ERA | EPDM ROOFING ASSOCIATION

COOL ROOFS IN NORTHERN CLIMATES: ENERGY EFFICIENCY AND MOISTURE PERFORMANCE IMPLICATIONS

Introduction

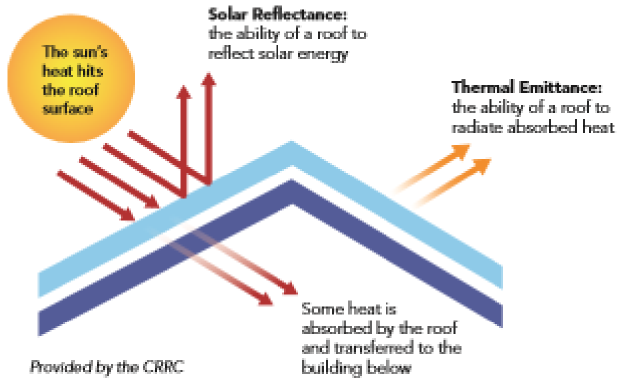
The growing awareness of climate change, as well as the related issues of urban heat islands and steadily increasing energy costs, has led to a growing interest in the effectiveness of reflective, or "cool" roofing. Proponents of reflective roofing have recommended its use throughout the US to save energy, and some cities have moved toward mandating the use of white roofs on all new construction, roofing removal and replacement as well. This enthusiasm for using reflective roofing as a "one size fits all" solution to energy-related problems gained momentum in 2009 when former Secretary of Energy Stephen Chu recommended that all "flat topped" buildings be painted white and all new buildings be constructed with reflective roofs.

In fact, rather than clarifying the way forward, former Secretary Chu's recommendation intensified debate in the construction community over the use of white roofing membranes throughout the United States. Opponents of the "one size fits" all approach pointed to the logic of using dark roofs in northern climates: they pointed out that while white roofs reflect the sun's heat and should be used in hot, southern climates, black roofs help absorb the sun's heat and are the most efficient choice in heating-dominated central and northern climates. Evolving energy codes and green building codes have followed this logic as a basis for mandating cool roofs (with certain exceptions allowed) in the southern regions of the U.S., particularly Climate Zones 1-3 as shown in Figure 1, and the roofing community has generally agreed with these actions. But disagreement persists about the appropriate approach for Zone 4 and moving north. Where do the benefits of using black roofs to save energy in colder seasons start to outweigh the benefits of using white roofing in the warmer months of the year? Where do high levels of thermal insulation make the issue of a roof cover color a moot point? And what are the other issues to consider in choosing between reflective and dark roofing membranes? The simplicity of the black-vs.-white logic begins to break down as one considers the application of cool roofs in the more northern cold climates (Climate Zone 4 or greater in Figure 1) and the right answer is typically more black than white.

As manufacturers of both black and white membrane, the members of the EPDM Roofing Association (ERA) commissioned an exhaustive review of the science supporting the use of either reflective or dark membranes in various climates. This resulting paper is designed to provide clarity for our current and potential customers, and bring balance to the frequently confused black-vs.-white debate.

Generally accepted definitions of a cool roof refers to a roof membrane or roof surface coating with solar reflectance above .55 and high thermal emittance properties. In cooling dominated climate zones (generally ASHRAE climate zones 1-3) these properties may help reduce electricity used for air conditioning by lowering roof temperatures on hot, sunny days. Solar reflectance refers to a material's ability to reflect the sun's solar energy back into the atmosphere. Thermal emittance provides a means of quantifying how much of the absorbed heat is rejected for a given material. Both properties are measured from 0 to 1.

Source: adapted from www.coolroofs.org



Source: http://www.energy.ca.gov/2012publications/CEC-400-2012-003/CEC-400-2012-003-BR.pdf

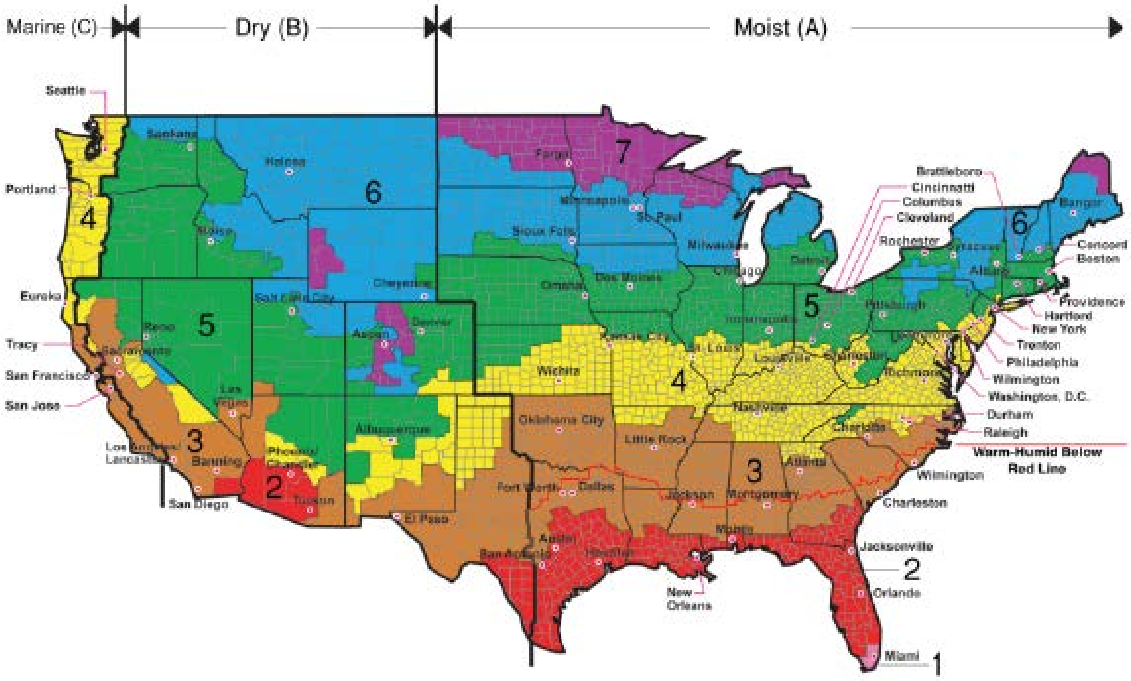


Figure 1. US Climate Zones
Source: EPA

The application of cool or white roofs becomes problematic in northern climates for two important reasons: (1) loss of energy savings benefits and (2) potential for increased moisture accumulation risk in the roof system. While there are other issues with cool roofs to consider in any climate, including a number of unintended consequences (Yang, et al 2013) and uncertainties in the actual urban heat island and global warming benefits (Jacobson and TenHoeve 2011), these other issues are beyond the scope of this article. But, a collective consideration of all of the issues does lend support to a pragmatic or "selective use" approach for cool roofs as called for by Jacobson and TenHoeve (2011). This draws a stark contrast to the effort to mandate white roofs across broadly defined climate zones without regard to many important factors that influence the performance outcome. Such an indiscriminate approach becomes even more problematic as one moves into northern climate zones (e.g., Climate Zones 4 and greater). For example, within Climate Zone 4 (Figure 1), the level of solar irradiance (Figure 2) varies from about 3,500 to 7,000 Watt-hour per square inch per day. A factor of two difference in incident solar radiation must certainly have significant performance implications for cool roofs that should be considered from a "selective use" standpoint.

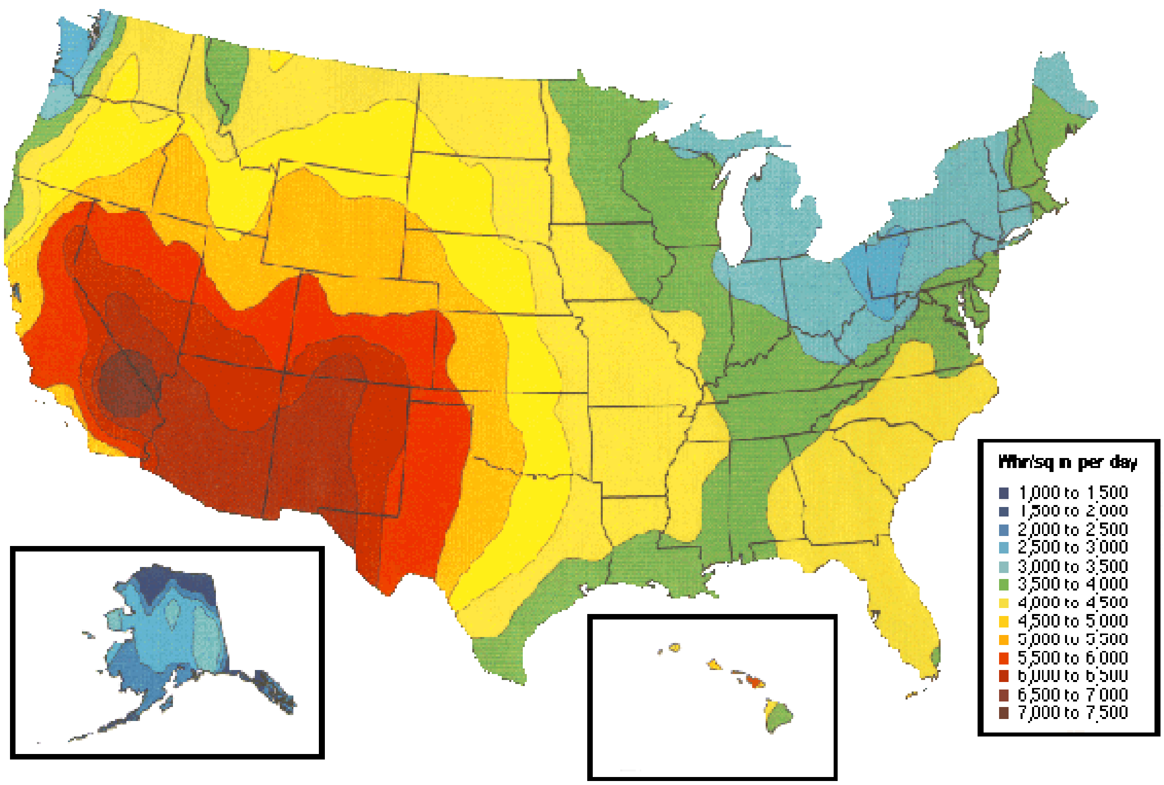


Figure 2. Solar Irradiation Intensity Map of the U.S.
Source: NREL

Energy Efficiency Implications

The energy efficiency benefits of cool roofs in any climate are dependent on a number of variables including:

- Average temperature in that climate (e.g., Figure 1)
- Aunniness or cloudiness of the climate (Figure 2)
- Amount of roof insulation: more insulation (greater thermal resistance) means the roof color (or solar reflectance) matters less
- Cleanliness of the roof surface to maintain assumed solar reflectance
- Roof area: Schools, warehouses versus smaller less square footage buildings
- Height of the building - the taller the building the less significant the roof color or insulation level to overall building energy efficiency, and
- Internal heat loads within the building: higher internal loads increase the cooling season length and, thus, improve benefits of cool roofs
- Building type
- Use of space below the roof

Multiple studies have investigated the energy saving potential of cool roofs with varying assumptions regarding the above parameters and others. In some cases, assumptions have been made that tend to inflate the energy-saving value of cool roofs, particularly in northern climates where there is sometimes a fine line between an "energy saving" or an "energy wasting" outcome. For example, a recent study by the University of Arizona (Yang, et al. 2013) included a critical review of a study by Lawrence Berkeley National Laboratory and found that "…the fantastic savings demonstrated are dependent on unrealistic assumptions used in the study and are of great uncertainty." While there is no shortage of such examples giving reason to question the assumptions and results of various studies, one seemingly consistent finding in many studies is that the savings, if not negative in the northern climates, are generally very small.

The erosion of cool roof benefits in northern climates occurs because (again depending on assumptions) the heating penalty of a cool roof during the heating season (e.g., fall/winter/spring) is significant and it tends to negate or exceed the cooling energy savings in the summer. For example, even when favorable assumptions are made for cool roofs in northern climates as done in a study by Konopacki et al. (1997), the estimated annual energy savings (+) or losses (-) range from about +$0.02/ft^2$ to - $0.02/ft^2$ for commercial and residential buildings in various cities or regions within Climate Zones 3 through 5 (Figure 1). Thus, in these moderately cold or mixed climates (climate zones 6 through 8 are much colder), the annual energy savings or losses are a meager +/- 2 cents per square foot of roof area.

The low level of savings or loss is reinforced by other studies. For example, a field monitoring study in Climate Zone 5 of actual roofs near Syracuse, NY (OCDC 2011) found that the white roof produced an annual energy loss of about -$0.02/ft^2$ in comparison to the dark roof system. In more northern climates and even for a single story commercial building with high internal heat loads and a low window-to-wall area ratio representing conditions ideally favorable to realize cool roof energy saving benefits, a study by

Freund, Dettmers, and Reindl (2006) found total annual savings as low as $0.008/ft^2 (less than 1 cent per square foot of roof) in Minneapolis (Climate Zone 6) and $0.017/ft^2 (less than 2 cents per square foot of roof) for Denver (Climate Zone 5) despite it being a very sunny climate. Such findings consistently highlight the need to be very selective in the use of cool roof membranes to achieve even a thin margin of energy savings in moderately cold northern climates.

When other costs are considered, such as periodic roof cleaning necessary to maintain the effectiveness of a reflective roof surface, the meager energy savings (if any) for a particular cool roof application may be quickly consumed. For example, Roodvoets, Miller, and Desjarlais (2004) indicate that a typical cost to power wash a roof is about 1 cent per square foot. Consequently, they found that the cost-benefit of washing a cool roof was positive in Phoenix, AZ (a hot and sunny climate). But, in Knoxville, TN located in less sunny Climate Zone 4, the cost of cleaning a white roof to maintain its solar reflectance could not be justified by the energy saving benefits of doing so. Whalen (2014) suggests the cost of cleaning a cool roof can be as much as 5 cents per square foot - five times greater than the previous reference (and others in the industry suggest a cost as much as 10x greater)! Thus, as one moves into more northern climates, the economic justification of a cool roof becomes much more difficult to achieve and may be realized only for a "selective use" where an ideal set of application conditions exist (e.g., high internal heat load, sunny climate, one-story building, low window-to-wall area ratio, etc). This is not meant to be an argument for not cleaning roofs to maintain reflectivity or for other reasons. It is merely a realization that the cost-benefits of a cool roof are closely associated with and dependent on keeping the roof reasonably "shiny" so it can perform its intended energy saving purpose. One only needs to make a casual inspection of roofs while flying into an airport to see that this degree of cleanliness is often not achieved in the real world.

Moisture Control Implications

Regardless of whether or not a white roof can be economically justified in a particular northern climate building application, the economic question is moot if moisture vapor problems occur. First, it is important to recognize that moisture vapor control is a concern for all roof systems. It is also important to recognize that there may be distinctions in how different roof systems perform and that roof color plays a role in the moisture performance of a compact, low-slope roofs that must dry to the interior *not* through the roof membrane. Also, this issue is not so "black and white" that one roof membrane is considered bad and the other is considered good. Instead, there are shades of gray for moisture accumulation risk. What this means is that there may be modest differences in moisture risk that should be considered and perhaps mitigated if white roofs are intended to perform at least equivalently to dark roofs in northern climates. Historically darker colored roof surfaces promoted downward drying, which is not a characteristic of cool roofing and thus moisture accumulation can be cumulative.

The concern with increased moisture accumulation risk below cool roof membranes is recognized in the U.S. Department of Energy's guideline for selecting cool roofs (Urban, Bryan, and Roth 2010) and the following statement serves as basis for one recent study into the matter (Kehrer and Pallin 2013):

> "There have been questions raised about the sustainability of using cool membranes in northern U.S. climate zones due to the potential of moisture accumulation below the membrane."

The following summarizes some of the key findings reported by Kehrer and Pallin (2013) and Bludau, Zirkelbach, and Kunzel (2009) related to the relative moisture control performance of cool roofs and dark-colored roofs.

1. The two most dominant factors governing moisture performance and risk are air-leakage rate into the roof and indoor relative humidity.
2. Moist indoor air leakage into the roof system can be greater in mechanically attached roof membranes (typical of cool roofs) due to fluttering or billowing caused by wind.
3. While all roofs are sensitive to indoor relative humidity and air-leakage, white roofs show a greater sensitivity.
4. Compared to a traditional black roof, the amount of accumulated moisture during the winter can be two to three times greater in a cool roof construction.
5. For a given climate such as Chicago and for a roof system with all other factors equal, a white roof could cause wood sheathing to exceed a maximum acceptable moisture content of 20% whereas a black roof was predicted to keep wood sheathing moisture contents in a safe range between 11% to 16%.
6. Once 1mm of condensation accumulation is exceeded, the risk of problems becomes greater. In most of the normal humidity data points, black membrane stayed below 1 mm.

Because of the above differences in modeled performance, some researchers recommend that roofs systems using a cool roof in northern climates should be designed based on "…hygrothermal simulations in order to avoid critical water content in the construction. If necessary, a darker color roof surface should be considered." (Bludau, Zirkelbach, and Kunzel, 2009) While not associated with any detrimental effect, a field study of several white and black roofs and hygrothermal modeling of those roofs indicated a tendency of white roofs to accumulate a greater amount of moisture during the winter and to dry more slowly during the summer (Ennis and Kehrer, 2011). (Most designers and certainly all the researchers perform the hygrothermal analysis through solid insulation when in fact it is the joints that are of concern. This is especially important that if a single layer of insulation is used that air loss to the underside of the membrane be considered, which will provide dramatically differ results than if modeled on solid insulation. Here is where the modeler needs to have a using knowledge of roofing.) In a study by Kunzel, Zirkelbach, and Schafaczek (2012) where a roof system's solar absorptivity (the inverse of reflectance) was decreased from 0.6 to 0.3, the roof system changed from one that was annually drying to one that was showing annually increasing moisture levels. The increase in roof reflectivity reduced the solar-driven inward drying effect to a point where it was unable to keep up with moisture accumulations occurring during winter months. These findings demonstrate that an appropriate use of a white roof in a northern climate may require additional moisture control considerations such as improved air-leakage control and indoor relative humidity control. Alternatively, they may be "selectively used" on buildings where conditions are inherently less risky (e.g., occupancies with lower internal moisture generation and inherently lower indoor relative humidity levels in the winter).

Conclusion

In hot and sunny climates, the logic of cool roofs to save energy is generally accepted (although the effect is diminishing with greater insulation levels) … and so are some benefits. However, in northern climates, the heating penalty virtually always outweighs or offsets the cooling benefit and moisture control or condensation risks are greater than experienced in conventional black roof membranes. This reality necessitates a "very selective use" approach for cool roofs. Such an approach strives to identify the limited cases where specific end use conditions may provide a benefit while also considering appropriate measures like the addition of air/vapor barriers to mitigate increased moisture accumulation risks. For cool roofs in northern climates, one has to understand the heating penalty, moisture accumulation potential as well as the other performance trade-offs associated with their selection and use.

Good roofing practice must be the dominant criterion in any roof design. The licensed design professional, an Architect/Engineer, has long-term experience and access to science to effectively weigh the broad variety of issues that inform the choice of a roofing membrane. These include not only the color of the membrane, but also issues such as the durability of the membrane, the method of attaching the membrane, the choice of insulation, and the use of air or vapor barriers. Ultimately, the licensed designer should be relied upon to make the correct roof system design choices, including that of roofing membrane for any individual building project.

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