Being in the Know ABOUT SOLAR REFLECTIVE COATINGS

BY STEVE HEINJE AND TOM MEYER

Now that building energy efficiency is a national priority, roof consultants need to be in the know and up to date about roof coatings. Building owners and building professionals – and now policymakers and even taxpayers – are asking hard questions: What are the benefits of coatings? How do they work? What are the various types of coatings? Where should they be applied? They would like to know about alternatives to white coatings such as "cool colors," garden roofs, shading, light-colored gravel, insulation, and remedies against hot summers in the city, (e.g., urban heat islands). What are the code requirements? What are the incentives? They would like to know what's new in research.

Now more than ever it is necessary for roof consultants to separate fact from fiction and provide the right coating solutions for their clients. Before looking at coating formulations for roof cooling, a little physics is needed to understand the basic science behind why roofs get so hot in the first place. Familiarity with the underlying physics can go a long way in understanding coatings.

Photo 1 – A specialized gray base coat on this modified-bitumen roofing system blocks asphalt from bleeding into the bright white acrylic topcoat. (Photograph courtesy of Quest Construction Products: United Coatings, Spokane, WA.)

REFLECTING AND EMITTING

Coatings and insulation regulate roof temperatures in the same manner that oceans, atmosphere, clouds, and land masses regulate planetary temperatures. (See page 11 sidebar on "The Albedo of Earth.") The solar spectrum can be divided into three wavelength bands, including ultraviolet (300 - 400 nm), visible (410 - 722 nm), and near infrared (724-2500 nm), accounting for approximately 5%, 43%, and 52% of solar power, respectively.

As more photons strike the roof, they break more molecular bonds of roofing materials, ultimately leading to deterioration of the roof. The most harmful of these are photons of ultraviolet radiation. Although there are fewer UV photons, they are potentially more damaging to roofing materials, so it is important for roof coatings to reflect or block them.

The metal-oxide pigments used in white coatings scatter light by the same mechanism as water droplets in a cloud or fog; the scattering is due to the tiny particle size. (Coatings on a roof are analogous to cloud cover over the Earth.)

The usual pigments are zinc oxide (ZnO) or titanium dioxide (TiO_2). These scatter a large fraction of the photons back into the sky, especially in the visible and near infrared bands. Most white coatings have a very high reflectance across all visible wavelengths as well as a high reflectance for near-infrared radiation (NIR). Typical

Photo 2 – *Workmanship and extensive use of fabric bring new life to an old mod-bit roof, with a monolithic, adhesively attached acrylic membrane. (Photograph courtesy of Quest Construction Products: United Coatings, Spokane, WA.)*

ENERGY PROGRAM REQUIREMENTS AS OF 2009		
	Reflectivity	**Emissivity**
Energy Star	0.65	Not Required **
LEED	0.65	0.9
Title 24*	0.70	0.75

*The latest Title 24 update (effective January 1, 2010) will no longer use these values but instead calls for a three-year aged solar reflectance of 0.55 and a thermal emittance of 0.75, or the equivalent in terms of a minimum solar reflective index (SRI) of 64.

**The EPA ENERGY STAR® program does not have an emissivity requirement, but it does require manufacturers to test for emissivity so that values may be listed on the site.

Table 1

reflectance values averaged over these wavelengths are in the neighborhood of 70% or 80%. (See *Photo 1*.)

Emissivity is the ability of a material to release heat and is a significant factor in determining roof temperature. In roofing, this is usually measured in accordance with ASTM C1371, which yields a ratio to answer how much heat a material will store in the sun and how quickly it will cool down.

The solar reflective index (SRI) as defined by ASTM Standard E1980-01 attempts to account for both solar reflectance and thermal emittance. A standard white roof is then assigned a value of SRI = 100, and a standard black roof is assigned a value of SRI = 0. Under standard solar and ambient conditions, an aged, dirty, real-world roof would heat up to a temperature higher than a stark white roof but lower than a jet black roof.

Tweak either emissivity or reflectivity higher, and the roof temperature goes down. This temperature balance is the basis for the SRI and can be calculated from measured values of reflectance and emissivity. It is important to become familiar with SRI values, since SRI is often the preferred index in many standards and codes dealing with cool roofing. Armed with this understanding of basic physics, we can now examine the chemistry and properties of various tried-and-true coatings and new research and developments. (See *Photo 2*.)

Table 1 lists the minimal reflectivity and

Photo 3 – A monolithic acrylic coating system on this school in Texas provides waterproofing as well as reflectivity and energy savings. (Photograph courtesy of Quest Construction Products: United Coatings, Spokane, WA.)

Photos 4A and 4B – This metal roof at Disney World was first detailed with a stable rust primer and foundation coat (left) and then finished with a water-based fluoropolymer coating product (below). The original red color was restored with a color-stable, biologically resistant, "cool color" infrared reflective (IRR) roof. (Photographs courtesy of Quest Construction Products: United Coatings, Spokane, WA.)

emissivity values required by several well-known cool roofing and energy-efficiency programs.

PHYSICAL PROPERTIES

Regarding the physical or material properties of roof coatings, the first reference that a roof consultant needs to know is the ASTM D6083 standard. It addresses neither reflectivity nor emissivity, but it has everything to do with the quality of white coatings. This standard prescribes limits for certain physical properties of white acrylic coatings, one of the most popular coating materials on the market. The knowledge captured in ASTM D6083 has a 30-year track record, since the standard adopted in 1997 was based on materials in use since 1974. This standard sets the benchmark by which white elastomeric coatings are measured and ensures a definite level of quality in the marketplace. Most white acrylic formulations from reputable companies meet it (see *Photo 3*).

ASTM standards also exist for the specification and application of other types of roof coatings, e.g., aluminum-pigmented asphalt roof coatings.

COOL COLORS

For many reasons, there is a trend toward "cool colors" in the marketplace. Research continues on providing more color options for building owners. It seems that architects do not like being told that they can "have any color you want as long as it's white." Roofs, especially metal roofs, can be important architectural details (*Photos 4A* and *4B*).

Fortunately, a coating does not have to be bright white to reflect significant amounts of solar energy. A cool coating can appear quite dark if it reflects strongly in the near infrared band and yet absorbs in the visible band. As mentioned, more than half of the energy reaching Earth from the sun comes from the invisible, near-infrared part of the solar spectrum. This reflected radiation has no effect on the color of the roof and yet has a major effect on roof temperature.

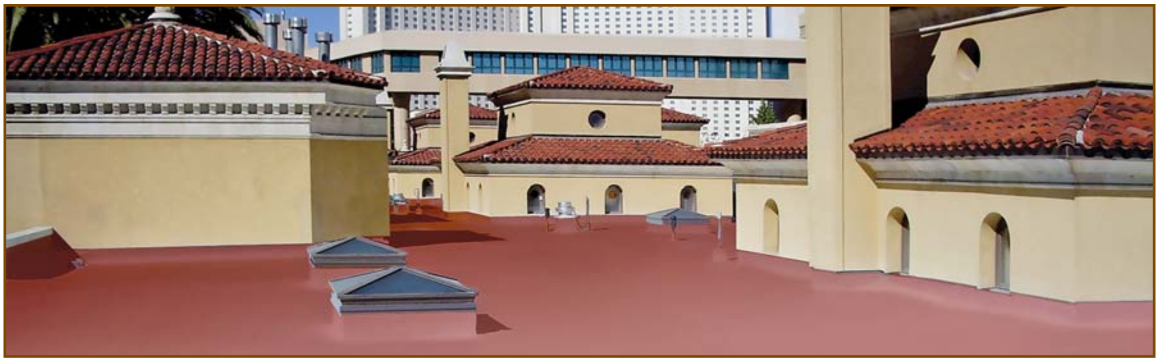


Photo 5 – The cool-colored roof coating on these hotel villas in Las Vegas is decorative and color-stable. The terra cotta cool color was created with infrared reflective (IRR) pigments in a fluoropolymer coating. (Photograph courtesy of Quest Construction Products: United Coatings, Spokane, WA.)

Cool colors follow the lead of nature. They are colors that reflect near infrared light, i.e., the heat one feels directly from the sun. Since only a very narrow band of color is visible, the green leaf of a tree may appear to match the color of a house or lawn furniture, but the tree is cool. If we could see infrared colors, tree leaves would appear like pastels, while most building materials would appear very dark. Some pigments reflect heat much the same way plants and trees do, and these are the so-called "cool colors." In other words, cool pigments reflect the heat of the sun similarly to the way plants do. They may appear dark in color, but they remain cool in the sun.

An excellent example of cool colors for roofs is found on the terra-cotta-colored roofs of the MGM Grand villas in Las Vegas (see *Photo 5*). This technology results in less heating of the roof for a longer-lived elastomer and longer-lasting colors. The pigments are very color-stable and available in a broad range of colors, although obtaining an exact color match is limited. To achieve the highest SRI, users may have to accept a "standard" color that does not match exactly, but one with pigments so outstanding that their infrared reflective (IRR) colors will probably match truer after six years than a less reflective, less stable color would after six months in the elements.

ALUMINUM COATINGS

A well-established technology for roof coatings involves the use of aluminum in asphalt coatings. The silvery-metallic color of aluminum coatings represents the original cool color, possibly accounting for nearly half of all roof coatings today. They are economically important because of their proven effectiveness in extending roof service life (*Photo 6*).

Photo 6 – Silvery-metallic, aluminum-asphalt coatings are economically important because of their proven effectiveness in extending roof service life. (Photograph courtesy of the Garland Company, Cleveland, OH.)

Suffice it to say that one of the first things that a roof consultant should know about coatings is the distinction between white (or other colored) coatings and aluminum coatings.

Despite the media attention on white coatings and reflective coatings, aluminum in asphalt remains a vital technology for the preservation of roofs. These coatings typically have a silvery-metallic color and, just like their cool-colored cousins, they can reflect significant amounts of solar energy.

Aluminum coatings are well suited to asphalt BUR and MB roofing systems. While white coatings may be more reflective, aluminum pigments work very well with asphalt, and asphalt coatings bond best to asphalt surfaces, so aluminized asphalt coatings are especially suitable for protecting asphalt roofing systems.

Aluminum pigments can be used to formulate solvent- and water-borne asphalt coatings to protect against ultraviolet (UV) radiation and provide significant reflectivity. These coatings have small flakes of aluminum pigment dispersed in them. They typically have solar reflectivity values between 0.40 and 0.50, though premium formulations have demonstrated initial solar reflectivity values in excess of 0.70.

SETTING AND CURING

One goal in the development of advanced coatings is to decrease the setting or curing time. The setting time is especially important in wetter climates, where unexpected rainfall can occur. If the setting time could be reduced by two-thirds (for example, from one hour to 20 minutes, or from three hours to one hour, depending on the temperature and humidity), then the number of working days per year could be increased significantly. Setting time is especially important in semitropical and tropical climates (e.g., the southern United States).

Today's contractor has a tool for managing curing conditions with the real-time weather reports on the Internet. All water-based coatings are strongly affected by weather. Knowing when rain or dew will

Photo 7 – A fast-setting acrylic coating was used on this building in Guam. (Photograph Courtesy of Quest Construction Products: United Coatings, Spokane, WA.)

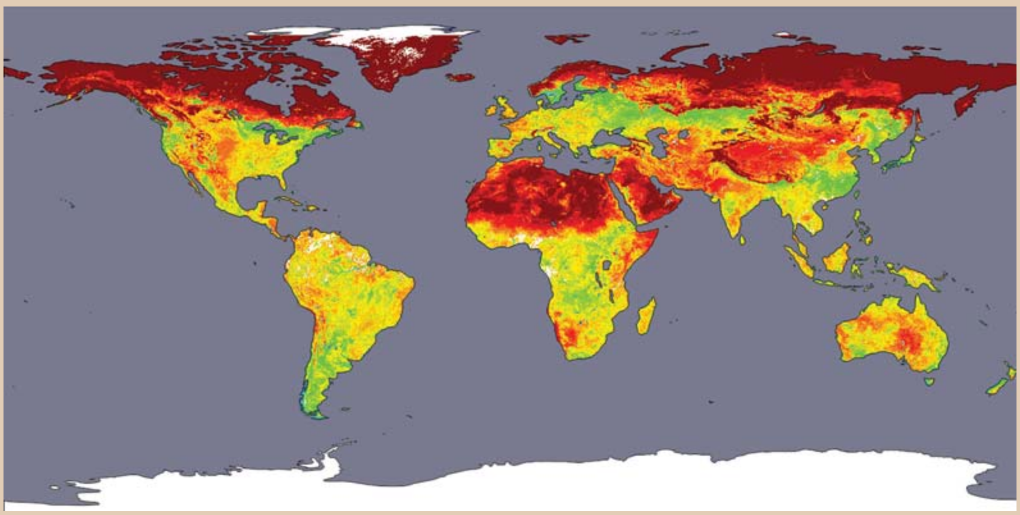
The Albedo of Earth

It is instructive to draw an analogy between the temperature of a roof and the temperature of the Earth. The roof surface affects roof temperature in much the same manner as the Earth's surface and atmosphere affect its temperature.

NASA and the U.S. Geological Survey regularly measure the albedo (reflectance) of the Earth in detail via satellite sensors.[1] The average albedo of Earth is about 0.30, but it varies widely; for example, the oceans present a very low albedo in comparison to cloud coverage or ice caps.

Earth also releases heat back into space, a property called emissivity. Its overall emissivity is determined by the emissivity of its water bodies, land masses, vegetation, and rooftops, as well as the composition of its atmosphere. Greenhouse gases by definition decrease the emissivity of Earth as a whole and hence are implicated in global warming.

Geoengineering or climate engineering attempts to change the emissivity and reflectivity of Earth on a global scale. It may sound like science fiction, but such discussions are now being taken seriously.[2] Emissivity could be increased by sequestering carbon dioxide or lowering carbon dioxide emissions, e.g., through energy efficiency and renewable energy. There is even speculation that reflectivity of the Earth could be changed on a grand scale by launching particles into the upper atmosphere, producing cooling effects similar to those created by volcanic microparticulates, which may take years to be cleansed from the atmosphere.



A moderate resolution imaging spectroradiometer aboard NASA's Terra satellite measures how much sunlight the Earth's surface reflects back to the atmosphere, quantifying its albedo. The colors in this image emphasize the albedo over the Earth's land surfaces, ranging from 0.0 to 0.4. Areas colored red show the brightest, most reflective regions; yellows and greens are intermediate values; and blues and violets show relatively dark surfaces. White indicates where no data were available, and no albedo data are provided over the oceans. This image was produced using data collected over a 16-day period, from April 7-22, 2002. (Image courtesy of Crystal Schaaf, Boston University, based upon data processed by the MODIS Land Science Team, NASA. Accessed at http://visibleearth.nasa.gov/view_rec.php?id=3411 on October 30, 2009.)

REFERENCES

1. The Land Processes Distributed Active Archive Center. https://lpdaac.usgs.gov/
2. John Tierney, "Engineer the Climate?" *The New York Times*, published August 10, 2009, http://tierneylab.blogs.nytimes.com/2009/08/10/climate-engineering/

threaten a water-based coating application is far easier today and can help contractors manage projects. Next-generation, quick-set coatings are being developed that meet or exceed the ASTM D6083 standard and set about three times faster (*Photo 7*).

A distinction should be made between setting time and curing time. The setting time could be shorter than the curing time. In other words, a water-based coating could be "set" before it is completely dry. If rainfall occurs before the water is completely evaporated, the set coating would remain intact. There is some precedent in the development of such coatings for traffic striping. The same principles are now being applied to the development of roof coatings.

ABOUT THOSE VOCS

Solvent-based coatings typically set and cure faster than water-based coatings, and

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so allow more flexibility with regard to the weather; however, they also release volatile organic compounds (VOCs), which are being restricted from coast to coast. VOCs are most strictly regulated in California by the California Air Resources Board (CARB) and on the East Coast by the Ozone Transport Commission. The EPA's national architectural industrial maintenance (National AIM) regulations will significantly lower VOC emission limits in 2010. Therefore, it is essential for a roof consultant to understand what VOCs may be released in the application of roof coatings.

Not surprisingly, there has been a trend toward water-based coatings and away from solvent-borne coatings for roofs. Members of the Roof Coating Manufacturers Association (RCMA) have been continually improving the quality of water-based coatings and developing new coatings that release few, if any, VOCs. There is a need for water-based acrylics to fill the gap left as many older technologies decline due to these regulatory pressures.

Flouropolymer-modified acrylic coatings provide many of the benefits of solvent-borne technologies in a water-based system. Such coatings have been in the marketplace for several years. They exhibit very low water absorption, extremely good weathering, improved ponded water resistance, excellent resistance to dirt pick-up, and resistance to biological growth. Additionally, they are available in cool colors.

For asphalt and urethane coatings, a new solvent is allowing manufacturers to comply with VOC rules while maintaining traditional performance. This new technology will first be used in SEBS coatings, some cutbacks and adhesives, and especially in more expensive products such as aliphatic urethanes and silicones.

One way to eliminate VOCs is to use coatings that are applied as 100% solids. Polyureas have been known for well over a decade, and many are now being formulated in slower-setting or even pot-life grades. These products release zero VOCs and will continue to fill a niche. An impediment has been that, without modification, these industrial products often set too fast and are too hard for roofing applications.

Silicones in 100% solids are perhaps bigger news. Silicones are known to be the best available technology in the areas of building seals and waterproofing. They have had success in roofing for about three decades for these same reasons. The 100%-solids versions of these silicone products would be usable in any foreseeable regulatory environment.

NEW COATING SYSTEMS

Another trend is toward developing systems and products to coat and maintain newer roofing materials such as EPDM and TPO. For example, a wash primer has been developed that makes the coating of EPDM with acrylic commonplace (*Photo 7*). In a similar fashion, field tests are under way for a base coat designed specifically for coating TPO roofs. The latter allows the use of standard D-6083 acrylics over TPO roofs as fresh as 45 days. PVC roofs may require products that are compatible with high levels of plasticizer, yet several manufacturers are meeting that challenge as well.

COOL RESOURCES

Many existing buildings were constructed in an era of cheap energy, so there is ample room for improvement in energy efficiency. By focusing on improving energy efficiency through the retrofit of the current building stock, various green projects could not only create jobs but also create a built environment that uses less energy. Some noteworthy publications, codes, and programs are as follows:

- The Reflective Roof Program of the U.S. Environmental Protection Agency provides an ENERGYSTAR® label for products that meet its minimum specifications. Furthermore, the IRS provides a tax credit for ENERGYSTAR® metal and asphalt roofing products. The tax credit is for 30% of the cost of the roof up to $1,500. (See **www.energystar.gov** for details.)
- The International Code Council (ICC) and the American Society of Heating and Air-Conditioning Engineers (ASHRAE) have developed national model energy codes that include recommendations for reflective roofing.
- The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) program has been updated in 2009 and includes points available for cool roofing.
- In California, the Building Energy Efficiency Standard (also known as Title 24) written by the California Energy Commission includes a provision for cool roofs. A new version of Title 24 goes into effect on January 1, 2010.
- Utilities across the United States and Canada are providing incentives for cool roofs. A useful energy-efficient tax credits database is available at **www.dsireusa.org**. In Canada, find provincial and city incentives at the National Resources Canada Web site (**http://oee.nrcan.gc.ca/corporate/incentives.cfm**).
- *The NRCA's Guide to Roof Coatings*, Second Edition, published in 2009, is a valuable resource for roof consultants.
- The Cool Roof Rating Council (CRRC) provides a database of emissivity and reflectance values for a wide range of systems and coatings.

CONCLUSION

Roof consultants are being called upon to evaluate coatings for various buildings on the basis of life-cycle extension and energy efficiency. They need to be in the know about the basic physics as well as the physical properties of coatings, their compatibil-

ities with other coatings and with various roofs, their methods of application, and recommended cleaning and maintenance schedules. This article provides a brief overview of the broad subject of roof coatings. More information can be gathered from individual manufacturers as well as the many industry resources, including RCI and RCMA.

*The Roof Coatings Manufacturers Association is the national trade association representing the manufacturers of cold-applied, protective roof coatings and cements and the suppliers of products, equipment, and/or services to and for the industry. RCMA is committed to continually improving the performance and quality of roofing. For additional information, contact RCMA by phone (202-207-0919) or fax (202-223-9741) or visit the RCMA Web site at **www.roofcoatings.org**.*

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ROOF TILES THAT CHANGE COLOR WITH THE TEMPERATURE

Soon there may be a way to have "cool" white roofs in the summer and heat-absorbent black roofs when it's cold, thereby solving the argument over where to draw the climate line in the battle over energy use. A team of recent MIT graduates has developed roof tiles that change color based on their temperature. When it's cold, they turn black, and when it's hot, they are white. The team's lab measurements show that in their white state, the tiles reflect about 80% of the sunlight falling on them; however, when black, they reflect only about 30%. That means in their white state, they could save as much as 20% of present cooling costs, according to recent studies. Savings from the black state in winter have yet to be quantified.

The inventors were a team in this year's Making and Designing Materials Engineering Contest (MADMEC), a competition for teams of MIT students (or 2009 graduates). Now in its third year, the contest this year was specifically devoted to projects aimed at improving energy efficiency through innovative uses of materials. The winning team called itself Thermeleon (rhymes with chameleon, because of its color-changing property) and earned a $5,000 prize.

They used a common commercial polymer (in one version, a polymer that is commonly used in hair gels) in a water solution. That solution is encapsulated (between layers of glass and plastic in their original prototype, and between flexible plastic layers in their latest version) with a dark layer at the back.

When the temperature is below a certain level (which varies by formulation), the polymer stays dissolved, and the black backing shows through, absorbing the sun's heat. But when the temperature climbs, the polymer condenses to form tiny droplets whose small sizes scatter light and thus produce a white surface, reflecting the sun's heat.

They are now working on an even simpler version in which the polymer solution would be micro-encapsulated and the tiny capsules carried in a clear paint material that could be brushed or sprayed onto any existing surface. The tiny capsules would still have the color-changing property, but the surface could easily be applied over an existing black roof, much more inexpensively than installing new roofing material.

Because the materials are common and inexpensive, team members think the tiles could be manufactured at a price comparable to that of conventional roofing materials — although that won't be known for sure until they determine the exact materials and construction of their final version.

The biggest remaining question is over durability, and answering it will require spending some time to do accelerated testing by running the material through repeated hot-cold cycles.

Hashem Akbari, leader of the Heat Island Group at Lawrence Berkeley National Laboratory in California, is a longtime advocate of white roofs as an energy-saving measure. He says that some other groups, including a team at the University of Athens, have done research on the use of color-changing materials for roofs, but that in those tests, "the cost and durability has been a serious issue."

— Pysorg.com and web.mit.edu