Guidelines for Selecting Cool Roofs

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Introduction

Cool roofs can help many building owners save money while protecting the environment. This guidebook has been created to help you understand how cool roofs work, what kinds of cool roof options are available, and how to determine if cool roofing is appropriate for your building. If you are planning a new building or replacing or restoring an existing roof, cool roofs should be considered as an energy efficiency option. Cool roof products exist for virtually every kind of roof.

Just as wearing light-colored clothing can help keep a person cool on a sunny day, cool roofs use solar-reflective surfaces to maintain lower roof temperatures. Traditional dark roofs can reach temperatures of 150ºF (66ºC) or more in the summer sun. A cool roof under the same conditions could stay more than 50°F (28ºC) cooler, Figure 1.

Figure 1: Dark vs. Cool Roof Surface Temperatures

A dark roof (left) becomes much hotter than a cool white roof (right) on a sunny afternoon.

Why Use Cool Roofs

A cool roof can be desirable to a building owner for several reasons. Cool roofs can

- reduce energy bills by decreasing air conditioning needs,
- improve indoor thermal comfort for spaces that are not air conditioned, and
- decrease roof operating temperature, which may extend roof service life.

In many cases, cool roofs cost about the same as non-cool alternatives. The energy cost savings you can realize from a cool roof depends on many factors, including local climate; the amount of insulation in your roof; how your building is used; energy prices; and the type and efficiency of your heating and cooling systems.

Cool roofs can also benefit the environment, and policymakers may issue cool roof regulations to provide these benefits to society. Cool roofs can

- reduce local air temperatures, which improves air quality and slows smog formation;
- reduce peak electric power demand, which can help prevent power outages;
- reduce power plant emissions, including carbon dioxide, sulfur dioxide, nitrous oxides, and mercury, by reducing cooling energy use in buildings; and
- reduce heat trapped in the atmosphere by reflecting more sunlight back into space, which can slow climate change.

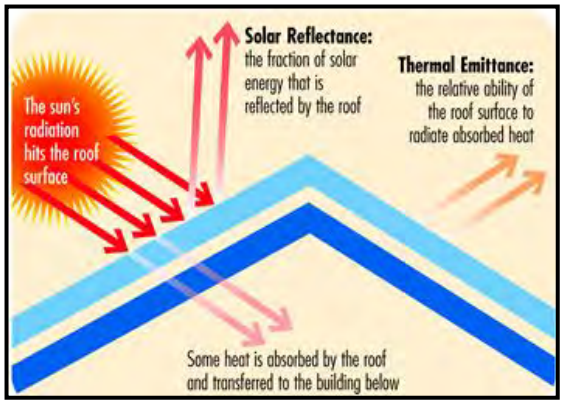
What Is a Cool Roof

Cool roofs are roofs that are designed to maintain a lower roof temperature than traditional roofs while the sun is shining. Sunlight is the primary factor that causes roofs to become very hot.

How Cool Roofs Work

Cool roofs have surfaces that reflect sunlight and emit heat more efficiently than *hot* or *dark roofs*, keeping them cooler in the sun. In contrast, *hot roofs* absorb much more solar energy than *cool roofs*, making them hotter. *Solar reflectance* and *thermal emittance* are the two key material surface properties that determine a roof's temperature, and they each range on a scale from 0 to 1. The larger these two values are, the cooler the roof will remain in the sun.

Figure 2: Roof Surface Properties



Typical dark roofs can absorb 90% or more of incoming solar energy, while cool roofs may absorb less than 50%. *Image Source: CRRC*

Since most dark roofs absorb 90% or more of the incoming solar energy, the roof can reach temperatures higher than 150°F (66ºC) when it's warm and sunny. Higher roof temperatures increase the heat flow into the building, causing the air conditioning system to work harder and use more energy in summertime. In contrast, light-colored roofs absorb less than 50% of the solar energy, reducing the roof temperature and decreasing air conditioning energy use.

Reducing the roof's temperature with a cool roof can also increase the need for heating during heating seasons. Later sections of this report show you how to evaluate the resulting cost savings for your building.

Solar Reflectance is the fraction of sunlight that a surface reflects. Sunlight that is not reflected is absorbed as heat. Solar reflectance is measured on a scale of 0 to 1. For example, a surface that reflects 55% of sunlight has a solar reflectance of 0.55. Most dark roof materials reflect 5 to 20% of incoming sunlight, while light-colored roof materials typically reflect 55 to 90%. Solar reflectance has the biggest effect on keeping your roof cool in the sun.

Thermal Emittance describes how efficiently a surface cools itself by emitting thermal radiation. Thermal emittance is measured on a scale of 0 to 1, where a value of 1 indicates a perfectly efficient emitter. Nearly all nonmetallic surfaces, like the unwrapped potato in Figure 3, have high thermal emittance, usually between 0.80 and 0.95, that helps them cool down. Bare, shiny metal surfaces, like aluminum foil, have low thermal emittance, which helps them stay

Figure 3: Understanding Thermal Emittance

Potato skins (left), like most roofing materials, have high thermal emittance. A potato wrapped in foil (right) stays warmer longer since its aluminum surface has low thermal emittance. *Image Source: Wikipedia, Free Clipart Images*

warm. A bare metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation.

Solar Reflectance Index (SRI) is another metric for comparing the "coolness" of roof surfaces[1]. It is calculated[i] from solar reflectance and thermal emittance values. The higher the SRI, the cooler the roof will be in the sun. For example[ii], a clean black roof could have an SRI of 0, while a clean white roof could have an SRI of 100. Dark roofs usually have an SRI less than 20.

What Qualifies as a Cool Roof

Typical minimum cool roof requirements are shown in Table 1, and this is what we mean by "cool roof" throughout this document. A roof can qualify as cool in one of two ways. The first way is by meeting or exceeding both the minimum solar reflectance and thermal emittance values. The alternative way is to meet or exceed the minimum SRI requirement. This allows some roofs that have a low thermal emittance and a high solar reflectance (or vice versa) to still qualify as a cool roof.

Table 1: Typical Minimum Cool Roof Requirements, California Energy Commission[2]

Roof Type		Solar Reflectance [3-year aged]	AND	Thermal Emittance [new or aged]	OR	Solar Reflectance Index (SRI) [3-year aged]
Low sloped		0.55		0.75		64
Steep sloped		0.20		0.75		16

Cool roof requirements depend on the roof's slope. Low sloped roofs have a pitch of 9.5° or less (2:12 rise over run), while steep sloped roofs have a pitch greater than this. Requirements are usually less stringent for steep sloped roofs. Some heavier roofs – such as those with concrete pavers, ballast, or vegetation – also have less stringent cool roof standards. The weight of these roofs causes them to heat up more slowly, and during the night some of that stored heat is returned to the outdoor environment.

Others use different cool roof definitions. For example, the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program currently uses minimum SRI values of 78 and 29 for low and steep sloped cool roofs, respectively[iii]. The U.S. Department of Energy (DOE) has decided to implement cool roofs on all its buildings whenever practicable[3]. The DOE uses the low sloped cool roof definition from Table 1 and defines steep sloped cool roofs as those with a 3-year aged SRI of 29 or greater. The ENERGY STAR® program specifies minimum solar reflectance (low slope: 0.65 initial, 0.50 aged; steep slope:

[i] A spreadsheet that calculates SRI is offered at http://coolcolors.lbl.gov/assets/docs/SRI Calculator/SRI-calc10.xls.
[ii] For these examples we assume the clean black roof has a solar reflectance of 0.05 and a thermal emittance of 0.90, and the clean white roof has a solar reflectance of 0.80 and thermal emittance of 0.90.
[iii] SRI 78 can be achieved by a roof with a solar reflectance of 0.77 and thermal emittance of 0.20. A less reflective (0.64) but more emissive roof (0.90) also achieves SRI 78. SRI 29 could be achieved with a solar reflectance of 0.28 and emittance of 0.90.

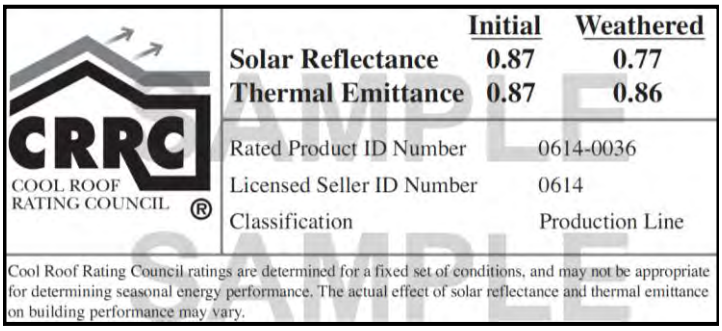
0.25 initial, 0.15 aged) and does not consider thermal emittance. To satisfy local building codes or to meet rebate program requirements, be sure to find and use the appropriate cool roof definition.

Reading Cool Roof Product Labels

To help consumers compare the cool aspects of roof materials and coatings, the Cool Roof Rating Council (CRRC) manages a system for independently evaluating and documenting their properties. Roof products that are tested to CRRC methods receive a performance label, Figure 4, showing the measured solar reflectance and thermal emittance values. **NOTE: Any roofing product that is tested by a CRRC accredited laboratory can be listed in the CRRC directory. Being listed does not imply that a product is cool.**

Because roof material surface properties can change over time due to soiling and weathering, values are measured and reported for both initial and three-year weathered conditions. The label in Figure 4 shows this product's solar reflectance has dropped from 0.87 to 0.77 after three years. Most weathering or soiling occurs during the first year or two, and then values tend to stabilize. Tested product data are published online[iv] by the CRRC.

Figure 4: A CRRC Product Label

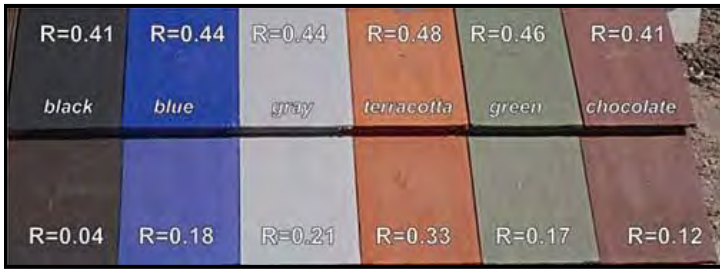


Weathered solar reflectance values should be used when evaluating roof energy cost savings. *Image Source: CRRC*

Not All Cool Roofs Are White

Although white materials tend to be very good solar reflectors, colored roofing materials, like those shown in Figure 5, can also be made to reflect more sunlight. More than half of the sunlight reaching the earth is invisible to the human eye, and this invisible sunlight heats the roof. A colored surface that reflects much of the invisible sunlight is a called a *cool dark color*, or *cool color*. A cool dark color reflects more sunlight than a similar-looking conventional dark color, but less than a light-colored surface. For example, a conventional dark colored surface might reflect 20% of incoming sunlight, a cool dark colored surface, 40%; and a light-colored surface, 80%.

Figure 5: Cool Dark Colors



Cool-colored tiles (top row) look just like conventionally colored tiles but have higher solar reflectance (R). *Image Source: American Rooftile Coatings and Lawrence Berkeley National Laboratory*

[iv] http://www.coolroofs.org/codes_and_programs.html

Heat Gains, Heat Losses, and Thermal Insulation

Heat flows naturally from a warmer space to a colder space. Heat that flows into the building is called *heat gain,* while heat that flows out of the building is called *heat loss*. When too much heat gain (loss) occurs, your air conditioning system (heating system) operates to keep the space comfortable. A large amount of heat can be gained (or lost) through a building's roof. Cool roofs reduce heat gains throughout the year. This can save you energy on cooling, but it can also increase the energy you need for heating. Often, the annual cooling energy cost savings is substantially higher than the heating penalty.

Thermal insulation can greatly reduce the amount of heat lost or gained through a roof system. Even though cool roofs reduce solar heat gains, they are never a substitute for using sufficient thermal insulation. Insulation reduces heat losses and heat gains through the roof in ways a reflective surface cannot. For more information about the importance of thermal insulation, see these DOE resources: Residential Insulation Fact Sheet[v] and Energy Savers[vi]

Types of Cool Roofs

Roof systems are made of one or more material layers. The surface exposed to the sun is the one that determines if a roof is cool or not. Different roofing systems present different surface options. By selecting the right surface, you can usually make your new or existing roof cool. Here are some common roof systems along with a description of how their surfaces can be made cool. To learn more about these and other roof systems, check with the National Roofing Contractors Association.[vii]

Cool Roof Coatings contain white or special reflective pigments that reflect sunlight. Coatings are like very thick paints that can protect the roof surface from ultra-violet (UV) light and chemical damage, and some offer water protection and restorative features as well. Coatings can extend a roof's service life as long as the roof is still in good condition, Figure 6. More than 500 different cool roof coatings are available, and products exist for most roof types. Manufacturers also coat some roof surfacing materials (membranes, metals, granules, etc.) at the factory to make them more reflective.

Low Sloped Roofs

Single-ply Membranes are pre-fabricated sheets that are rolled onto the roof and attached with mechanical fasteners, adhered with chemical adhesives, or held in place with ballast (gravel, stones, or pavers). Some kinds of membranes, like TPO[viii] and PVC[ix], are typically white and

[v] http://www.ornl.gov/sci/roofs+walls/insulation/
[vi] http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11330
[vii] http://www.nrca.net/consumer/roofsystems.aspx
[viii] TPO stands for thermoplastic polyolefin.
[ix] PVC stands for polyvinyl chloride.

reflect sunlight well. Others, like EPDM[x], are typically black, and must be formulated differently or coated to make them reflective.

Built-Up Roofs consist of a base sheet, fabric reinforcement layers, and a protective surface layer that is traditionally dark. The surface layer can be made in a few different ways, and each has cool options. One way involves embedding mineral aggregate (gravel) in a flood coat of asphalt. By substituting reflective marble chips or gray slag for dark gravel you can make the roof cool. A second way built-up roofs are finished is with a mineral surfaced sheet. These can be made cool with reflective mineral granules or with a factory-applied coating. Another surface option involves coating the roof with a dark asphaltic emulsion. This type can be made cool by applying a cool coating directly on top of the dark emulsion.

Modified Bitumen Sheet Membranes are composed of one or more layers of plastic or rubber material with reinforcing fabrics, and are surfaced with mineral granules or with a smooth finish. A modified bitumen sheet can also be used to surface a built-up roof, and this is called a "hybrid" roof. Modified bitumen surfaces can be pre-coated at the factory to make them cool.

Spray Polyurethane Foam roofs are constructed by mixing two liquid chemicals together that react and expand to form one solid piece that adheres to the roof. Since foams are highly susceptible to mechanical, moisture, and UV damage, they rely on a protective coating. These coatings are traditionally reflective and offer cool roof performance.

Figure 6:
Two Cool Roof Installations

A cool coating is applied to a dark roof (top), and a cool single-ply membrane roof is unrolled (bottom). *Image Source: DIY Advice*

Steep Sloped Roofs

Shingled Roofs consist of overlapping panels made from any of numerous materials. Fiberglass asphalt shingles, commonly used on homes, are coated with granules for protection. Cool asphalt shingles are use specially coated granules that provide better solar reflectance. While it is possible to coat existing asphalt shingles to make them cool, this is not normally recommended or approved by shingle manufacturers. Other shingles are made from wood, polymers, or metals and these can be coated at the factory or in the field to make them more reflective. Metal shingles are described in the *Metal Roofs* section that follows.

[x] EPDM stands for ethylene propylene diene M-class, a kind of synthetic rubber.

Tile Roofs can be made of clay, slate, or concrete. Clay and slate tiles come from the ground, so their colors differ depending on the earth's composition. Some varieties will naturally be reflective enough to achieve cool roof standards. Tiles can be also be glazed to provide waterproofing or coated to provide customized colors and surface properties. These surface treatments can transform tiles with low solar reflectance into cool roof tiles.

Low and Steep Sloped Roofs

Metal Roofs are available with natural metallic finishes, oven-baked paint finishes, or granular coated surfaces. Usually, unpainted metals are good solar reflectors but poor thermal emitters so they rarely satisfy low slope cool roof requirements, though some may still have a high enough SRI to count as a cool roof[xi]. Paint applied at the factory or in the field can increase a metal roof's solar reflectance and thermal emittance, allowing it to achieve cool roof status. Alternatively, cool reflective coatings can be applied as with low sloped metal roofs.

Should You Use a Cool Roof

In this section, we discuss the key factors outlined in Table 2 that can help you determine if a cool roof is appropriate for your project.

Table 2: Key Factors for Deciding on a Cool Roof

Key Factors	Questions
Project Requirements	What kinds of roof or repair options are appropriate for your building?
Regulations	Is a cool roof required by code for your building? Is a cool roof encouraged by voluntary programs?
Economics	How much more will a cool roof cost? Is there a rebate or tax incentive available? What cost savings can you expect from a cool roof?
Other Considerations	Are there ordinances that restrict roof appearance / color? Are cool roof products available? How will a cool roof affect roof durability?

Project Requirements

It is best to begin by determining the most appropriate roof systems or repair/maintenance methods for your building. For existing roofs, the three main options are to coat the roof, re-cover the roof with a new waterproofing surface, or tear off the existing roof and replace it with a new roof. If your roof is in poor condition or near the end of its life, it is usually best to re-cover, replace, or retrofit the roof. In some cases it is possible to build a second roof on top of an existing old roof, but this depends on building codes and the structural integrity of your roof. If,

[xi] Suppose a metal roof has an aged solar reflectance of 0.70 and a thermal emittance of only 0.10. Although the emittance is below the Table 1 requirements, the reflectance might be high enough to make up for it using the alternative SRI requirement. Using the SRI calculator, you find that this roof has an SRI of 60. This is high enough (SRI>16) to be cool for a steep-slope application, but too low (SRI>64) for a low-slope application.

instead, your roof is in moderate condition and needs only minor repairs, a coating can be used after any repairs have been made.

For new or replacement roofs, you should talk with your roofing contractor or consultant to decide which roof types make sense for your building. Knowing which roof types to consider will make it easier to determine if a cool roof makes sense.

Is a Cool Roof Required or Encouraged

In some regions, cool roofs are required by legislation. Voluntary programs may also encourage building owners to pursue cool roofs. For example, irrespective of climate, cool roofs qualify for 1 point under the USGBC's LEED-NC 2009, Sustainable Sites Credit. When cool roofs are optional yet encouraged, the decision should be considered carefully as cool roofs do not perform equally well everywhere.

On the web, the CRRC maintains a list[xii] of state codes, industry standards, and voluntary programs for cool roofs. Check with your roofing contractor and your local building authority, as these programs may change.

Cool Roof Economics

Roof cost should be evaluated using a lifecycle approach. This means taking into account the upfront costs as well as the ongoing savings and expenses incurred throughout the roof's service lifetime. Other non-cost considerations are shown in Table 3. Roof lifetime, expected maintenance (regular roof inspections, repairs, and recoatings), disposal, and replacement costs should be evaluated for each viable roof option. Table 4 shows the range of benefits and costs you can expect to encounter for cool roofs.

Table 3: Non-cost Considerations

Factor	Notes
Voluntary Programs	Some programs encourage cool roofs, even when they may not be the best choice
Comfort	In unconditioned spaces like warehouses, cool roofs can maintain cooler indoor temperatures
Durability	Cool roofs may degrade slower and last longer than similar non-cool roofs, but more data are needed to establish this benefit
Maintenance	Some cool roofs in hot, humid environments may be more susceptible to mold or algae growth; this can be cleaned off

[xii] http://www.coolroofs.org/codes_and_programs.html

Table 4: Cool vs. Hot Roofs, Typical Expected Savings and Premiums

	Cool vs. Hot Roof	Notes
Upfront Savings (Costs)	$/ft^2 roof area	
Installed Cost	(0.00-0.75)	Material cost premium. As shown in Tables 5 & 6, most cool options have only a slight cost premium or none at all.
Rebates	0.00-0.20	Rebates are available in select locations, check here: http://www.coolroofs.org/codes_and_programs.html.
HVAC Downsizing	0.00-0.07	Reductions in peak cooling capacity tend to be modest, and are only possible when cool roofing coincides with HVAC replacement and reductions enable use of smaller AC systems.
Annual Savings (Costs)	$/ft^2/yr roof area	
Cooling Energy	0.00-0.13	Varies by location, insulation levels, HVAC equipment and efficiency, and utility rates. Estimate energy cost savings with the Roof Savings Calculator: http://www.roofcalc.com. Snow on roofs can reduce the heating energy penalty.
Heating Energy	(0.00-0.03)	

How Much More Will It Cost

A cool roof need not cost more than a non-cool roof. Major roof costs include upfront installation (materials & labor) and ongoing maintenance (repair, recoating, and cleaning).

Materials & Labor

The installed costs of a roof can vary depending on several factors, including its type, size, complexity, method of attachment, and building location. Nevertheless, 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 (see Table 5). Slightly higher upfront costs occur mostly in colored roofs that require specialty reflective pigments. Manufacturers must research, develop, and test cool products, and this can also lead to higher prices. The labor required to install or coat cool roofs is about the same as for non-cool roofs.

On the other hand, converting a roof that is in good condition into a cool roof can cost more (see Table 6). For instance, if you want to coat your new dark roof just to make it a cool roof, the additional cost can be significant. More often, roofs are coated to extend their lifetimes. If you are already planning to coat your roof, then using a cool coating instead of a dark one will probably cost about the same. Notice that 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 more coating material to achieve the desired thickness. If the existing roof is not already cool, it may require one extra coating to ensure full coverage.

Typical, approximate installed roof cost premiums for different cool roof options are given in Tables 5 and 6. 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/ft^2 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.

Table 5: Roof Surfaces, Cool Alternatives, and Approximate Price Premiums*

Roof	Typical Non-Cool Surface	Cool Alternative	Price Premium ($/ft^2)
Built-Up Roof	Mineral aggregate embedded in flood coat	Light-colored aggregate, like marble chips, gray slag	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 surfaced 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

***Premiums are the extra cost, per square foot of roof area, of installing the cool roof option as compared with the corresponding non-cool option. Premiums are based on achieving the minimum cool roof characteristics described in Table 1. Values are approximate, and are based on discussions with roofing contractors, manufacturers, wholesalers, and RSMeans cost data.**
[§]These roofs may be used in steep slope applications where cool roof requirements are less stringent. Uncoated metal roofs normally meet requirements for steep slope, but not for low slope. Premiums for shingles & tiles are based on steep slope requirements. All other premiums are based on low slope requirements.

Table 6: Making an Existing Roof Cool, Approximate Price Premiums*

Roof	Maintenance Option	Cool Alternative	Price Premium ($/ft^2)
Smooth Dark Surface	Leave roof as-is	Apply cool coating	1.25-2.40
	Apply restorative dark coating (asphalt, bitumen, colored coating, etc.)	Apply cool coating instead	0.00-1.70
Rough Dark Surface	Leave roof as-is	Apply cool coating	1.45-2.75
	Apply restorative dark coating (asphalt, bitumen, colored coating, etc.)	Apply cool coating instead	0.00-1.90
Old Light or Cool Surface	Leave roof as-is	Apply maintenance coat (single coat)	0.80-2.00
	Apply restorative dark maintenance coating (asphalt, bitumen, colored coating, etc.)	Apply cool maintenance coating (single coat)	0.00-1.45
Any Roof	Replace roof	Replace with cool roof	See Table 5

***Premiums are the extra cost, per square foot of roof area, of installing the cool roof option as compared with the corresponding non-cool option. Premiums are based on achieving the minimum cool roof characteristics described in Table 1. Values are approximate, and are based on discussions with roofing contractors, manufacturers, wholesalers, and RSMeans cost data.**

Maintenance of cool roofs is similar to non-cool roofs. Dirtying of roofs reduces solar reflectance. Although annual cleaning can restore up to 90% of initial reflectance, the energy cost savings alone does not warrant the cost[4]. 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.

In warm, moist locations, cool roof surfaces can be more susceptible to algae or mold growth than hot roofs. 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, roofs 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. This phenomenon is discussed in more detail in the precautions section, and can be avoided using proper design techniques.

How Much Will You Save

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

Energy Savings from reducing cooling loads 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 predict the yearly energy and cost savings associated with cool roofs. Later, we will show you where to find and how to use one such tool to predict savings.

Rebates and Incentives **for cool roofs** are offered by some utilities and agencies. To find out if there are any programs in your location, visit the CRRC website[xiii] and check with your roofing contractor. Currently, certain kinds of residential cool roof projects are eligible for a Federal Tax Credit of 30% of materials, up to $1,500[5]. Nonresidential building rebate programs can be more complicated, and may also include other efficiency measures besides cool roofs. Contact the rebate program agencies to determine the probable savings associated with a cool roof rebate.

HVAC Equipment Savings may be achieved when a cool roof reduces peak cooling loads significantly enough to reduce the air conditioning capacity needed. At best, the associated savings are modest ($0.03-0.07/ft^2 of cool roof area), and can only be realized when HVAC equipment is being 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.

[xiii] http://www.coolroofs.org/codes_and_programs.html.

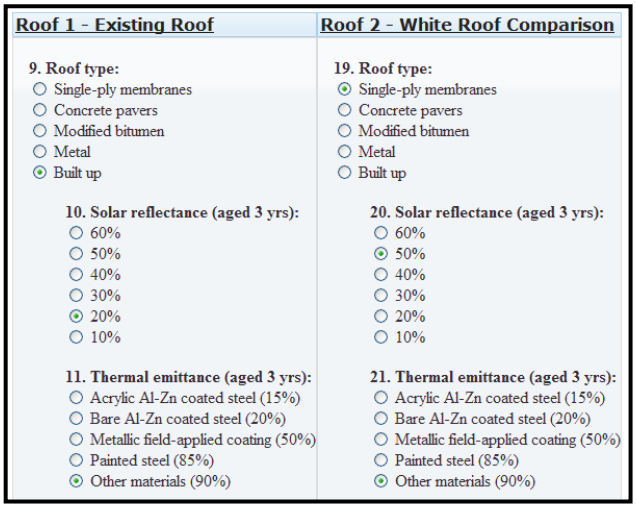
Extended Roof Lifetime is one possible advantage of using cool roofs. Roofs wear out and fail for many reasons, and some are linked to temperature. For example, higher temperatures can speed up material degradation. Cool roofs maintain a lower average temperature, so, in principle, this could slow heat-related degradation. 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.

Online Tools to Predict Energy Savings

The Roof Savings Calculator[xiv] 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. A portion of the interface is shown in Figure 7.

To use this tool, you will need to answer a few basic questions about your building and two proposed roofs. 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. Several key factors affect the amount of energy you can save.

Figure 7: Roof Savings Calculator

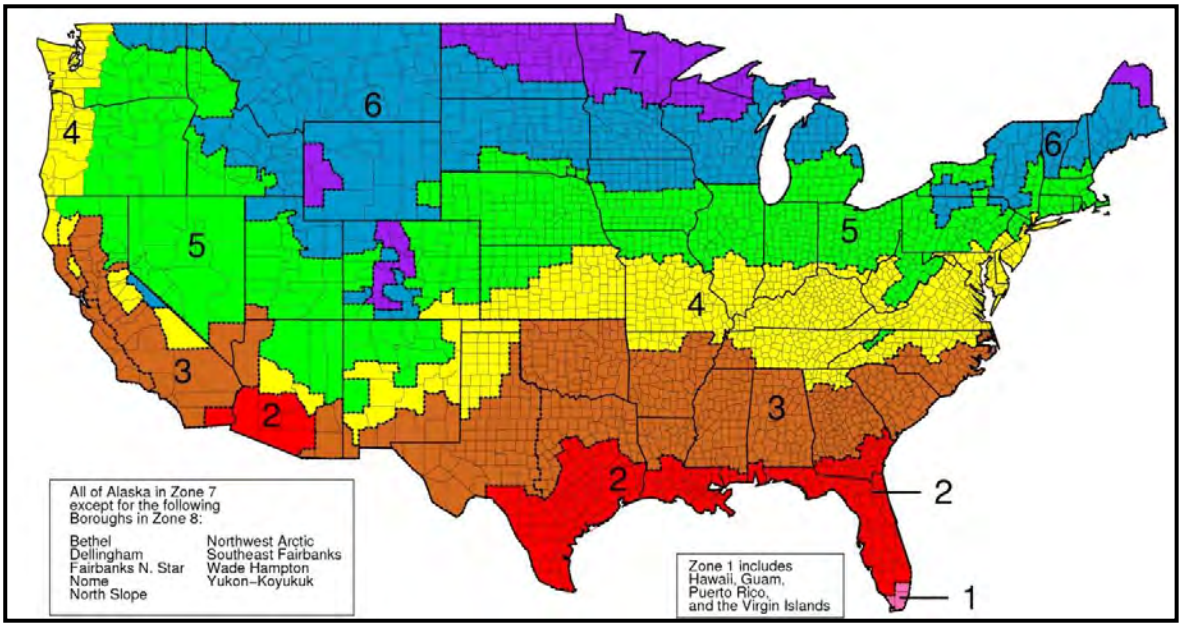


This online calculator lets users estimate the energy-savings from using a cool roof in place of a dark one.

Climate has the biggest impact on energy savings. Cool roofs achieve the greatest cooling savings in hot climates (Climate Zones 1-3; see Figure 8) but can increase energy costs in colder climates due to reduced beneficial winter time heat gains. The DOE Cool Roof Calculator takes into account your local climate when you select the state and a city nearest your building.

[xiv] http://www.roofcalc.com

Figure 8: U.S. Climate Zones



These 8 climate zones in the US represent a wide range of weather conditions. Cool roofs are recommended most strongly for buildings in Zones 1-3, where cooling loads are most significant. *Image Source: U.S. DOE*

Solar Reflectance and Thermal Emittance values of the roof surface help determine its temperature. Most roofs are not washed frequently, so we recommend using aged values to predict energy savings. If aged values for your roof are unknown, you can estimate the aged solar reflectance based on the initial solar reflectance by using this formula[xv]:

Aged Reflectance = 0.7 x (Initial Reflectance – 0.2) + 0.2

Some materials retain solar reflectance better than others, so use *measured* aged values whenever possible. Using initial values for thermal emittance is fine, since these values tend to change less over time.

Insulation reduces heat flow through the roof. A well-insulated roof will benefit less from a cool roof than a poorly insulated roof. Recent energy codes recommend R-20 insulation for nonresidential buildings in all U.S. climate zones, except for Climate Zone 1 (which is R-15). If you don't know your roof's insulation, you can use R-20 for a conservative savings estimate if your building was constructed in the past 15 years.

Utility Rates & Fuel Types vary by location and by customer. This tool allows you to specify what type of fuel you use for heating and cooling, as well as the price you pay. By clicking on the ? buttons, you can find recent average utility rates for your state.

[xv] For example, if a roof material has an initial solar reflectance of **0.80**, using the equation you can predict that the expected aged reflectance is **0.62** as shown here: **Aged Reflectance** = 0.7*(**0.80**-0.2) + 0.2 = **0.62**

Equipment Efficiency affects savings as well. Buildings with less efficient HVAC equipment will save more energy with cool roofs. If you plan to replace your inefficient HVAC equipment soon after replacing the roof, be sure to input the updated efficiency values.

Results are obtained after entering the above information and clicking the "Calculate" button. A calculation routine will predict your annual energy cost savings per square foot of roof area. *Cooling Savings* and *Heating Savings (penalty)* are presented, along with *Net Energy Savings (penalty)*. Heating penalties are usually smaller than cooling savings, so most locations will yield a net energy cost savings for cool roofs.

Hypothetical Example 1: Roof Coating Comparison[xvi]
Suppose your building has a 20,000 ft^2 roof that is in reasonable condition, and you want to coat the roof to make it last five years longer. Your roofing contractor gives you two proposals: one for a dark coating and one for a cool coating. If the cool coating costs $0.10 *more* per square foot, is it worth it to spend the extra **$2,000** ($0.10/ft^2 x 20,000 ft^2) to have a cool roof?

1. Begin by using the Roof Savings Calculator to compare the two roofs. Suppose you find that the cool roof lowers the cooling bill by $0.06/$ft^2$ and increases the heating bill by $0.02/$ft^2$. On average, you will save $0.04/$ft^2$ (= $0.06/$ft^2$ – $0.02/$ft^2$) on energy.
2. Next, calculate annual energy cost savings by multiplying the net savings by the roof area (20,000 ft^2). Each year you would save $800 on energy costs (= $1,200 cooling – $400 extra for heating). Since the coating lasts five years, you would expect to save $4,000 (= $800/yr x 5 yr) on energy over the life of the coating.
3. Finally, to find the simple net savings, subtract the premium (if any) for the cool roof. In this case, the cool roof was $2,000 more, so the net savings would be $2,000 = (= $4,000 saved – $2,000 extra). In this case, the cool roof looks like the better investment.

Note: even though the cool roof saves money, the net savings would only cover a small fraction of the *total* coating installation.

Table 7: Example 1 – Simple Cool Coating Comparison

	Incremental Benefit or Cost	Roof Area	Years		Lifetime Benefit or Cost
Extra Upfront Cost	$0.10/$ft^2$		**n/a**	=	-$2,000
Cooling Energy Savings	$0.06/ ft^2/yr	**x20,000 ft^2**	**x5 yr**	=	+$6,000
Heating Energy Penalty	$0.02/ ft^2/yr			=	-$2,000
			Lifetime Savings:		**$2,000**

[xvi] Costs used in these examples are for illustrative purposes only and do not represent actual costs.

Hypothetical Example 2: Roof Re-cover or Replacement
Suppose that the same roof has come to the end of its useful life and you must replace it. You are evaluating a dark and a white membrane, each with a 15-year warranty. As before, the cool option costs $\$0.10/ft^2$ more than the dark membrane, and the cooling savings and heating penalty are the same as Example 1. This time, the predicted simple net savings ($10,000) are much larger because the new roof lasts three times longer than the coating in Example 1.

Table 8: Example 2 – Simple Roof Replacement Comparison

	Incremental Benefit or Cost	Roof Area	Years		Lifetime Benefit or Cost
Extra Upfront Cost	$\$0.10/ft^2$		**n/a**	=	-$2,000
Cooling Energy Savings	$\$0.06/ ft^2/yr$	**x20,000 ft^2**	**x15 yr**	=	+$18,000
Heating Energy Penalty	$\$0.02/ ft^2/yr$			=	-$6,000
			Lifetime Savings:		**$10,000**

Cool Roof Selection and Applications

If you decide to consider a cool roof, these notes can help you select and install the right option for your building. The decision to make your existing roof a cool roof usually means deciding to coat the roof, replace the roof, or build another roof on top of the existing roof. If your roof is in good condition; has relatively few, easy-to-repair leaks; and has at least five years of expected service life, a cool coating may be a good option.

Note that the main reason for coating a roof is to extend its service life, and the energy savings alone will not normally provide sufficient financial reason to coat a roof to make it cool. If your roof is in poor condition, or is approaching the end of its service life, a roof re-covering (adding a new membrane) or replacement (removal of the existing roof, and installation of a new one) is the likely option. Roof re-covering or replacement gives you the opportunity to select any kind of roofing system and cool roof option you desire.

Above all, your roof must protect the building from the effects of weather, so be sure to select a roof system that will do this well. A durable roof is the result of the combined efforts of the building owner, specifier, manufacturer, and contractor. Insist that your installer follow all manufacturer installation procedures. Asking the right questions and being involved can help safeguard your investment. The following application notes will help guide you through this process.

Roof Coatings can be rolled, brushed, or sprayed onto most kinds of roofs. Any leaks or problems with the roof membrane must be repaired before coating the roof. If you plan to coat your roof, selecting the right coating for your particular roof is the most important thing you can do – cool roof or not. **NOTE: Roof coatings are not the same as exterior paints.** Ordinary paints are not designed to last on roof surfaces and will not provide protection. Three major

kinds of coatings include acrylic, silicone, and urethanes, and cool roof formulations are available for each, Table 9. Aluminized asphaltic emulsions provide a glossy finish for some roof types, but fall short of meeting cool roof standards for low sloped roofs.
Coating quality varies widely by manufacturer. Improper coating installation can produce coatings that flake off or wear out faster than they should. Insist that the installer follow the manufacturer's recommended installation procedures, especially regarding weather condition restrictions during application and minimum coating thickness.

Table 9: Roof Coating Types Available in Cool Options[6]

Coating Type	Properties	Cost
Acrylic	Water based, easy to handle, good adhesion to most roof types, most commonly used reflective coating, cures by evaporation, reasonably strong, very sensitive to weather	Moderate
Silicone	Solvent based, typically used for spray polyurethane roofs, weather very well, weaker tensile strength, good water resistance	More expensive
Urethane	Solvent based, 3-10 times stronger than acrylic, greater adhesion to most roof types than acrylic, most cure with exposure to air, less sensitive to weather, more difficult to work with	More expensive

Roof Replacement or **New Construction** gives you an opportunity to select from many cool roof options. In some cases an existing roof must be removed and a new roof installed in its place. In other cases, it may be possible to build a second roof atop an existing roof, though this depends on your roof's condition and local building codes. Regardless of how the roof is installed or replaced, here are some notes about cool roof options.

Single-Ply Membranes come in several types. TPO and PVC membranes are usually white and reflective, and do not require additional formulations or cool coatings. EPDM membranes are black, but can also be produced in white or cool colors. Durable cool EPDM options use black EPDM that is pre-coated with a reflective coating or laminated with a reflective material. The designer should consider membrane durability, since all membranes are not equally durable[xvii].

Roof membranes that are attached with chemical adhesives must reach and maintain a minimum temperature to bond properly. To compensate for reduced surface temperatures, cool roofs that are chemically adhered might require warmer outdoor temperatures during installation to bond properly. Make sure your contractor follows the recommended installation procedures.

Built-Up Roofs can be surfaced in three ways, and each has a cool option. First, light-colored aggregate, such as marble chips, can replace the dark mineral aggregate commonly used with hot bituminous flood coat surfacing. It is usually impractical to coat a gravel-surfaced built-up roof

[xvii] Although roofing manufacturers' warranties can provide useful information about expected roof longevity, they may not necessarily tell the entire story. For example, while manufacturers may offer up to a 30-year material warranty, this usually does not cover the seams, where premature failure can occur.

with a cool coating. Doing so requires the removal of the non-embedded gravel, which may affect the roof's fire rating. Second, reflective aluminum pigments can be added, at some cost, to an asphalt-coated smooth surface, however these have a low thermal emittance and are not cool. To make this surface cool requires an additional cool coating. Finally, cap sheets with white mineral granules can be substituted for those with dark mineral surface, also at a small premium.

Modified Bitumen roofs should have protective coatings to provide heat resistance, ultraviolet resistance, and fire resistance. SBS modified roofs[xviii] must be coated to prevent rapid ozone and UV degradation. APP modified roofs[xix] may be left unsurfaced, but this is not recommended because irregular surface cracks can develop that lead to premature aging. The protective surfacing layer can be made of aggregate, mineral, metal foil laminate, or smooth surfaced with a liquid coating. If a large amount of protective granules fall off, recoating becomes necessary.

Metal Roofs are often coated with Fluoropolymer- or Silicone-Polyester based paints, and many colors can achieve cool roof performance. Some manufacturers offer cool colors almost exclusively, since lower surface temperatures reduce color fading and cost premiums for the reflective pigments are modest. Unpainted metal roofs tend to have a high reflectance but a low thermal emittance, which prevents them from being considered cool in low slope applications.

Spray Polyurethane Foam roofs are typically coated and periodically re-coated with reflective coatings to protect the foam from UV and water damage. As with membrane roofs, there are many suitable cool roof coatings for spray foam roofs, with acrylic being the most common. Some slightly pitched foam roofs cannot be white according to building appearance ordinances, so gray or tan colors may be used instead.

Asphalt Shingles are not typically coated in the field and doing so may void the manufacturer's warranty. If you have asphalt shingles and wish to make your roof cool, you may need to replace the shingles with reflective shingles. In such cases, it may be more cost effective to wait until the shingles reach the end of their service life before replacing them with cool shingles. Other shingles, like those made from wood, polymer, or metal, can be coated to achieve cool roof status.

Tile Roofs may retain their color or not with aging depending on the type of tile. The color of clay tiles depends on naturally occurring chemicals and minerals in the clay. The surface of clay tiles may be altered by glazing the tiles during the manufacturing process. Concrete tiles can receive a surface coating after being produced, or color can be dispersed throughout the tile as it is produced (color through). The color of roofing slate depends on its chemical and mineral makeup. *Weathering* slate exhibits color changes as it weathers, while *permanent* or *unfading* slate retains its color with weathering. Selecting cool roof tiles that retain their surface properties can yield better lifetime energy savings.

[xviii] SBS stands for Styrene Butadiene Styrene. SBS modified bitumen roofs have a flexible, rubber-like quality.
[xix] APP stands for Atactic Polypropylene. APP modified bitumen roofs have a more rigid, plastic-like quality.

Cool Roof Maintenance As a cool roof becomes dirty from pollution, foot traffic, wind-deposited debris, ponded water, and mold or algae growth, its reflectance will decrease, leading to higher temperatures. Especially dirty roofs may perform substantially worse than product labels indicate. Dirt from foot traffic may be minimized by specifying designated walkways or by limiting access to the roof. Steep sloped roofs have less of a problem with dirt accumulation because rainwater can more easily wash away dirt and debris. Some cool roof surfaces are "self-cleaning" which means they shed dirt more easily and may better retain their reflectance. Cleaning a cool roof can restore solar reflectance close to its installed condition. Always check with your roof manufacturer for the proper cleaning procedure, as some methods may damage your roof. While it is generally not cost effective to clean a roof just for the energy savings, roof cleaning can be integrated as one component of your roof's routine maintenance program. It is therefore best to estimate energy savings based on weathered solar reflectance values rather than clean roof values.

Precautions & Considerations

Although cool roofs have been used successfully for many years, their use is growing and cool roofs are now being installed in a wider range of climates. There are some important questions about the durability of cool roof systems in certain applications.

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. The following considerations illustrate how cool roofs handle moisture differently than dark roofs.

Ponding occurs when water, typically from rain, accumulates in pools on the roof. This happens when a roof has insufficient slope (caused by poor design or damage) or drain blockage. It takes longer for ponded water to evaporate from a cool roof due to its lower temperature. If your cool roof cannot tolerate ponding, it may be necessary to inspect the roof more frequently to prevent damage or leaks.

Moisture from the indoor air can also 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 climates, like Phoenix, AZ (Climate Zones 1-3 in Figure 8), there is little risk for this kind of moisture build-up.[7] In colder climates, like Chicago or Alaska (Climate Zones 5-8 in Figure 8), there is less heat available to dry out the roof and more 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,[8] the authors are not aware of any data that clearly demonstrate a higher occurrence in cool roofs. The potential for persistent moisture levels to arise in different roof designs and climates is the subject of ongoing research.

Mind Your Surroundings

Cool roofs must be considered in the context of your 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, reflective roof could reflect light and heat into the higher windows of taller neighboring buildings. In sunny conditions, this could cause uncomfortable glare and unwanted heat for you or your neighbors. Excess heat caused by reflections increases air conditioning energy use, negating some of the energy saving benefits of the cool roof.

Highly Energy Efficient Buildings and Rooftop Solar Equipment

Cool roofs may add only marginal energy savings to buildings that are already highly energy efficient. Highly efficient buildings are often well insulated to minimize the flow of heat through the walls and roof. This helps the occupied space stay cool in summer and warm in winter, regardless of the roof's surface temperature. However, dark roofs on well-insulated buildings can become very hot, so cool roofs help achieve the environmental benefits associated with lower roof temperatures. Keeping a roof cool may also extend its lifetime.

Solar energy systems, such as photovoltaic (PV) panels and solar thermal collectors, absorb solar energy and can become hot in the sun. Solar equipment mounted flush with the roof's surface can act like a dark roof, transmitting heat to the building and increasing air conditioning demand. Physical gaps between the solar equipment and roof can reduce this effect, since airflow through the gap can remove some of the heat that would otherwise flow into the roof. On permanently shaded portions of the roof, the roof's solar reflectance does not affect air conditioning demand. This includes regions of the roof that are completely shaded by solar panels[xx].

Some newer thin-film PV modules can be integrated directly with roofing materials. They may meet current cool roof requirements for steep sloped roofs[9] but do not satisfy the more stringent standards for low sloped roofs.

[xx] Some newer types of solar equipment, such as PV tubes, can also collect solar energy reflected from roof surfaces. These systems generally do not completely shade the underlying roof space. Instead, they rely on a reflective roof surface to collect sunlight on the underside of the tubes.

Resources

Additional information about cool roof benefits, applications, incentives, and policy can be found at the organizations and links listed below.

Energy & Cost Savings Calculator

Roof Savings Calculator
http://www.roofcalc.com

Industry Associations

Asphalt Roofing Manufacturers Association
750 National Press Building
529 14th Street, NW
Washington, DC 20045
Phone: (202) 207-0919
http://www.asphaltroofing.org

Center for Environmental Innovation in Roofing
816 Connecticut Ave., NW, 5th Floor
Washington, DC 20006
Phone: (866) 928-2347
http://www.roofingcenter.org

Cool Metal Roofing Coalition
680 Andersen Drive
Pittsburgh, PA 15220
Phone: (412) 922-2772
http://www.coolmetalroofing.org

Metal Building Manufacturers Association
1300 Sumner Ave.
Cleveland, OH 44115-2851
Phone: (216) 241-7333
http://www.mbma.com

Metal Construction Association
4700 W. Lake Avenue
Glenview, IL 60025
Phone: (847) 375-4718
http://www.metalconstruction.org

Metal Roofing Alliance
E. 4142 Hwy 302
Belfair, WA 98528
Phone: (360) 275-6164
http://www.metalroofing.com

National Roofing Contractors Association
10255 W. Higgins Road, Suite 600
Rosemont, IL 60018-5607
Phone: (847) 299-9070
http://www.nrca.net

Reflective Roof Coating Institute
400 Admiral Boulevard
Kansas City, MO 64106
Phone: (816) 221-1297
http://www.therrci.org

Roof Coating Manufacturers Association
750 National Press Building
529 14th Street, NW
Washington, DC 20045
Phone: (202) 207-0919
http://www.roofcoatings.org

Roof Consultants Institute
1500 Sunday Drive, Suite 204
Raleigh, North Carolina 27607
Phone: (800) 828-1902 or (919) 859-0742
http://www.rci-online.org

Single Ply Roofing Industry
411 Waverley Oaks Road, Suite 331B
Waltham, MA 02452
Phone: (781) 647-7026
http://www.spri.org

Tile Roofing Institute
230 East Ohio St., Suite 400
Chicago, IL 60611
Phone: (312) 670-4177
http://www.tileroofing.org

Material & Product Ratings

Cool Roofing Materials Database
Lawrence Berkeley National Labs
http://eetd.lbl.gov/CoolRoofs

Cool Roof Rating Council
1610 Harrison Street
Oakland, CA 94612
Phone: (866) 465-2523 or (510) 485-7175
http://www.coolroofs.org

ENERGY STAR Reflective Roof Products
1200 Pennsylvania Ave., NW
Washington, DC 20460
Phone: (888) 782-7937
http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_products

Cool Roof Research Groups

Lawrence Berkeley National Laboratory
Heat Island Group
http://eetd.lbl.gov/HeatIsland

Oak Ridge National Laboratory
Building Envelopes Program
http://www.ornl.gov/sci/roofs+walls

Other Resources

Consumer Energy Center
California Energy Commission
http://www.consumerenergycenter.org/coolroof

Flex Your Power
Cool Roofs Product Guide
http://www.fypower.org/com/tools/products_results.html?id=100123

U.S. Department of Energy
Federal Energy Management Program
http://www1.eere.energy.gov/femp/features/cool_roof_resources.html

End Notes

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