PROCEEDINGS

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The Great Debate: Nonreflective vs. Reflective Roofing Membranes

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Abstract

The prevalence of reflective roofing membranes has increased in recent years. From an environmental standpoint, the trend toward reflective roofing membranes can be attributed to the material's role in a building's energy usage, global warming potential (GWP), and the urban heat island (UHI) effect. Recent research shows that the color of a roofing membrane can also affect rooftop condensation and longevity. Some studies even indicate a "heating penalty" for using reflective roofs in certain climates, possibly negating the energy savings achieved from the cool roof.

This presentation will review the impact of color and reflectivity on buildings and the environment.

Speaker

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The Great Debate: Nonreflective vs. Reflective Roofing Membranes

INTRODUCTION

The use of reflective roof membranes has increased steadily in recent years. Growth can be attributed, in part, to cost and system preference. The trend toward reflective roofing membranes is also being driven by environmental concerns.

A building owner may be partial to reflective roofing because of the material's role in maximizing his or her building's energy usage and reducing operating costs—a more localized benefit. Additionally, building owners may feel that a reflective roof is providing a societal benefit by reducing the urban heat island (UHI) effect or the global warming potential (GWP) of the building.

Voluntary environmentally focused programs, like the United States Green Building Council's (USGBC's) LEED® program, promote the use of reflective roof coverings. These coverings are also mentioned in prescriptive energy standards like ASHRAE 90.1, *Energy Standard for Buildings*.

Despite the trend towards reflective options for cost or environmental benefits, commercial roofing products with a nonreflective surface continue to be a significant part of the low-slope roofing market.

In northern climates, for example, where heating days outnumber cooling, some believe that a nonreflective black roof membrane is the logical choice for optimized energy performance.

Recent research has suggested that the color of a roofing membrane can also affect rooftop condensation and overall longevity. Some studies even indicate a "heating penalty" for using white, reflective roofs in certain climates, negating the energy savings achieved from the cool roof. It should be noted that the effect of a membrane's reflectivity is fairly nonexistent when it is covered with snow.

The topics of cool and reflective roofing have been studied and reported upon since at least the late 1980s, and new findings continue to appear on a regular basis. Is a reflective roof the best choice? Today, there is still no absolute answer for this question. A design professional must evaluate each building to thoughtfully respond and recommend the best material for peak performance.

In order to separate fact from opinion, research has been conducted to help guide designers and members of the building community. The published literature on this topic is fairly extensive; some reports contradict others, but certain conclusions can be drawn.

First, it is important to recognize that this is not a "black and white" issue. In many parts of Canada and Western Europe, for example, gray-colored roofing is often used. In fact, a Canadian field monitoring study of black-, gray-, and white-colored roofing was included in last year's RCI International Convention.[1]

What about vegetative roofing, aggregate-ballasted roofing, and dirty white roofing? These are generally considered "cool" roofs, but do they provide the same benefits as reflective roofs? There are many variables to consider when designing a roof.

From the data, a key conclusion is: There are several factors that contribute to the energy performance of a roof system, and each of these factors—not just membrane reflectance—should be evaluated to make a responsible roofing decision.

WHAT IS REFLECTIVE ROOFING? WHY DOES IT MATTER?

"Reflective roofing" is not synonymous with "cool roofing," nor does it always refer to white roofs. Additionally, the performance specifications for low-slope roofs (a slope of 2:12 or less, based on ASTM Standard E1918-97[2]) are different from the expectations of steep-slope options (greater than 2:12).

To provide clarity and consistency, this paper focuses on low-slope roofing, which typically has more stringent requirements than steep-slope roofing. A 2002 study showed that a membrane's reflectivity diminishes with weathering, but typically stabilizes after about three years.[3] Though some still consider initial reflectance, many programs and standards now focus on aged reflectivity for this reason. To qualify as an Energy Star® roof, a low-slope roofing material must have an initial reflectivity of at least 0.65 and a three-year aged reflectivity of 0.50.[4] This means that the roof covering, when new, must reflect 65% of the incident solar energy.

The Solar Reflectance Index (SRI) is a similar but more comprehensive rating that is a measure of a roof's ability to cast-off solar heat,[5] incorporating not just a material's reflectance, but also its emittance (ability to shed heat). The USGBC employs the SRI measure in its LEED® guidelines. To contribute to a LEED® point, a low-slope roof must have an initial SRI of 82.[6] The California Energy Commission qualifies either a minimum aged solar reflectance of 0.63 or a minimum SRI of 75 to qualify as an acceptable cool roof.[7] These various programs and authorities will be discussed later, but this serves to point out that there is not an agreed-upon definition of a cool or reflective roof. A generally light-colored roof having an initial reflectance of at least 0.65 is a good starting point to be considered reflective.

"Cool roofing," however, is a broader term. "Cool" roofing materials include vegetative[8] and ballasted options. Due largely to absorptiveness and thermal mass—rather than reflectance values—vegetative and ballasted roofing systems have been shown to perform "in a manner that is equivalent to (or better than) the white membrane for a substantial portion of their service life."[9]

Generally speaking, there are two motivating factors to install a reflective roof. The most obvious is the impression that a reflective roof will help lower cooling energy costs in hot temperatures.

The other motivating factor is the perceived societal benefit of a reflective roof. Many studies have suggested that reflective roofing can mitigate the UHI effect[10,11] or reduce the GWP of a building. This is related to the first factor pertaining to energy savings. It is reasonable to assume that reduced energy use helps to mitigate carbon emissions.

Urban areas tend to be warmer than their rural surroundings, resulting in "an 'island' of higher temperatures ... [both] on the surface and in the atmosphere."[12] This

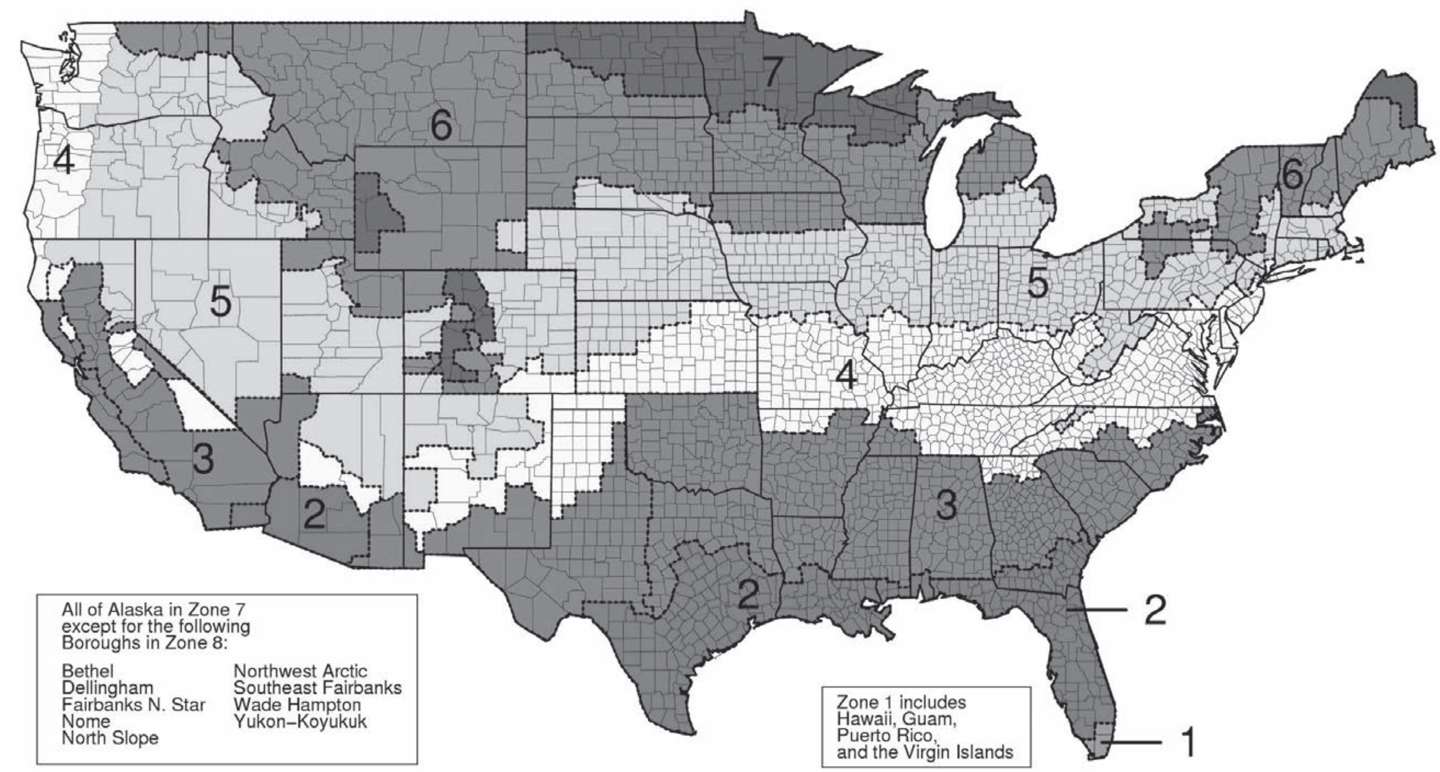


Figure 1 – Climate zone map from ASHRAE 90.1-2010 Appendix B.

means that urban areas take more energy to cool in the hotter months, but also less energy to heat in the cold months. Although it seems reasonable to assume that if a roof can reflect solar energy away from the building, it could mitigate the UHI effect, but there is no recorded evidence of this. This social and environmental advocacy aspect of reflective roofing has led to a number of decrees—both voluntary and statutory—by various organizations and agencies calling for reflective roofs.

WHO SAYS?

The LEED® and ENERGY STAR® programs have already been cited, and it is important to note what these and other voluntary programs have to say about reflective roofing because they impact the materials that designers and builders use. However, it is also important to recognize the difference between elective programs, consensus-based standards, and building codes. Cities like Chicago, Houston, New York, and Los Angeles all have some requirement for reflective roofing[13] with standards informing the city codes.

ASHRAE 90.1-2010

ASHRAE (formerly the American Society of Heating, Refrigeration and Air Conditioning Engineers) is a "global society advancing human well-being through sustainable technology for the built environment."[14] The organization has produced a number of standards to further that advancement. For example, in 1975, ASHRAE first published its Standard 90, which has today evolved into ANSI/ASHRAE/IES Standard 90.1-2010, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. This often-cited energy standard includes one section related to reflective roofing. Section 5.5.3.1.1, "Roof Solar Reflectance and Thermal Emittance," outlines the prescriptive measures that must be taken to have a compliant roof surface. Notably, ASHRAE limits the application of this section to Climate Zones 1 to 3 only (see *Figure 1*).

In these three climate zones, the standard mandates that a roof must have a minimum three-year aged SRI of 64 (or equivalent reflectance and emittance values) or increased insulation levels (R-33 to R-35, depending on the roof assembly). Additionally, this section of the standard allows for a number of exceptions for roofs with a sufficient amount of ballast, vegetation, shading, or other factors.[15] This standard makes no suggestion or requirement for reflective roofing in climate zones 4 and above.

ASHRAE 90.1 is significant because it has become the basis for many building codes worldwide. Specifically focusing on the U.S., starting with the passage of the U.S. Energy Policy Act of 1992, ASHRAE 90.1 has been the benchmark for energy-efficient building. When the act was passed, all states were required to adopt energy standards at least as stringent as the most recent Department of Energy-approved version of ASHRAE 90.1.

Today, ASHRAE 90.1 is revised and republished every three years to align with the International Energy Conservation Code's (IECC's) three-year revision cycle. ASHRAE 90.1-2010 forms the basis of the 2012 IECC, just as ASHRAE 90.1-2007 did for the 2009 IECC.

As of July 2014 and as shown in *Figure 2*, a minority of states had yet to enact a statewide energy code, but more than 40 are currently enforcing some version of ASHRAE 90.1. Twelve have already adopted the most recent version.[16]

For those states operating under the current ASHRAE 90.1 in climate zones 1 to 3, a reflective roof (aged SRI of 64) must be used. ASHRAE 90.1 does not include a requirement for reflective roofing in other climate zones.

ASHRAE 189.1-2011

Sometimes called "the green standard," this is officially ANSI/ASHRAE/USGBC/IES Standard 189.1-2011, *Standard for the Design of High-Performance Green Buildings*. The "green standard" is for high-performance green buildings and is intended to exceed the energy standards of ASHRAE 90.1. However, this standard's section 5.3.2.3 on the "Mitigation of Heat Island Effect – Roofs" still only applies to building projects in Climate Zones 1 to 3.[17] Section 5.3.2.3 does utilize different compliance criteria than ASHRAE 90.1. However, like ASHRAE 90.1, there is still no prescription or suggestion to install reflective roofs except in these southern climate zones.

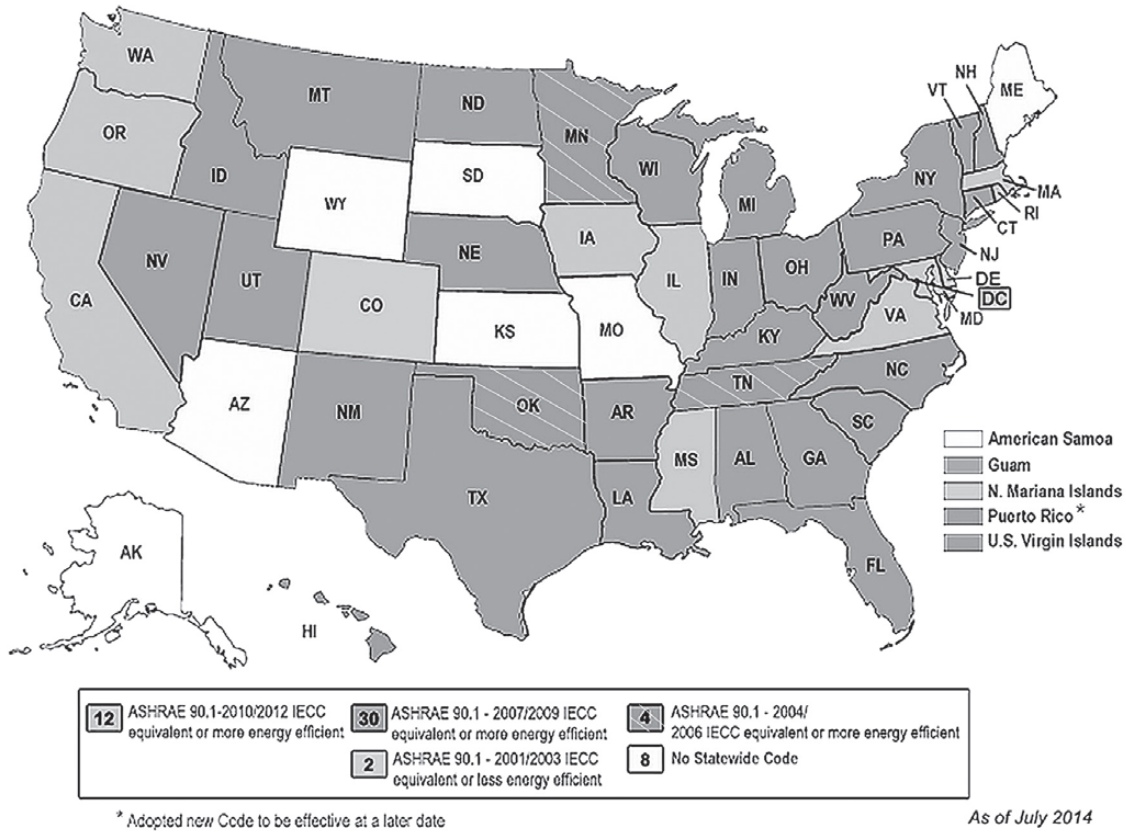


Figure 2 – IECC adoptions by state.

ASHRAE 189.1 has also been noticed by the International Code Council (ICC), and it is a compliance option in the 2012 International Green Construction Code™ (IgCC). That means that if one's building satisfies the ASHRAE 189.1 standard, then it is automatically compliant with the IgCC. Sometimes called an "overlay code," the IgCC can be adopted by jurisdictions that have interest in a regulatory framework for green buildings that goes beyond the scope of the IECC.

LEED®

The USGBC states that its LEED® program is the most widely used green building program worldwide, comprising more than 10.1 billion square feet of construction space.[18] LEED® is a voluntary program that is motivated by the social factor of reducing the UHI effect.

The latest version, LEED® v4, offers two points if a building can be designed with intent to reduce UHI. Despite this credit's goal of mitigating UHI, the credit is not limited to buildings located in urban areas.

To qualify under credit SSc5, one must perform a calculation that incorporates "non-roof measures" (shading over parking areas, reflective paving, etc.), high-reflectance roofs, and vegetated roofs.

Low-slope roofs with an initial SRI of 82 or an aged SRI of 64 are weighted equally to vegetative roof areas.[19] Roof membranes with a lower SRI value cannot contribute to this credit.

LEED® does not evaluate other roofing assembly components (vapor retarders, insulation, etc.), and it does not consider climate zones.

THE FUTURE STANDARD – ANSI/ASHRAE/IES/USGBC STANDARD 189.1

Though not expected to take effect until at least 2017, there is a new agreement among ASHRAE, the ICC, USGBC, the Illuminating Engineering Society (IES), and the American Institute of Architects (AIA) to create a combined green building standard. The goal is to simplify the array of standards, regulations, and voluntary programs in order to increase the number of buildings that are designed as high-performance "green" buildings.

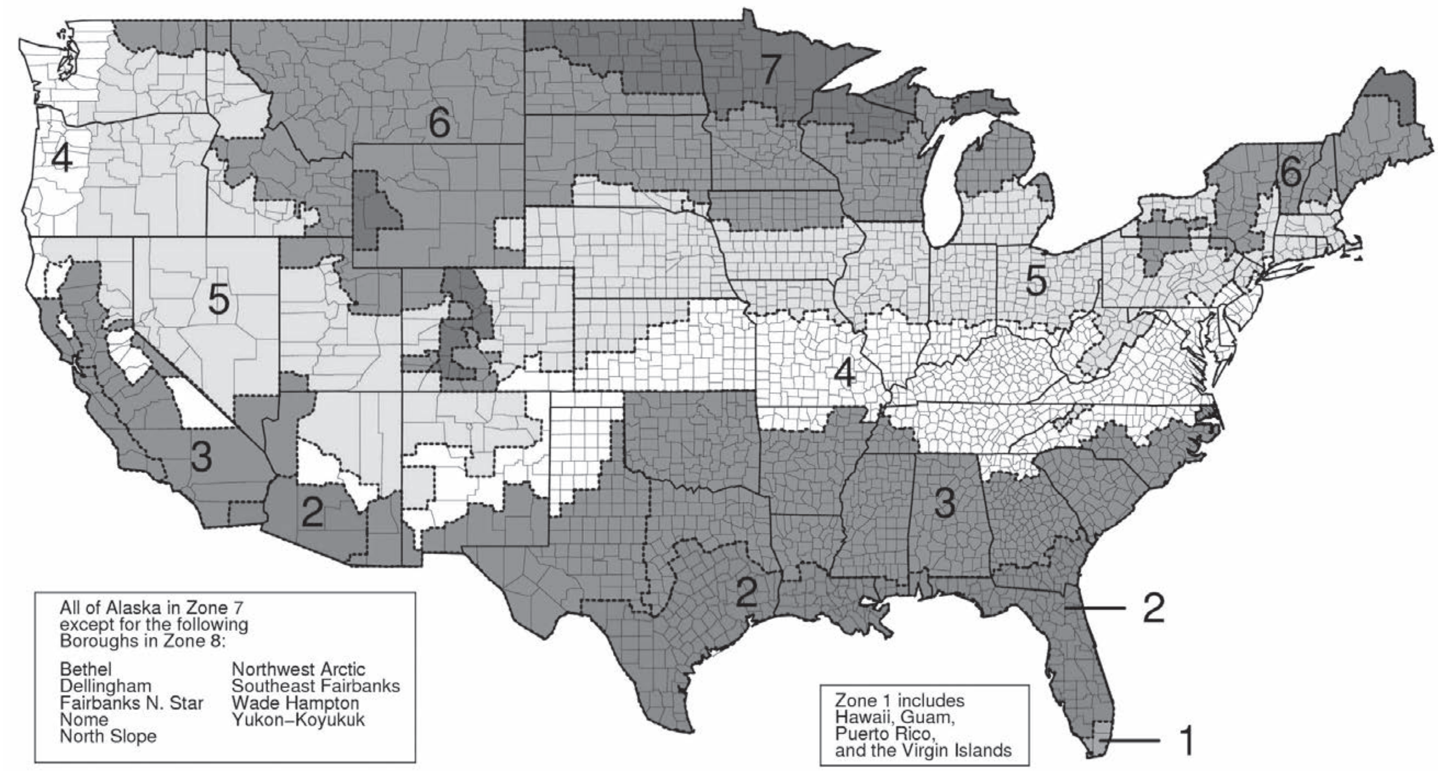
The idea is that the IgCC will simply "become an adoptable, code-enforceable version of [ASHRAE] 189.1," and IgCC compliance will also "serve as an alternative system of prerequisites for LEED®."[20]

While ASHRAE and LEED® will still be developing their own requirements and credits, the two bodies are expected to be aligned. When it happens, this new system should provide a more cohesive, understandable framework for code officials, architects, and building owners.

Energy Star®

Energy Star® is a voluntary program within the U.S. Environmental Protection Agency (EPA) that was initially established in 1992. It has a stated goal of helping "businesses and individuals save money and protect our climate." Today, Energy Star® qualifies certain roof products that can carry the Energy Star® label; and for low-slope roofing, the products are roof coatings and membranes with an initial solar reflectance of at least 0.65 and a reflectance of at least 0.50 three years after installation.[21]

Like LEED®, Energy Star® takes a blanket approach to reflectivity. Assuming that reflectivity is typically beneficial, it is not concerned with whether an Energy Star® product is used in an urban or rural area. To its credit, Energy Star® does recommend



Zone	Add Insulation to Attic		Floor
	Uninsulated Attic	Existing 3-4 in. of Insulation	
1	R30 to R49	R25 to R30	R13
2	R30 to R660	R25 to R38	R13 to R19
3	R30 to R60	R25 to R38	R19 to R25
4	R38 to R60	R38	R25 to R30
5 to 8	R49 to R60	R38 to R49	R25 to R30

Figure 3 – Energy Star®-recommended levels of insulation.

residential insulation levels, and it considers climate zones when doing so.[22] *Figure 3* clearly employs the map from ASHRAE 90.1, though it is a simplified version.

However, Energy Star® does not currently approve insulation products, nor does it mention insulation in any of its commercial construction recommendations.

ROOFPOINT®

Officially launched in 2012 by the Center for Environmental Innovation in Roofing (CEIR), ROOFPOINT® is a voluntary program described as a "Guideline for Environmentally Innovative Nonresidential Roofing." This program is by far the most comprehensive in its consideration of a roof's impact on the environment. In addition to energy management, ROOFPOINT® evaluates the impact of a roof's water management, material management, and overall durability. Within the Energy Management section, there are six available credits.

Only one of the six credits pertains to roof surface thermal contribution.[23] The recognition that there are at least five other factors that contribute to a building's energy management is encouraging to many roofing professionals. ROOFPOINT® does not take a "one-size-fits-all" approach to roof design.

The Roof Surface Thermal Contribution credit is further divided into three separate parts to address three separate intents: optimizing net annual building energy efficiency, optimizing peak energy demand, and reducing heat island effects. According to ROOFPOINT®, a ballasted or vegetated roof can satisfy all three of these goals in any climate zone. On the subject of reflectivity, though, the program takes a more nuanced approach. Instead of using the word "reflective," ROOFPOINT® refers to high-, medium- and low-albedo roofs. While one definition of albedo is "reflective power," ROOFPOINT® uses albedo to refer to a material's SRI, which incorporates emittance and reflectivity. The ROOFPOINT® classifications are as follows:

- A high-albedo roof has an initial SRI of at least 78 and aged SRI of at least 64
- A medium-albedo roof has a new or aged SRI between 20 and 64
- A low-albedo roof has a surface with a new or aged SRI less than or equal to 20

A high-albedo roof can satisfy the requirement to reduce heat island effects in any climate zone, but it is only seen as an option to optimize peak energy demand in Climate Zones 1 to 5.

In Zones 6 to 8, ROOFPOINT® asserts that a medium- or low-albedo roof is the appropriate choice.

The program takes a similar stance on the topic of optimizing net annual energy efficiency, where a high-albedo roof qualifies in Climate Zones 1 to 6, a medium albedo roof qualifies in Zones 4 to 8 and a low albedo roof is seen as optimizing net annual energy efficiency in Climate Zones 5 to 8.[24]

With ROOFPOINT®, CEIR has inferred there are regions of the country where a nonreflective roof has greater energy efficiency than a reflective roof.

ROOFPOINT® also makes it clear within its section on "Energy Management" that there are several factors within a roofing system that affect a building's energy performance.

In addition to the Roof Surface Thermal Contribution, the ROOFPOINT® program also provides credits for employing a "High-R Roof System" (referring to a well-insulated system with a high R value) and for utilizing best thermal practices, a roof air barrier, daylighting and rooftop energy systems.[25] This voluntary, consensus-based program is the most thorough environmental evaluation guideline in the roofing industry.

WHAT DOES THE RESEARCH SAY?

Researchers continue to study reflective roofing and its impact on the UHI effect, global climate change, and energy costs. Many studies demonstrate that reflective roofs do provide energy cost savings in certain areas. Similarly, several published papers have used models to illustrate that reflective roof surfaces can minimize the UHI effect.

However, research does not unanimously support recommendations to use highly reflective roofs in all climate zones. Furthermore, the building community needs to ask if the models are comprehensive enough to justify reflective roofing codes and regulations.

The following review of key research from the last 10 years may not provide definitive answers to these questions, but it should serve to further illuminate the issue.

A note on energy models: All software models are inherently reliant on inputted data. Assumptive figures are incorporated in any program's simulations, and these figures can have significant impacts on simulation outcomes. This review notes the software models in each study, but it cannot cite every inputted assumption. Some assumptions are noted, but the reader is directed to the original publications to examine their full methodology.

ENERGY USAGE AND COSTS

In 2005, James Hoff presented "The Economics of Cool Roofing: A Local and Regional Approach" at the Cool Roofing Symposium. Using the U.S. Department of Energy Cool Roof Calculator, buildings in 40 cities in the contiguous U.S. were modeled with both reflective (55% reflectance) and nonreflective (5% reflectance) roofs. The model assumed electric cooling and natural gas heating systems with average efficiency, using cost data from the Energy Information Administration. The calculated annual energy savings of using the reflective option on a 20,000-sq.-ft. roof varied from a high of $860 (Phoenix, AZ) to a net loss of $100 (Seattle, WA), and geographic bands were created to help visualize the regional impact (see *Figure 4*).

Overall, this study concluded:

> Perhaps the most significant observation that may be derived from this analysis is that the energy savings provided by a reflective roof may offer little economic incentive for the average building owner in many areas of the United States. ...In major mid-west cities, such as Chicago, Cleveland, and Pittsburgh, where reflective roofs offer minimal annual savings of $20 to $60, it is difficult to see how such small savings will affect the purchase decision of an informed building owner."[26]

Since at least the late 1980s, Hashem Akbari and his colleagues at Lawrence Berkeley National Lab have been publishing work on the effects of both in-situ reflective roofing and reflective roofing within predictive energy models.[27] Akbari continues to be a prolific researcher on this topic, both in terms of energy savings and global environmental impact.

In 2010, Akbari and Levinson published a comprehensive study that used the DOE-2.1E building energy model to compare "weathered cool white" roofing with a solar reflectance of 0.55 to roofing with a solar reflectance of 0.20. This study simulated multiple building types ("old" and "new" building stock, across multiple end uses). Using local energy generation, emission, and cost data for 236 cities, Akbari and Levinson created an estimate of energy cost savings by switching to reflective roofing. The research demonstrates that every state in the U.S. would experience annual energy cost savings on a "per-unit conditioned roof area" basis if it switched its roofing from a 0.20 reflectivity to 0.55.

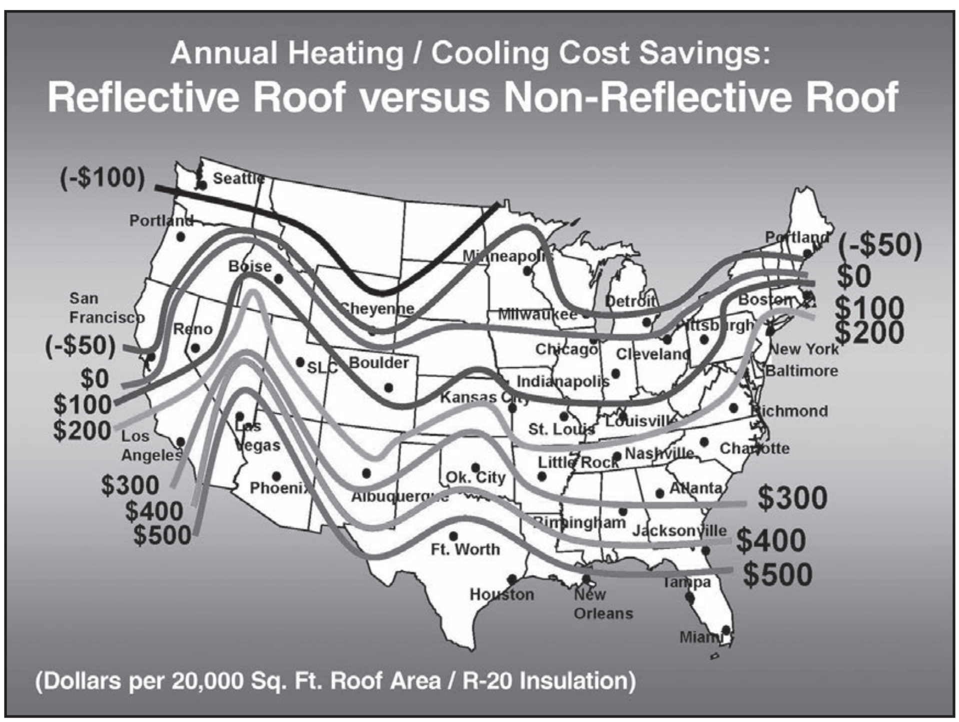


Figure 4 – Regional energy savings for 20,000 sq.-ft. roof area (Hoff, 2005).

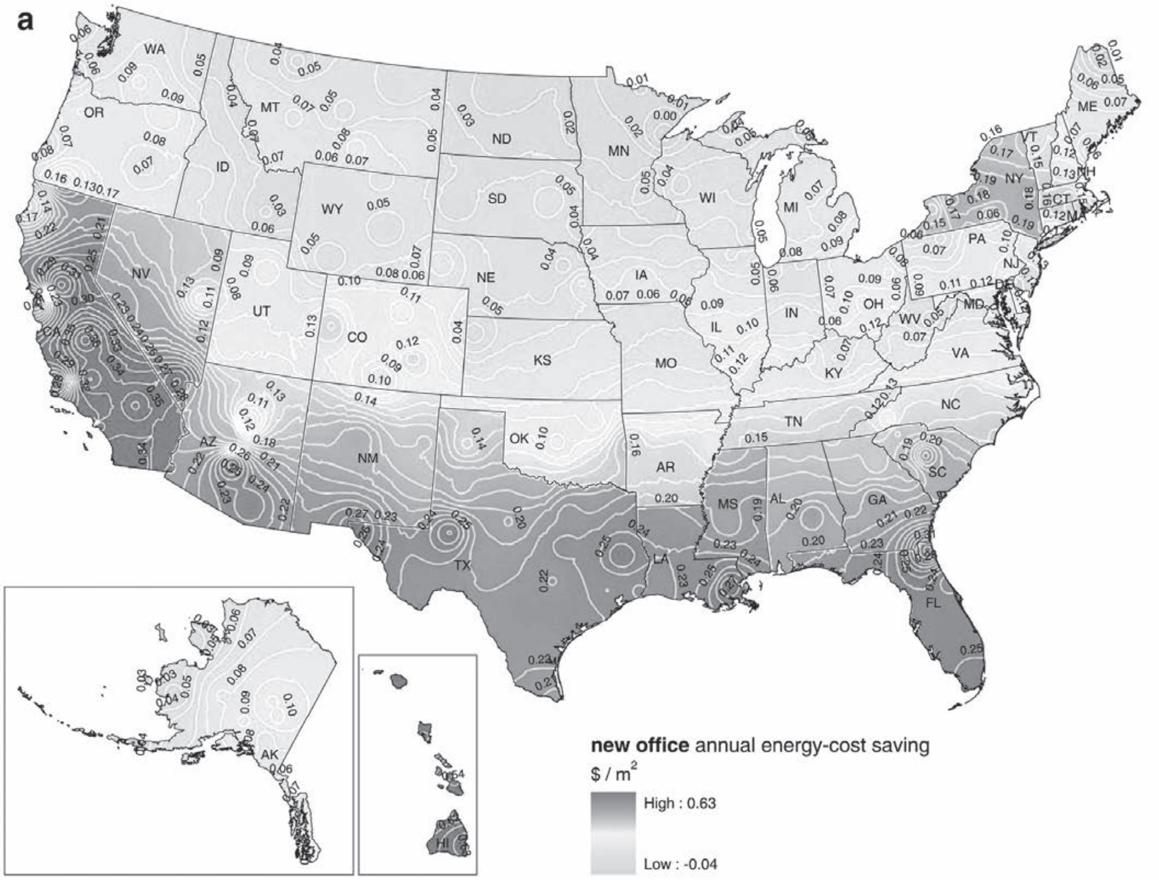


Fig. 12 Annual net energy cost saving per unit conditioned roof area $c(x, y)$ ($/m^2) for each of four building prototypes: **a** new office, **b** old office, **c** new retail, and **d** old retail

Figure 5 – Annual energy cost savings for new office prototype (Akbari and Levinson, 2010).

Furthermore, it demonstrated that "retrofitting 80 percent of the 2.58 billion square meters of commercial building conditioned roof area in the USA would yield …an annual energy cost saving of $735 million." The study acknowledges a heating penalty for using reflective roofs in some northern climates, but it is very nearly always offset by the savings from less cool energy. The model shows energy cost savings in all regions with "old" building stock, and in nearly every region with "new" building stock (*Figure 5*).[28]

In a paper from the *Proceedings of the 2014 RCI International Convention*, energy use was also modeled on both black and white roofs. This study did not take the step of converting usage to actual costs, but the findings are still relevant.

Using the U.S. Department of Energy's EnergyPlus modeling program and Building Energy Codes Program stand-alone retail building model, researchers examined one representative city from each climate zone. Roof assemblies with three alternative insulation systems were modeled with both reflective white roofing (SRI of 70) and black roofing (SRI of -4). The multifaceted study draws several conclusions, but regarding the energy usage of buildings with reflective and nonreflective roof coverings, the paper's authors state:

> Overall energy use is lower for white roofs in cooling-dominated climate zones (zones 1 and 2), and lower for black roofs in heating-dominated climate zones (zones 5 to 8). In mixed heating and cooling climate zones (zones 3 and 4), the differences are very small between light- and dark-colored roof membranes."[29]

Note: This study also has findings regarding reduction of greenhouse gasses, to be covered in a later section.

THE UHI EFFECT AND GWP

When looking at the UHI and GWP studies, it is important to note that the results are based on complicated predictive modeling software. Though the market shift toward increased reflective roofing has been underway for two decades, there are no published studies that evince a reduction of a regional heat island. Individual buildings have been analyzed, but regional or global impacts on the use of reflective roofing have only been modeled.

The rooftops of Athens, Greece, were the subject of a paper published in 2008. The research looked at the potential heat island mitigation of converting all roofs in Athens to a higher reflectivity. They judged the base albedo of the area as 0.18 and ran simulations on both a modest increase (to 0.45) and an extreme rise (to 0.85) using "the 'urbanized' version of the nonhydrostatic fifth-generation Pennsylvania State University-NCAR Mesoscale Model (MM5, version 3-6-1)." Measured at a 2-meter height, the reduction in Athens' temperature was as high as 1.5°C given the 0.45 albedo scenario, and as high as 2.2°C for the extreme scenario. The publication provided no justification on the basis for the 2-meter height, but this measurement dimension is often used. The researchers suggest that increasing the rooftop reflectivity would reduce the UHI effect, stating:

> This analysis shows that adopting large-scale high albedo measures by using building materials with high solar reflectance can significantly reduce ambient temperatures. City-scale application of cool materials will result in a reduction in energy consumption by reducing both direct radiative heating of buildings and ambient temperatures.[30]

In 2010, there were at least three major studies that were published on the effects

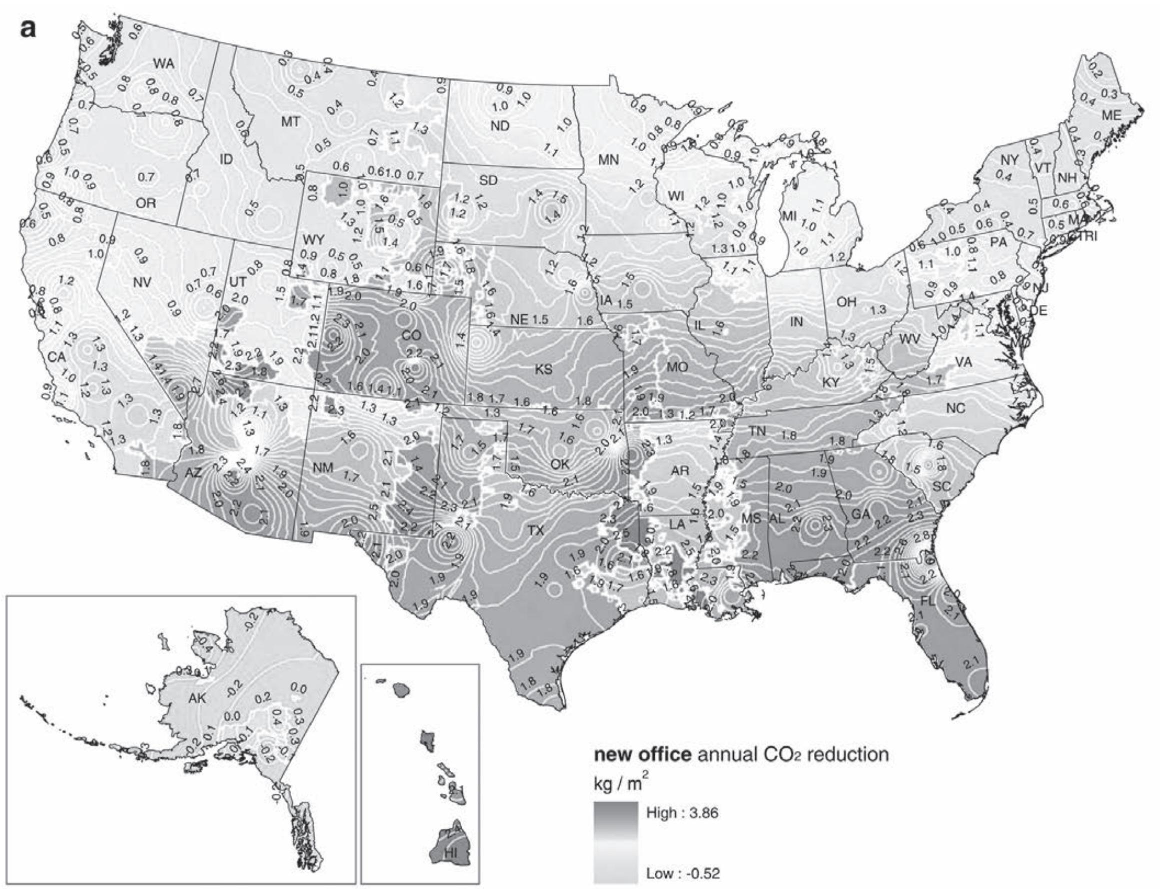


Fig. 13 Annual reduction in emission of carbon dioxide (CO_2) per unit conditioned roof area $p_{CO_2,k}(x, y)$ (kg/m^2) for each of four building prototypes k: **a** new office, **b** old office, **c** new retail, and **d** old retail

Figure 6 – Annual CO_2 emission reduction for new office prototype (Akbari and Levinson, 2010).

of reflective roofing on climate, and they each relied on different energy models. The previously mentioned Akbari and Levinson paper used the DOE-2.1E building energy model to compare roofs with a solar reflectance of 0.20 to "weathered," reflective roofing with a reflectance of 0.55 nationwide. Its findings related to CO_2 emissions were similar to its discoveries on energy cost savings: There were reductions with the reflective roofing model.

Measured as an average per conditioned roof area, the study claimed that every state except Alaska would realize annual reductions in CO^2 emissions if all of their rooftops had a reflectivity of 0.55 instead of 0.20 (*Figure 6*). This paper also included an attention-grabbing statistic: "retrofitting 80 percent of the …commercial building conditioned roof areas in the U.S. [to a reflectance of 0.55] would yield…an annual CO_2 reduction of 6.23 Mt, offsetting the annual CO_2 emissions of 1.20 million cars or 25.4 peak power plants."[31]

Along with three other colleagues, the authors of that paper were also involved in publishing another study in 2010 related to the issue. This time, the Catchment Land Surface Model within the NASA GEOS-5 Atmospheric General Circulation Model was used to look at the outgoing radiation from the earth to assess the climate effects of a 0.10 increase in the reflectivity of all "roofs and pavements in the urban areas in temperate and tropical regions of the globe."[32] The inclusion of pavement is notable, as the study does not differentiate the roofing impact versus the paving impact. Nonetheless, the researchers found that for every 0.03 increase in surface albedo, global temperature would decrease by ~0.008 K during the months of June, July, and August. Though the study notes that "a more meaningful evaluation …would require simulations which better characterize urban surfaces and represent the full annual cycle," it still does indicate that a higher surface reflectivity can decrease global temperatures.[33]

"Effects of White Roofs on Urban Temperature in a Global Climate Model," also published in 2010, contains relevant findings on reflectivity and UHI. This study used the urban canyon model (CLMU) coupled with the Community Climate System Model (CCSM) to compare the effects of urban roof surfaces with a 0.90 roof albedo to a "control" albedo of 0.32 using climate simulations from 1941 to 1999. Across all urban areas that were modeled, their control UHI was 1.2°C warmer than the 2-meter air temperature of rural surfaces, while the high albedo heat island was only 0.8°C warmer, a 33% reduction in the UHI effect. Before getting too excited about this reduction, the authors point out that the extremely high 0.90 albedo that was modeled "could not practically be achieved." Additionally, they found that the use of white roofing will significantly increase the use of space heaters. In fact, space heating increased by a greater amount than air conditioning use decreased in this model, so "end-use energy costs must be considered in evaluating the benefits of white roofs." The paper also notes that in higher latitudes, the heat island reduction is smaller, and "any benefits gained from a reduction in the summertime heat island need to be considered in the context of increased heating costs in winter." Despite the study's limitations, it does clearly conclude that increased reflectivity "is an effective way of reducing the urban heat island."[34]

Despite the different methodologies employed in those three studies of 2010, they all imply that more reflective roofing leads to decreased ambient temperatures. In 2011, a new study showed a different result. "Effects of Urban Surfaces and White Roofs on Global and Regional Climate" included a simulation that converted all roofs to white, with a reflectance of 0.65 (from a base assumption of 0.12), using

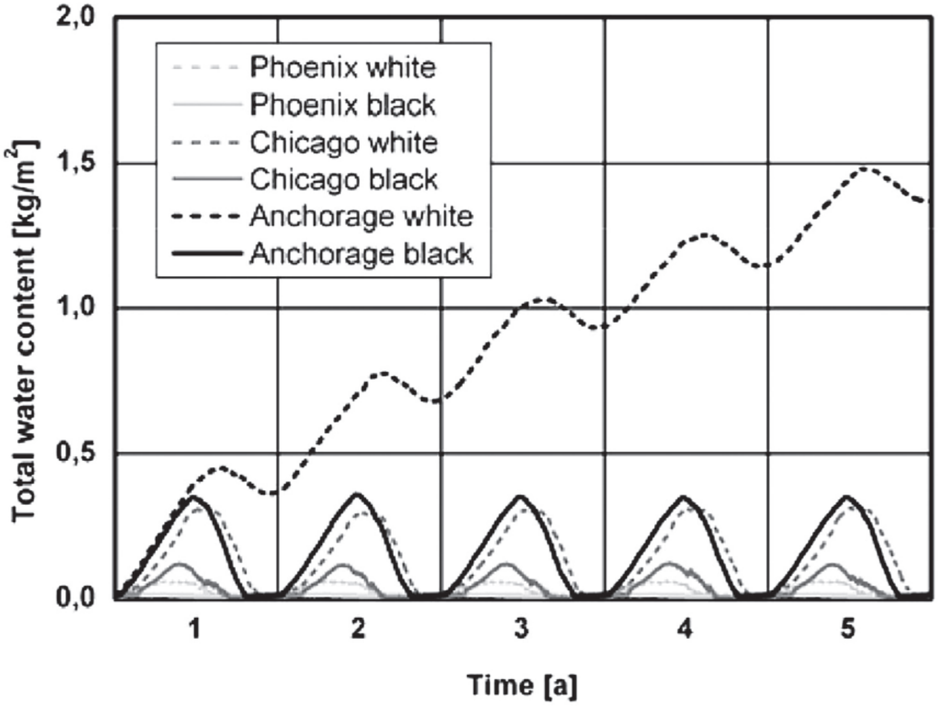


Figure 7 – Water content of flat self-drying roof (Bludau et al., 2008).

the GATOR-GCMOM computer model, "a global gas, aerosol, transport, radiation, general circulation, mesoscale, and ocean model." This model did show that white roofs caused cooling in "local" population-weighted ground and ambient temperatures. "However, feedbacks of the local changes to the large scale resulted in a gross global warming. …Whereas, the population-weighted air temperature decrease due to white roofs was ~0.02 K, the global temperature increase was ~0.07 K." This study, too, has limitations; the authors note white roofing's effect on local energy demand and emissions is not accounted for in the study. The comprehensive model used in this study does include an atmospheric model, though, and it implies that high-albedo roofs change atmospheric stability and clouds. It also incorporates "feedbacks to the larger scale," where "higher reflection also increased air heating by black and brown carbon in soot."[35] The study found that a worldwide conversion to white roofs would warm the Earth.

REFLECTIVE ROOF SURFACES AND CONDENSATION

Commonly, condensation is considered to be what happens when warm, moist air contacts a cold surface, resulting in moisture collection. In roofing assemblies, this can happen when air from the interior of a conditioned/heated building infiltrates through a roof deck and insulation joints before finding a condensing surface on the underside of a roofing membrane, typically in a cool climate. Within the last decade, some published papers have considered the potential for a cooler white membrane to increase the amount of moisture within a roof assembly, as compared to a dark membrane.

WUFI®, a hygrothermic modeling program, was used to model moisture in roofing assemblies for the 2008 study, "Condensation Problems in Cool Roofs." Here, researchers simulated both black and white roofing membranes in three representative U.S. cities—Phoenix (warm), Chicago (temperate), and Anchorage (cold)—on two different multilayer roof assemblies over a period of five years. The first type of roof assembly modeled was a "self-drying roof." This is a common type of roof construction that has no vapor barrier other than the roof membrane, allowing any moisture within the roof assembly to "dry out to the interior of the building." Though self-drying roof assemblies are not often used in Alaska, when the roof has the ability to self-dry, they found accumulation of moisture within the roofing assembly only in the extreme temperature of Anchorage with the white roof. In each of the three cities, the model showed white rooftops would generate more moisture during the course of the year than the black roofs; but except for the white roof simulation in Anchorage, all were able to dry out during the summer. The study determines that self-drying roofs perform well in most locations "independent of the applied surface color," except "locations with low average temperatures" (*Figure 7*).

When analyzing an unventilated roof deck assembly with the membrane applied

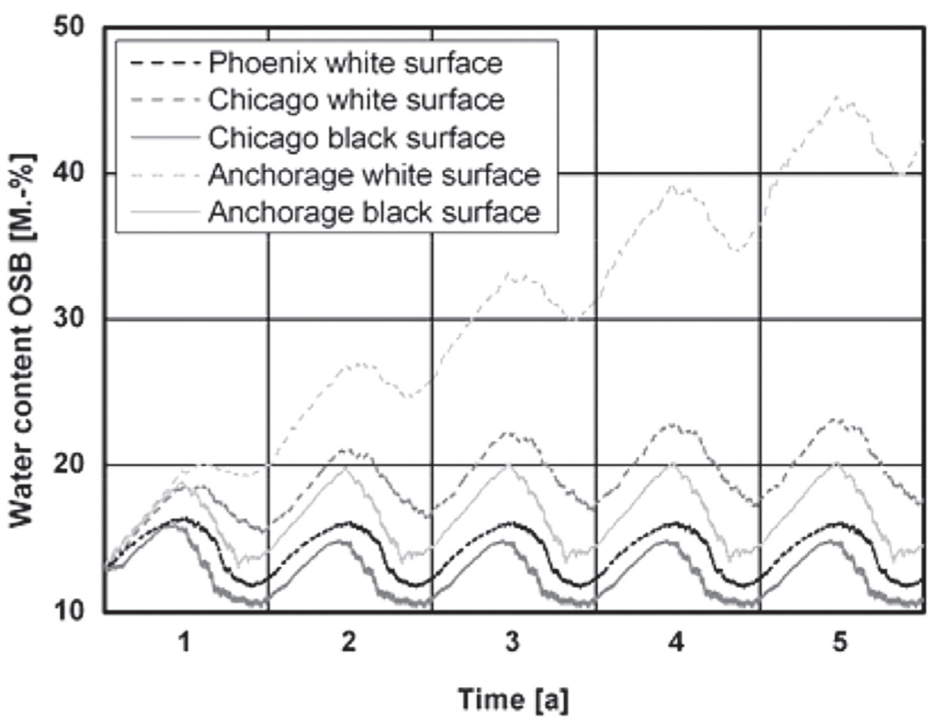


Figure 8 – Moisture content in OSB layer (Bludau et al., 2008).

to oriented strand board (OSB, wood) over wooden rafters infilled with fiber insulation and an interior vapor retarder, the results were different. In these simulations, the moisture content of the OSB was closely monitored to ensure that its water content did not exceed the critical 20%, a point where the material faces potential degradation. The 20% threshold was exceeded in both Chicago and Anchorage when the white roof was used. When an interior vapor barrier is used in these climates, the authors recommend that "construction should be built up with a dark surface" (*Figure 8*).

This study cautions that "if a cool roof is designed for a temperate or cold climate, its moisture behavior should be analyzed . . .to avoid critical water content."[36]

When looking at a traditional metal deck with 2- to 3-in. insulation boards and a white membrane roof, Ennis and Kehrer seemed to confirm those results for a self-drying roof in their 2011 paper. Again using the WUFI tool, their model concluded that white roofs in Climate Zone 5 produced more than double the amount of condensation as black roofing. "However, within the parameters used in this study, both roofs returned to a dry condition during the course of the year."[37] Another facet of this paper was the inclusion of actual field research. Test cuts were performed on ten light-colored roof systems in climate zone 5. The test cuts were done in the winter (February and March, 2010) in the morning (before 10:30 a.m.) on roof systems with vapor retarders that had been in service no less than five years. Three of the ten investigated roofing systems were damp below the membrane, and "minimal damage" to the insulation was observed. The conclusion on this moisture, though, was that "minimal effect had occurred to the roofing assembly that would affect its integrity, insulating value, or performance. No detrimental effect to the roof system was noted."[38] A third portion of this paper focused on a two-year field evaluation of a re-covered roofing assembly, which resulted in a now-familiar finding: the black roofing membrane had a greater "drying rate" than the white membrane, but the difference was negligible—it "did not affect the performance of the fasteners or insulation over the two-year period of the study."[39] This study contains several overall conclusions, and the first two are noteworthy in the context of this review:

1. Situations where moisture accumulation occurs are design issues.
2. When designing a roof system membrane color, in addition to other variables such as building conditions, insulation levels and local weather conditions must be considered in order to prevent moisture condensation and subsequent accumulation within the assembly.[40]

This is consistent with the comments of Hutchinson in his 2009 publication, though his comments about cool roofing and the design community are even more candid. He urges designers to take a comprehensive approach to evaluating roof system performance and warns, "Cool roofing and its single-component mentality are resulting in roof-system failures and impending litigation." The paper documents existing roof systems with condensation and mold growth on the surfaces below reflective roofing, as well as condensation leading to the presence of ice within the lap seams of reflective membranes. It also relates another concern with reflective roofing—the detrimental effect of roof-reflected radiation on materials adjacent to the reflective roof. Excessive heating from reflected solar energy is shown to have deteriorated masonry joints and other cladding systems. Concerned with condensation and other consequences of reflective roofing, the paper concludes:

> It is imperative that everyone in the design and construction industry realize the benefits of designing quality roof systems regardless of the type of roof cover and move away from suggesting a single-component solution.[41]

CONCLUSION

Though not included in the literature review herein, a thoughtful analysis of the energy use of black and white roofs was presented for the 2009 RCI Building Envelope Symposium. After pages of roof energy-use modeling graphs (using the DOE Cool Roof Calculator), the author concludes:

> The issue of reflectivity has been overstated and can lead to undesirable outcomes. ...Conserving energy when designing a roofing assembly can be accomplished by a responsible selection of the different components and the proper level of insulation.[42]

After reviewing these recent research updates on reflective roofing, it is hard not to agree with that statement. There is little or no debate on the notion that reflective roofing will lower heating and cooling energy usage on minimally insulated buildings in the southern U.S. On the topic of reflective roofing, the absence of debate ends there. The color of a roof surface will have an impact—sometimes positive and sometimes negative—on a building's interior conditions such as occupant comfort, the service life of the roof itself, adjacent building materials, local air temperatures, and, potentially, even global climate. However, it is only one factor that a responsible designer should consider as he or she takes a holistic approach to designing a roof. If a roof membrane color is chosen without consideration of the attachment method, the amount of insulation, and the air and vapor barriers within the assembly, then the opportunity to optimize the building's energy use will be missed. Furthermore, this entire roof system must be designed with continuity to the walls to truly serve its role within the building envelope. Only after this multicomponent roof system analysis and weighing of the needs of the building, its owner, and its occupants can the "correct" roof surface be determined.

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