphalt chip seals: A cool material technology. Asphalt chip sealing is a paving treatment in which a thin layer of asphalt binder is applied and immediately covered with a layer of light-colored aggregate. Afterwards, the aggregate is pressed into the binder using a heavy roller. Using a light-colored aggregate increases the solar reflectance of the roof's paved surface.

ASTM: The American Society for Testing and Materials. The Society provides international technical standards. See CEN and EN for the European equivalent bodies. The ASTM publishes reference standards for solar and thermal testing of cool roof materials.

building envelope: The separation between the interior and the exterior environments of a building. The exterior can be the outdoor environment as well as another built environment. The main components of the building envelope include the ground construction, roof, walls, doors, and windows. The building envelope serves as the outer shell to protect the indoor environment and should ensure comfortable conditions with minimum energy consumption.

built-up roof: A product widely used for flat roofs. It is a membrane consisting of layers of asphalt, which serve as a waterproofing component, alternating with felt fabrics. Cool roof materials and technologies improve the thermal performance of built-up roofs under solar radiation.

canopy (layer): A "mattress-type" layer of air just above the ground in cities, extending up to the average height of buildings. Above the urban canopy layer lies the urban boundary layer, the thickness of which varies from a few hundred meters up to one kilometer. The urban heat island often refers to both layers, but usually the urban heat island effect refers to the layer below the canopy.

Clean Energy Ministerial (CEM): A high-level global forum to promote policies and programs that advance clean energy technology, share lessons learned and best practices, and encourage the transition to a global clean energy economy. Initiatives are based on areas of common interest among participating governments and other stakeholders. The CEM brings together ministers with responsibility for clean energy technologies from the world's major economies and ministers from a select number of smaller countries that are leading in various areas of clean energy.

climate change: Sometimes used to refer to all forms of climatic inconsistency, the term is properly used to imply a significant change from one climatic condition (human driven or natural) to another because the Earth's climate is never static.

climate zone: Portion of the earth's surface within which the climate is generally homogeneous in some respect. The performance of cool roof materials and technology is related to the climatic characteristics of the site. The hotter the climate is, the greater the benefits will be in terms of energy savings and thermal comfort.

coatings: Products that can be applied with a brush, roller or spray equipment, over a roofing system for several purposes (like protection from moisture, water, hail, UV rays, physical damage). Elastomeric coatings have elastic properties (in the summertime heat they expand and then return to their original shape without damage) and are widely used in roof applications.

concrete: Construction material often used in roof and road pavements. Concrete is a hardened mixture of Portland cement, sand, and coarse aggregate. Waste materials like fly ash, slag, and plastic fibers can also be used in concrete mixture. Cool roof materials and technologies improve the thermal performance of concrete roofs under solar radiation.

cool colored roofs: Roofs made of highly reflective building materials that are not white, but a range of traditional roof colors (e.g., gray and red). Many building materials can be treated with a reflective coating, regardless of the color.

cool roofs: Roofs with reflective and emissive properties that help improve the energy efficiency of the building and/or mitigate the urban heat island effect.

Cool Roof Rating Council (CRRC): The U.S. supervising entity for standards and testing of roofing products. The CRRC is responsible for administering the certification program relating to reflectivity and emissivity ratings for those roofing products. No similar body exists in Europe.

degree days: Cooling and heating degree days (CDD/HDD) are often used to estimate how hot the climate is and how much energy may be needed to keep buildings at a comfortable temperature.

CDD are calculated by subtracting a reference indoor temperature from the mean daily temperature, and summing only positive values over an entire year.

HDD are calculated by subtracting the mean daily temperature from a reference indoor temperature, and summing up only positive values over an entire year.

The reference temperature is generally the comfort temperature and varies according to regulations or standards. CDD and HDD are climatic indicators, useful for assessing the energy performance of cool roof technology in different climatic zones. CDH or cooling degree hours rely on the same methodology (as does heating degree hours or HDH), with hours not days.

As an example, the HDD in Rome and Brussels are 2092 and 3758, at a reference indoor temperature of 20 degrees Celcius; the CDD in Rome and Brussels are 346 and 23, at a reference indoor temperature of 20 degrees Celcius. (Please note, these are not official figures for Rome and Brussels. They were determined using a typical reference year and are presented simply to demonstrate the concept.)

energy consumption: The amount of energy consumed in a process or a system. In buildings it refers to the energy consumed by the energy systems to ensure comfortable indoor conditions. Energy consumption can also refer to a single energy system, for example heating, cooling, ventilation, or artificial lighting. More efficient buildings use less energy ensuring the same comfort conditions. Cool roof technology applications can reduce the cooling and the overall energy consumption of a building and improve its efficiency.

ENERGY STAR: A voluntary labeling program designed to identify and promote energy-efficient products, including roofing products, developed by the Environmental Protection Agency of the USA. Several energy efficient products for buildings are labeled, including heating and cooling systems, lighting, windows, and insulation. Including cool roof products in the ENERGY STAR Program recognizes the importance of the technology to achieve significant energy savings. The EU has also launched an ENERGY STAR Program dedicated to energy efficient equipment.

global warming: The gradual rise of the Earth's surface temperature. Global warming is believed to be caused by the greenhouse effect and is responsible for changes in global climate patterns and an increase in the near-surface temperature of the Earth.

greenhouse gas: Any gas that absorbs infrared radiation in the atmosphere. The most well known greenhouse gases are carbon dioxide, methane, nitrous oxide, halogenated fluoro-carbons, ozone, per-fluorinated carbons, and hydro- fluorocarbons; however, water vapor is also included. By reducing energy consumption in buildings, cool roofs reduce greenhouse gas emissions in the atmosphere.

Global Superior Energy Performance Partnership (GSEP): A new initiative to accelerate energy efficiency improvements throughout industrial facilities and large buildings. Announced by government and corporate leaders, on On July 20, 2010, at the Clean Energy Ministerial (CEM) in Washington, DC, the purpose of the initiative is to significantly cut global energy use by: (1) encouraging industrial facilities and commercial buildings to pursue continuous improvements in energy efficiency, and (2) promoting public-private partnerships for cooperation on specific technologies or in individual energy-intensive sectors. Cool Roofs and Pavements is one of six working groups within GSEP.

Heat transfer: The transition of thermal energy from a heated item to a cooler item. Classical transfer of thermal energy occurs only through conduction, convection, radiation, or any combination of these.

IECC: The International Energy Conservation Code a model energy building code produced by the International Code Council. It is developed, and revised on a periodic basis, through a public hearing process by national experts under the direction of the International Code Council.

IgCC: The International Green Construction Code, which provides model code language to establish baseline regulations for new and existing buildings related to energy conservation, water efficiency, building owner responsibilities, site impacts, building waste, materials, and other considerations. Like the IECC, IgCC is a model building code produced by the International Code Council.

ISO: International Organization for Standardization, an international standard setting body composed of representatives from various national standards organizations. The organization promulgates worldwide proprietary industrial and commercial standards. ISO standards are often implemented in the EU as EN standards.

Leadership in Energy and Environmental Design (LEED): A points-based building certification using independent, third-party verification to ensure that a building, home, or community was designed and built using strategies to achieve sustainable site development, water savings, energy efficiency, green materials selection, and indoor environmental quality.

membranes: Roof products, fabricated from strong, flexible, and waterproof materials. They can be applied in multiple layers or consist of a single-ply membrane. Membranes usually contain a fabric made from felt, fiberglass, or polyester for strength, which is laminated or impregnated with a flexible polymeric material. Cool roof materials and technologies improve the thermal performance of built-up roofs under solar radiation.

solar reflectance: Also known as reflectivity, the fraction of the solar energy that is reflected by a roof's surface back to the sky, expressed with a number between 0 and 1 (or 0 percent and 100 percent). White surfaces have the highest solar reflectivity, while black have the lowest.

solar spectrum: The spectral distribution of radiative energy in sunlight. The solar spectrum includes three main types of radiation: Ultra-violet is short wavelength sunlight that cannot be seen. The visible portion is medium wavelength light that can be seen by humans. Near infrared is the longest wavelength light and cannot be seen.

reflectivity: Another word for albedo or reflectance.

roof slope: Inclination of a roof, which determines the roof's classification and consequently the choice of cool roof technology on a given roof. There are ASTM standards that define the criteria for roof classification.

Flat roofs generally have a small slope so that water will run off to a drain system and not collect.

Low-sloped roofs have a surface with a maximum slope of 5 centimeters rise for 30 centimeters run, corresponding to somewhat less than a 10 degree inclination, as defined in ASTM Standard E 1918-97.

Steep-sloped roofs, or sloped roofs, are surfaces with a minimum slope of 5 centimeters rise for 30 centimeters run, corresponding to more than a 10 degree inclination, as defined in ASTM Standard E 1918-97.

shingles (asphalt): Cool roof materials composed of asphalt saturated mats made from organic felts or fiberglass. The asphalt is protected from the sun's ultraviolet light by roofing granules pressed into the shingle during the manufacturing process while it is hot (and soft). The roofing granules are 1 millimeter-sized stones, which are coated with an inorganic silicate material. The coating contains microscopic pigment particles, similar to those used in paint, to provide color and can be used for both roof and road pavements.

shingles (roof): Roofing technology consisting of individual overlapping elements. These elements are normally flat rectangular shapes that are laid in rows. Shingles are laid from the bottom edge of the roof up, with the bottom edge of each row overlapping the previous row by about one third its length. Cool roof materials and technologies improve the thermal performance of roof shingles under solar radiation.

single-ply roof: Single-ply roofing is a flexible or semi-flexible pre-manufactured membrane typically made of rubber or plastic materials. Single-ply roofing comes in large rolls and must be glued or mechanically fastened to a roof, and sealed at all seams. Cool roof materials and technologies improve the thermal performance of single-ply roofs under solar radiation.

smog: A type of air pollution containing ozone and other reactive chemical compounds formed by the reaction of sunlight with hydrocarbons and nitrogen oxides. Derived from the combination of "smoke" and "fog."

Solar Reflective Index (SRI): A measure of the constructed surface's ability to reflect solar heat, as shown by a small temperature rise. This indicator was developed by the Heat Island Project within the Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. SRI combines reflectance and emittance into one number.

temperature rise: The maximum rise of the roof surface temperature above the outdoor air temperature. This indicator was developed by the Heat Island Project within the Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division. The maximum roof surface temperature is calculated adding the maximum air temperature to the temperature rise. Cool materials have very small temperature rise, while traditional construction materials reach temperature rises of 20-25°C or even higher.

thermal comfort: A condition of mind that expresses satisfaction with the thermal environment. The most commonly used indicator of thermal comfort is air temperature. But air temperature alone is neither a valid nor an accurate indicator of thermal comfort, as it must be considered in relation to other main environmental and personal factors. Cool roofs help maintain thermal comfort conditions in the built environment by lowering the indoor air temperature and radiant temperature (responsible for the radiant thermal exchange between the human body and the temperature of the surface around the built environment).

thermal emittance: The ability of material to release absorbed heat, expressed with a number between 0 and 1 (or 0 percent and 100 percent), also known as infrared emittance or emissivity. Metallic surfaces have a low infrared emissivity. Most construction materials have high emittance.

High infrared emissivity helps keep surfaces cool, even if a high solar reflectance is needed as well.

tiles: Roofing technology usually consisting of overlapping individual elements made of ceramic (e.g., clay fired at a high temperature) or fabricated from cement concrete or other stone types. Some of the lighter tile types use fibers (e.g., cellulose) added for strength. Cool roof materials and technologies improve the thermal performance of tiles under solar radiation. The light color of a tile may be dispersed throughout, or it may be applied in the form of a coating.

Title 24: The Energy Efficiency Standards for Residential and Nonresidential Buildings in California, established in 1978 in response to a legislative mandate to reduce California's energy consumption. The standards are updated periodically to allow consideration and possible incorporation of new energy efficiency technologies and methods. Title 24 is a part of the California Code of Regulations.

urban fabric: A generic term used to describe the physical composition of cities including building types, paved areas, tree cover, and open space.

urban heat island effect: The increased air temperatures in urban areas in contrast to cooler surrounding rural areas. The main cause of the urban heat island effect is modification of the land surface through urban development, where vegetation is replaced by built surfaces characterized by low solar reflectance, high impermeability, and favorable thermal properties for energy storage and heat release. Many studies show that the urban heat island effect is higher at night. The urban heat island effect depends on several factors, but is typically between 2 and 4 degrees Celcius. Yet intensities up to 12 degrees Celcius have been measured.

vegetated roofs: Rooftops planted with vegetation. Intensive vegetated roofs have thick layers of soil that can support a broad variety of plant or tree species. Extensive roofs are simpler vegetated roofs with a soil layer to support turf, grass, or other thin ground cover. Vegetated roofs can be considered as an alternative to cool roofs because they keep the surface cool, reduce the cooling demand of the building and, in addition to cool roofs, provide thermal insulation. Vegetated roofs have higher construction and maintenance costs compared to cool roofs. They are also not reflective, so would not have a significant impact on global temperatures even if they were widely implemented.

white and tinted roof coatings: Roof coatings that contain transparent polymeric materials, such as acrylic, and a white pigment, to make them opaque and reflective. These coatings typically reflect 70 to 90 percent of the sun's energy. Despite the white appearance, these coatings absorb the 5 percent or so of the sun's energy that falls in the ultraviolet range (apart from the white cement-based coatings which can reflect up to 60 percent of ultraviolet light). In this way, the pigments help protect the polymer material and the substrate underneath from UV damage. The solar reflectance of colored coatings is in general lower than white coatings, but still can reach reflectance as high as 85 percent, particularly the lightly colored ones. Additionally organic coatings can be produced, using natural products such as milk and vinegar.

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