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Editors
Radoje V. Pantovic
Zoran S. Marković

Vrnjacka Banja, Serbia
12-15 June 2017

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XXV International Conference

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COOL ROOFS IN SUSTAINABLE CIVIL ENGINEERING

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ABSTRACT

The urban heat island effects can be detected throughout the year, but they are of particular importance for the health of human population during summer when air temperatures are high. These heat islands cause increased electricity demand for air conditioning, as well as air pollution which increases with the increase of environment temperature.

Mitigation of the urban heat island effect, among other methods, can be accomplished through the use of Cool Roofs. A cool roof is one that reflects the sun's heat and emits absorbed radiation back into the atmosphere at a higher rate than standard materials. These types of roofs literally stay cooler, thus reducing the amount of heat held and transferred to the building below. In this way the building remains cooler and at a more constant temperature. The paper presents the properties and types of cool roofs and the advantages of their usage in urban environments.

Key words: cool roofs, solar reflectance (SR), thermal emittance (TE).

INTRODUCTION

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 this century. This dramatic change in temperature will produce a climate unfavorable for human population . 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.

The difference between air temperatures in a city and its surrounding rural areas can be 5 to 9 degrees Celsius or more in summer months [1,2]. This phenomenon gave rise to the term - the urban heat island effect (UHI). The urban heat island effect can be observed throughout the year, but it is specially prominent during summer.

It should be mentioned that the temperature difference is usually larger at night than during the day, and is most apparent when winds are weak because the warm air cannot be removed and in addition the surfaces which make up the structures emit at night the thermal energy absorbed by day. All the mentioned factors increase the health problems due to thermal stress, and somtimes lead to fatal outcomes.

As such, urban heat island effect is a serous problem faced by the built up urban areas [3].

Addressing this heating effect will 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 [1,4] 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 [5]. These surfaces are dark and typically absorb over 80 percent of sunlight and in this way heat up the surrounding air. The effects of roofs on warming the environment can be mitigated by using cold material, the so called cold roofs. They feature high solar reflectance and infrared emittance values [1].

Cool roofs paired with appropriate levels of roof insulation help keep buildings more thermally comfortable.

Cool roofs and pavements should be a priority strategy because they are cost-effective and typically pay back within one year. This is the most acceptable way of helping cities both mitigate the climate change while making them more desirable and comfortable places to live.

COOL ROOFS

Cool roofs are roofs made of high reflectance and emittance materials which can be cooler for 28-33°C during the hottest summer days than the traditional roofs [6]. Reflecting the sun's energy to keep cool is an ancient strategy that has been made modern with science and innovation. Cool roofs have been widely available in the U.S. marketplace for more than 25 years.

For any of these roofing products to be "cool" by today's standards, the minimum percentage of solar heat reflected away from the building typically falls within a range of 0.50 (50 percent) to 0.70 (70 percent depending on the particular standard being applied and the aging of the sample tested. The table 1 shows the building codes and standards used for cool roofs [5].

CURRENT COOL ROOF REFLECTANCE STANDARDS		
Reference Standard	Minimum Roof Reflectance	
	Initial	Aged
International Energy Conservation Code (2012)	0.70	0.55
ASHRAE 90.1 Energy Standard for Buildings (2011)	0.70	0.55
Energy Star for Roofs (U.S. EPA, 2012)	065	0.50
California Title 23 Energy Standard (2012)	N/A	0.63

Table 1. Current cool roof reflectance standards [5].

The two radiative properties that characterize cool roofs are solar reflectance and thermal emittance, Figure 1. A cool roof minimizes the solar heat gain of a building by first reflecting incoming radiation and then by quickly re-emitting the remaining absorbed portion. As a result, the cool roof stays cooler than a traditional roof of similar construction.

Solar Reflectance is the fraction of sunlight that a surface reflects. Solar radiation consists of three forms of energy: around 5% of ultra violet light, 45% of visible light and 50% of infrared light. 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 [6].

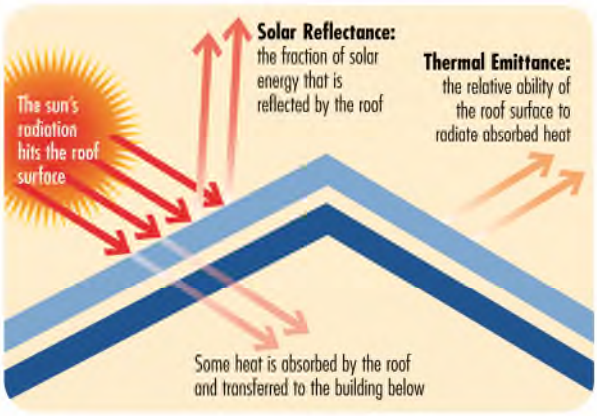

Figure 1. Typical dark roofs absorb 90% and more of solar energy, and white cool roofs can absorb less than 50% of sunlight [6].

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, 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 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 [6].

Though most roofing materials have a fairly high thermal emittance, in order to accurately determine a roofing product's "coolness," or its ability to shield the building beneath it from heat, both solar reflectance and thermal emittance must be measured. It is possible for a roofing product to have a very high emittance value and a reflectance value ranging from very high to very low, or vice versa, which leads to the conclusion that such products would not typically be considered "cool" roofs [7].

Solar Reflectance Index (SRI) – Codes and standards that specify cool roofing requirements may also reference an additional calculated value, the Solar Reflectance

Index (SRI). SRI allows actual measured solar reflectance and thermal emittance values to be combined into a single value by determining how hot a surface would get relative to standard black and standard white surfaces. The standard black roofing material has a high emittance value (90 percent) but a low reflectance value (5 percent). This creates a hot roof surface because even though the emittance is high, there is not enough reflectance to help cool the roof. As such, the standard black roof is given an SRI value of 0.

The standard white roofing material is highly reflective (80 percent) and has the same emittance as the standard black surface (90 percent). Its surface is much cooler and the standard white roof is assigned an SRI value of 100. Like solar reflectance and thermal emittance, a higher SRI value is synonymous with a cooler roof [7].

COOL ROOF QUALITY REQUIREMENTS

Typical minimum cool roof requirements are shown in Table 2. A roof can qualify as cool in one of two ways. The first way is by meeting the minimum solar reflectance and thermal emittance values provided in the table. The alternative way is to meet 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 2. Typical Minimum Cool Roof Requirements, California Energy Commission [8].

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

NOT ALL COOL ROOFS ARE WHITE

It is known that white materials tend to be very good solar reflectors. However, colored roofing materials can also be made to reflect more sunlight, Figure 2.

More than half of the sunlight heating the roofs is in the spectrum invisible to the human eye, - infrared and ultraviolet (which does not affect the color of the objects). 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% [6].

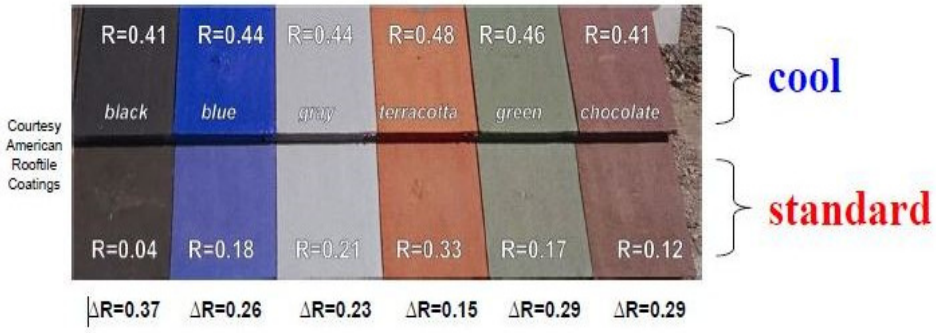

Figure 2. Cool Dark Colors, Cool-colored tiles (top row) look just like conventionally colored tiles but have higher solar reflectance (R) [9].

PRODUCT TYPES

Materials for roofs can vary from asphalt to acrylics, and many of these products have cool roof alternatives. The following list provides examples of some common roofing product types, but does not account for every single type of roofing material in the market:

Built-up Roofing (includes asphalt and coal tar pitch): Built-up Roofing (BUR) consists of built-up layers of coated asphalt and insulation applied on site and can be covered with a capsheet or field-applied coating. The "cool" part of this particular roof type refers to the properties of the capsheet, typically a white mineral fiberglass surface, or coating, which are UV-resistant.

Foam Roof Systems:

a) Field-applied foam systems are sprayed on in liquid form and harden as they set on top of the roof.

b) Factory-applied foam systems are formed into rigid panels and coated with a reflective coating in the factory. The foam usually gives the roof system additional insulation properties and the coatings provide the "cool" rating.

Metal - Metal roofing products can be shaped to look like shingles or shakes, or to fit unique curvatures, in addition to a typical standing seam configuration. They come in a variety of factory-applied textures and colors, including darker "cool" colors with infrared reflective pigments. Metal products can also be coated in "cool" custom colors to meet the cool roof conditions..

Modified Bitumen - Modified bitumen is bitumen (asphalt or tar) modified with plastic and layered with reinforcing materials then topped with a surfacing material. Like BURs, the radiative properties of modified bitumen are determined by the surfacing material, so a "cool" modified bitumen product will be finished off with a capsheet or coating to achieve a high solar reflectance.

Roof Coatings - Roof coatings can be divided into two categories: **field-applied** and **factory-applied.** Field-applied coatings are applied directly onto the roof surface, either on a new roof assembly or over an existing roof surface and may require an appropriate primer. Factory-applied coatings are applied directly to products at the factory. Examples of factory-applied coatings include coatings applied to metal, and glazes that are applied to tiles. Once applied, the coating is what determines the reflective properties of the roofing product.

Shingles, Slate, or Tile: These roofing products are commonly used for residential buildings, or steeper-sloped buildings, and rarely for public buildings. For "cool" colored shingles, the heightened solar reflectance comes from granules that contain solar-reflective pigments. Slate and tile products have solar-reflective surfaces in a number colors. The earthen composition of slate and tile products provides increased thermal mass, which has detrimental effects on thermal emittance.

Single-ply: Single-ply roofing is a pre-fabricated sheet of rubber polymers. The single-ply membrane can be loose-laid and weighted down with ballast or pavers or firmly set on the roof and attached with mechanical fasteners or adhesives. There are two main types of single-ply materials: **single-ply thermoset** and **single-ply thermoplastic**. These roofing products can be specified with an ultra-violet-resistant and highly reflective surface [7] .

BENEFITS OF COOL ROOFS

Cool roofs may be made from a wide variety of materials, such as: metal, modified bitumen, slates, paints, roof tiles, coatings, shingles and rubber polymers. They can be installed on flat and sloped roofs, on commercial and residential buildings, in new construction and on existing structures. Although many cool roofs are light-colored or white, they are increasingly being created in a range of colors and can look nearly identical to traditional roofing materials. A cool roof can be 28 to 33°C cooler than a dark, conventional roof on a hot summer day. Cool roofs help reduce energy use and GHG emissions, save money on air-conditioning costs, and improve air quality. When enough are installed on a citywide scale, cool roofs can also reduce the urban heat island effect—helping to lower temperatures across whole urban communities [10].

CONCLUSION

A cool roof is one that strongly reflects sunlight and also cools itself by efficiently emitting radiation to its surroundings. However, a cool roof need not be white. There are many "cool color" products which use darker-colored pigments that are highly reflective in the near infrared (non-visible) portion of the solar spectrum. Because a white roof strongly reflects both visible and near infrared sunlight, a white roof will typically be cooler than a cool colored roof. The two basic characteristics that determine the "coolness" of a roof are solar reflectance (SR) and thermal emittance (TE). Both properties are rated on a scale from 0 to 1, where 1 is the most reflective or emissive. A cool roof can significantly reduce the cooling energy costs and increase the comfort level

by reducing temperature fluctuations inside building. Average energy savings range from 7%-15% of total cooling costs [11].

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