Reflective Roofs and Urban Heat islands:
Protecting People, the Environment, and the Economy

Executive Summary

This article provides an overview of the urban heat island effect that impacts almost all major cities across the globe. The article suggests that urban heat islands pose a significant problem, negatively affecting the world economy, environment, public safety, and human health. Based on a review of the available strategies to mitigate the negative consequences of the heat island effect, the article also suggests that reflective roofs offer the most feasible and cost-effective way to immediately start improving conditions in urban heat islands. Finally, the article suggests that cool reflective roofs, when designed and installed correctly, may provide many years of useful service while reducing heat island impacts at the same time.

What is an Urban Heat Island?

As urban areas across the globe have grown in size and density, significant changes have taken place in their landscape. Buildings, roads, parking lots, and other infrastructure replaced open land and vegetation. Surfaces that once were permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape.

It is important to note that the heat island effect occurs both on the surface and in the atmosphere. By noon on a hot summer day, the sun can heat urban surfaces such as roofs and pavements to temperatures 50 to 90 degrees Fahrenheit hotter than the air. In turn, these surfaces radiate additional heat into the atmosphere, causing a similar but not as extreme increase in air temperature. This atmospheric heating becomes more pronounced after sunset as urban surfaces continue to radiate heat into the surrounding air. According to the U.S. Environmental Protection Agency, the annual mean air temperature of a typical city with one million residents may be 2 to 5 degrees warmer than its surroundings. And on a summer night, this increase in temperature may be as much as 22 degrees Fahrenheit.[2]

A cross-section of a typical urban heat island is illustrated in Figure 1. The illustration shows how urban temperatures typically are lower at the urban-rural border than in dense downtown areas. The illustration also shows how parks, open land, and bodies of water can create cooler areas within a city.

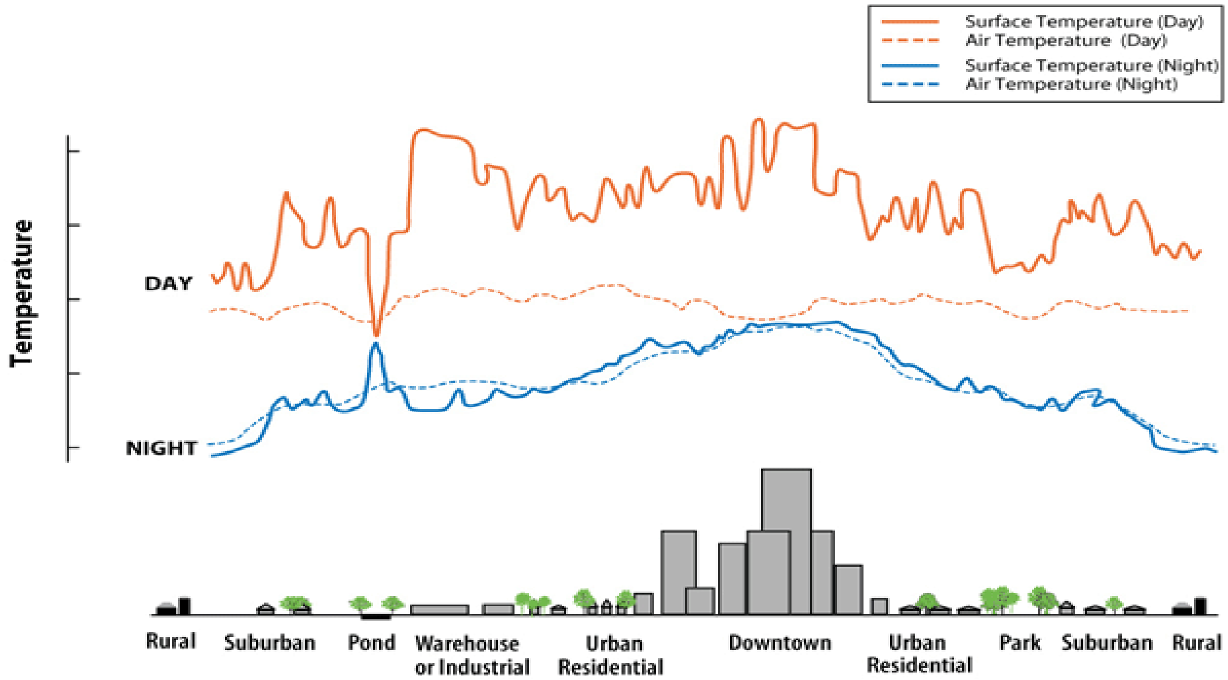

Figure 1. Typical Urban Heat Island Profile

(Source: U.S. EPA[3])

Figure 1 also helps illustrate the critical relationship between surface and air temperatures. Once heated, the hard surfaces of asphalt and concrete typical in urban areas tend to maintain an increased temperature for almost the entire day. And the heat retained and emitted by these hard surfaces during the evening causes the air temperature at night to become almost identical to the temperature of the heated urban surfaces.

However, one critical factor not illustrated in Figure 1 is the ultimate source of urban heating. With the exception of heat from geothermal sources as well as man-made and natural combustion, over 99 percent of the heat in our atmosphere is a result of solar radiation.[4] As a result, almost all temperature effects associated with urban heat islands can be traced to increased absorption of solar radiation by urban surfaces. And as we will discuss later in this article, reducing solar heat absorption is the most critical factor in addressing the problems of urban heat islands.

Why are Heat Islands a Problem?

Elevated temperatures in urban heat islands, especially during the summer, may have numerous negative consequences for the environment and quality of life in urban areas. These adverse consequences may include:

- **Increased peak energy consumption and costs.** Higher urban temperatures in summer increase demand for air conditioning and related electricity consumption. Studies conducted by researchers at Lawrence Berkeley Laboratory estimate that the heat island effect is responsible for 5 to 10 percent of peak electricity demand.[2] In addition, the actual cost for this electricity to the individual building owner may be much higher when peak demand charges are included in the monthly electric bill.[5]

- **Increased risk for brownouts and blackouts**. Increased peak air conditioning demand in urban heat islands poses additional risks beyond higher electric bills. Even without the additional heat load associated with heat islands, peak electrical demand in the summer may run dangerously close to the maximum capacity the electric grid can provide. And when the grid fails to meet peak demand, the results may be devastating. As an example, heat island-driven peak demand is closely related to a number of well-known power failures in the United States, including the state of California in 2000 to 2001 and the city of Chicago in 1995. In all of these cases, peak demand for electricity during prolonged heat waves exceeded the capacity of the electric grid, causing frequent brownouts as well as occasional complete failure of the grid.

- **Increased air pollution**. Increased peak energy demand generally results in greater emissions of pollutants from power plants. And much of this increased pollution may impinge directly on the air in an urban area since the power plants providing peak power frequently are located close to the cities that generate the peak demand. In addition to raising power plant emissions, higher air temperatures also promote the formation of smog, or low-level ozone.

- **Compromised human health and comfort.** Every degree of increased temperature in an urban heat island makes it more and more difficult for a city's population to remain comfortable, productive, and even safe in the event of natural emergencies, especially events that may shut down the electric grid. Warmer days and nights, along with higher air pollution levels, can contribute to general discomfort, respiratory difficulties, heat cramps, exhaustion, non-fatal heat stroke, and heat-related mortality.

- **Impaired water quality**. Hot pavement and rooftop surfaces transfer their excess heat to storm water, which then drains into storm sewers. This heated storm water then raises water temperatures as it is released into streams, rivers, ponds, and lakes, causing temperature changes that may be stressful to aquatic organisms. Elevated water temperatures also reduce the oxygen capacity of water and its ability to decompose sewage and other pollutants.

What Can We Do About Urban Heat Islands?

Although the urban heat island effect could be addressed simply by removing a city's buildings and pavements and replacing them with open land and vegetation, such a solution would effectively eliminate the urban area itself along with the heat island. As a consequence, the only practical way to address this challenge is to *transform* these urban surfaces rather than eliminate them. And this transformation must somehow eliminate or reduce the tendency of these surfaces to absorb and retain heat. Without a doubt, pavements and roofs offer the best opportunity to reduce urban heat absorption. When combined, roofs and pavements account for over 60 percent of the entire surface area of modern urban areas, with roofs contributing 20 to 25 percent and pavements contributing 30 to 35 percent.[6]

Because transformation of roofs and pavements appears to be the most effective approach to heat island mitigation, almost all current global strategies are directed toward making the roofs and pavements of cities less heat absorptive. In lieu of this solution, we can plant more trees and create more parks. But given the scarcity and economic value of urban real estate, such a strategy may have only a limited impact on overall urban temperatures. As a result, this article will focus primarily on the various ways we can reduce the heat absorption of roofs and pavements.

It's easy to understand why there is so much public reference to the word "cool," as in cool pavements and cool roofs. If the fundamental problem is related to excessive heat in urban pavements and rooftops, then the obvious solution would be to reduce their temperatures and make them much cooler. Without getting into a complex discussion of thermodynamics, there are a number of ways to make hot surfaces cool, and a brief review of these different approaches should be helpful.

Shading. Hot urban surfaces may be cooled through the use of shading, or blocking the sun's radiation before it is absorbed by the surface. Common examples of this strategy include the planting of trees to provide shade as well as the installation of awnings or solar shades to block sunlight from hitting highly absorptive surfaces. Although shading may be a useful strategy for small heat reductions in highly targeted areas such as sidewalks and patios, it is difficult to envision large-scale applications that would address more than a small percentage of current urban area.

Evaporation / Transpiration. The temperature of urban surfaces also may be reduced by evaporation, or the heat transfer achieved when water moves from a liquid to a gaseous state. As an example, water fountains can be very effective in cooling nearby surfaces as well as the surrounding air. Unfortunately, just like shading strategies, the overall reduction in urban heating achieved through evaporation may be relatively small. In addition to the direct evaporation of a water fountain, it should be noted that a portion of heat reduction attributed to trees and other plants involves a form of evaporation called transpiration. During transpiration, plants give off water vapor in order to cool their leaves and facilitate the movement of nutrients. The most obvious applications of transpiration to reduce surface temperatures in urban areas would include any garden or park area where pavements have been replaced by extensive plant cultivation. But just like shading strategies, the amount of urban area that may be dedicated to, or suitable for, gardens and parks likely is limited.

One final application of transpiration in urban areas involves the installation of "green" roofs consisting of a variety of plants that may be installed in a depth of planting media directly over new or existing roof surfaces. Many cities across the globe have adopted programs to encourage the installation of green roofs, but the cost of a vegetated roof may be difficult to justify for the sole benefit of surface cooling. As a result, green roofs tend to comprise a very small proportion of urban roof installations. For instance, a survey of green roof installations estimated that slightly over 20 million square feet of green roofs were installed in North America in 2013.[7] Although 20 million square feet may appear to be a sizeable number, it accounts for less than 1% of the 3 billion square feet of low-slope non-residential roofs installed annually in North America.[8] Therefore, the potential for green roofs to make a significant impact on heat islands appears to be almost as limited as previously discussed shading strategies.

Advection. The temperature of urban surfaces also can be reduced through advection, or the effects of wind blowing across a heated surface and cooling it. As an example, a 2005 modeling study of rooftops in downtown Chicago suggested that roof surface temperature may be reduced by the effects of wind.[9] However, other studies using larger "urban canyon" models suggest that the effect of wind on urban surfaces is very complicated and in many cases can actually lead to increased heat absorption.[10] Regardless, it should be obvious that whatever benefits attributed to wind would be highly unpredictable and probably not useful as a heat island strategy.

Reflection. Finally, the temperature of urban surfaces can be reduced through reflection, or the redirection of solar energy away from urban surfaces and the heat island itself. Although both roof and pavement surfaces can be made to be reflective, cost-effective technology suitable for immediate and scalable application is only available at this time for reflective roofs. Given the urgency of reducing heat island effects, it is likely that new reflective paving products will become commercialized in time; but for today's cities, reflective roofing offers the best immediate answer to reducing heat island effects.

Because reflective roofs offer the primary technology available today to address heat islands, it is important not to underestimate their potential contribution. As previously stated, roofs account for approximately one-quarter of urban surface area; and if reflective roof technology can be used to significantly reduce heat absorption over such a sizeable surface area, its potential contribution would be substantial.

In order to better understand the potential contribution of reflective roof technology, it may be useful to evaluate how a typical reflective roof compares with a traditional non-reflective roof in removing solar heat from urban areas. Figure 2 provides such a comparison based on data developed by the Heat Island Group of Lawrence Berkeley National Laboratory and published by the Global Cool Cities Alliance.[11]

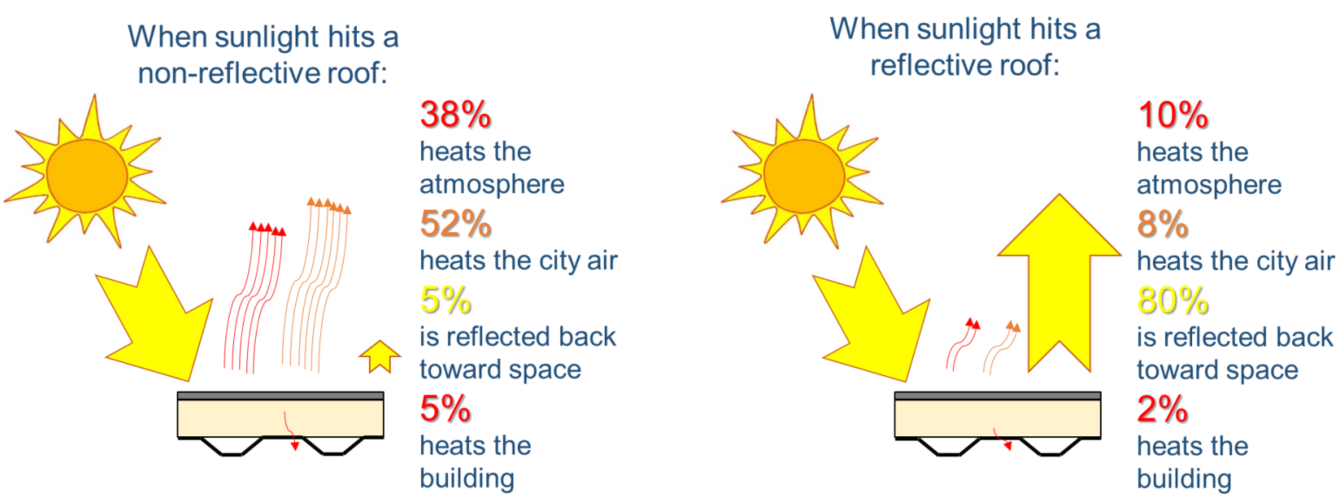

Figure 2. Reflective versus Non-reflective Roof: Where Does the Heat Go?

(Source: Global Cities Cool Roofs and Cool Pavements Tool Kit[11])

As shown in Figure 2, when sunlight strikes a traditional non-reflective roof surface, only 5 percent of the total heat energy is effectively removed from the urban heat island by reflection back toward space. Instead, 52 percent of the energy heats the air directly around the urban area, 38 percent heats the larger atmosphere above the heat island, and 5 percent heats the building or area directly beneath the roof. However, when sunlight strikes a reflective roof, up to 80 percent of the total heat energy is reflected back toward space, leaving only 8 percent of the energy to heat the city air, 10 percent to heat the atmosphere above the city, and 2 percent to heat the building. As a result, the reflective roof may effectively remove up to 80 percent of the heat energy that otherwise would impact the heat island. Assuming that roofs account for 25 percent of the urban area, the overall potential decrease in solar heat absorption would be 80 percent times 25 percent, or a 20 percent total reduction*. That's pretty impressive for a single technology available for immediate and full-scale deployment today.

Benefits of Reflective Roofs

For cities and their inhabitants. Just as elevated temperatures in urban heat islands pose numerous negative consequences, reflective roofs offer an equally long list of potential benefits to improve the environment and quality of life in urban areas. Important benefits of reflective roofs for cities and their inhabitants include:

- **Lower heat island temperatures.** Simulations run for several cities in the United States suggest that citywide installations of highly reflective roofs and pavements, along with planting shade trees will, on average, reduce ambient air temperatures by 4 to 9 degrees Fahrenheit in summer months.[12]
- **Reduced peak energy demand.** By reducing air temperatures and the associated demand for air conditioning at critical peak periods during the day, the installation of reflective roofs and surfaces may reduce overall peak electricity demand in urban areas by as much as 5 to 10 percent.[2]
- **Lower air pollution.** The combination of lower overall temperature and reduced peak demand offered by reflective roofs and surfaces may lead to reduced air pollution by lowering the amount of power plant emissions and by reducing the temperature-related formation of smog, or low-level ozone.
- **Reduced risks from blackouts**. By lowering peak electricity demand, reflective roofs may reduce the risk of power blackouts. And in the event a blackout does occur, reflective roofs continue to divert solar heat away from buildings and help occupants stay cool without the use of air conditioning.
- **Improved quality of life**. Reductions in overall air temperature and urban air pollution combine to provide a healthier and a safer environment for a city's inhabitants, leading to improvements in work productivity and leisure activity.

For building owners. Perhaps the most noteworthy aspect of reflective roofs is that so many of their benefits accrue directly to the building owners who invest in them. Important benefits of reflective roofs for building owners include:

- **Lower electric bills**. Because many electric utilities, especially in urban areas, add peak demand charges to their electric bills, the dollar savings available from installing a reflective roof may be many times more than the actual reduction in peak usage. For example, a recent study of peak electric charges suggests that the costs associated with peak electricity demand charges may account for over 50 percent of some electric bills during the summer. In addition, this study suggests that the annual savings available from a reflective roof installed on an existing 20,000-square-foot commercial building may vary between $880 and $3040, depending on utility rates and climate zone.[5]
- **Reduced equipment sizing / improved service life**. Because air conditioning equipment must be sized to accommodate peak cooling loads, reflective roofs may help

lower the overall size of the compressors and air handlers needed to cool a building. And because reflective roofs may lower roof surface temperatures by as much as 50 to 60 degrees Fahrenheit, rooftop air conditioning units will operate at reduced temperature differentials, which may extend the service life of equipment.

- **Competitive cost.** In many cases, a reflective roof may cost no more than non-reflective roofing options. Table A provides a comparison of reflective surface cost premiums for the most popular commercial roofing materials, as estimated by the U.S. Department of Energy (DOE).[13]

Table A. Cost Premiums for Commercial Reflective Roofing Options
(Dollars per Square Foot)

Roofing Material	Traditional Surface Options	Reflective Surface Options	Cost Premium
Asphalt Built-Up Roofing (BUR)	Crushed stone	Reflective aggregate (e.g. marble chips)	\$0.00 - \$0.20
Modified Bitumen	Mineral cap sheet	White or other reflective mineral cap	\$0.50
Thermoplastic (PVC, TPO)	White or colored surface	White or other reflective surface	\$0.00
Thermoset (EPDM)	Dark surface	White surface or other reflective surface	\$0.10 - \$0.50
Spray Polyurethane Foam (SPF)	Field-applied coating	White field-applied coating	\$0.00
Architectural Metal Roofing	Factory-applied coating	White or other reflective coating	\$0.00

Source: U. S. Department of Energy[13]

In addition to the DOE estimates shown in Table A, the cost effectiveness of reflective roofs may be demonstrated by the significant increase in market share they have achieved in the past 10 to 15 years. From less than 20 percent of the low-slope commercial roofing market in 2000, reflective roofs have grown to around 50 percent of the market ten years later in 2010 and probably well over 50 percent today.[8]

- **High return on investment.** Because there is little or no cost premium associated with reflective roofs, the return on investment may be very high, especially for new buildings or existing buildings requiring a new roof simply due to age or other reasons. So when a building owner selects any of the roofing options shown in Table A that require no cost premium, all of the dollar savings from reduced electricity bills drop directly to the bottom line.

Selecting a Reflective Roof: Important Considerations

Although a suitable reflective roof may be available for almost any commercial roofing need, a number of additional considerations should be examined before selecting the best reflective roofing system for any particular application.

Reflective roofing standards. As a starting point, the roofing option selected should meet or exceed the best current codes and standards for reflective roofing in order to maximize long-term benefit and performance. For roofing products to be considered reflective by today's standards, the product must be tested to achieve a minimum Solar Reflectance Index (SRI) rating. This index combines two measures critical to evaluating the total reflective potential of a roofing product. The first measure is Solar Reflectance (SR), which quantifies the amount of solar energy that is directly reflected by the material. The second measure is Thermal Emittance (TE), which quantifies the amount of solar energy that is indirectly released to the atmosphere or adjacent spaces after the material is heated by the sun. Looking back at Figure 2, the solid arrows represent the SR portion of solar energy that is directly reflected, while the wavy arrows represent the TE portion of energy that is indirectly emitted after the material has been heated.

In order to evaluate the total amount of energy removed by a reflective roof, it is necessary to combine the SR and TE of the material into a single SRI index. Almost all national energy codes and standards now use SRI as the reference standard for roof reflectance, and many of these codes and standards have established minimum SRI levels, both initial and after aging for 3 years. Table B provides a brief summary of both initial and aged minimum SRI values for three of the most-recognized U.S. building codes and standards—the International Energy Conservation Code, the ASHRAE 90.1 building energy standard, and the State of California Title 24 energy standard.

Table B: Current Reflective Roof Standards

(Low-Slope Roofing Applications)

Building Code / Energy Standard	Min. Solar Reflectance Index (SRI)	
	Initial	3-Year Aged
International Energy Conservation Code (2012-2015)	82	64
ASHRAE 90.1 Energy Standard (2013)	n/a	64
California Title 24 Energy Standard (2013)	n/a	75

The building owner and designer should use the SRI range in this table as a guideline for product selection. To help verify that a product selected meets or exceeds the relevant SRI value, most roof system manufacturers identify the SRI of their products on published product information sheets and other technical literature. In addition, a free online listing of the tested and certified SRI of hundreds of roofing products is maintained by the Cool Roof Rating Council, which also maintains the building code-recognized standard for testing and reporting SRI. Additional information about the Cool Roof Rating Council is included in the "For More Information" section of this article.

Reflective roofs and aging. As shown in Table B, reflectivity values for roofing products are measured both initially and after an aging period. This is because the reflectivity of a roof surface tends to degrade due to aging of pigments and discoloration caused by surface accumulation of dirt, airborne pollutants, and biological growth. Although some roofing researchers originally suspected that the decrease in reflectivity over time might be significant, field studies conducted on a wide variety of reflective roofing types suggest that roof reflectivity tends to stabilize over time and probably never falls much below an SRI of 50 under typical field conditions.[14]

Because most reflective roofing systems maintain a relatively high level of reflectivity over time, it is likely that any attempts to wash or clean the surface of the roof will not offer any significant economic benefit. In fact, many roofing professionals do not favor the cleaning of roofing surfaces because the cleaning process may accelerate the overall aging of the system and reduce service life.[14]

Finally, it is important in any discussion of roof aging to draw a distinction between installing a high-performance commercial roofing system and merely painting an existing roof. In general, most commercial-grade roofing systems are available with in-service performance warranties that may extend for up to twenty years or more. In the case of paint or a commodity roof coating obtained from a local building supply, however, the available warranty may be non-existent or less than a few years. Although warranty terms and conditions may vary widely from product-to-product, it is important that the building owner or designer carefully verify the type and extent of warranty coverage that is available for the roofing system or product selected.

Comparing reflective roofing options. Because reflective roofs are available in all major technologies, the selection of the best reflective roof for any application may be made based on economics and performance. Perhaps the best approach is to combine economics and performance by looking at the long-term life cycle cost of the roofing system. Such an approach may be especially useful if there are periodic maintenance requirements for one type of reflective roofing system as compared to another. As an example, if a reflective roof coating system requires recoating every so many years, it may have a higher long-term life cycle cost than a reflective single-ply system that requires minimal maintenance over its service life.

Reflective roofs and roof insulation. After finalizing a decision to install a new reflective roofing system, it is important not to neglect the underlying thermal insulation. In terms of return on investment, the best time to increase insulation levels is at the time a new roof is installed, especially when reroofing over an existing roof. As a general guide for roof insulation levels, the same major codes and energy standards mentioned previously may serve as the best references. In these codes, the thermal performance of roof insulation is measured by R-value; and in general, all of these codes and standards recommend R-value levels from between R-20 to R-35 for typical commercial roofs with insulation above the roof deck. Table C provides a summary by climate zone of minimum above-deck R-value levels in the most recent editions of the International Energy Conservation Code and the ASHRAE 90.1 building energy standard.

Table C: Minimum Above-Deck Roof R-Values

(Source: 2015 International Energy Conservation Code / ASHRAE 90.1-2013)

Climate Zone[a]	Example U. S. City	Min. Roof R-Value[b]
1	Miami, FL	20
2	Houston, TX; Phoenix, AZ	25
3	Atlanta, GA; Dallas TX	25
4	Baltimore, MD; St. Louis, MO	30
5	Chicago, IL; Pittsburgh, PA	30
6	Milwaukee, WI; Minneapolis, MN	30
7 & 8	Duluth, MN	35

a. Per ASHRAE 90.1-2013 climate map

b. Roofs with insulation entirely above deck

In addition to designing for at least the minimum amount of roof insulation required by code, it is also important to install the insulation in two layers with staggered joints, in order to limit air infiltration and thermal loss.

Reflective roofs and adjacent surfaces. Some building researchers have reported incidents when the heat and light reflected from a reflective roof may impinge on nearby surfaces such as walls and windows. In some cases, the increased heat on adjacent surfaces appeared to accelerate the aging of the surface; in other cases the reflected light caused an observation of glare through nearby windows.[15] Although the reports to date appear to be limited in scope and anecdotal, it may be prudent for the building or roofing designers to consider the potential for heat and light reflection on adjacent structures during the design stage of any project involving a reflective roof.

Reflective roofs and moisture movement. Some building researchers also have reported incidents where moisture may have condensed and accumulated within reflective roofing systems, mostly in very cold climates. Similar to reports of the effects of reflective roofs on adjacent surfaces, many of the reports of roof condensation are anecdotal and appear to frequently be associated with other roof design or quality issues.[15] For additional information, a recent paper reviewing the issue of roof condensation in reflective roofs is included in the "For More Information" section of this article.

Installing a Reflective Roof: How to Maximize the Benefits

After selecting the best reflective roof for any application, it is also important to maximize the benefits of the roof by minimizing the potential for degradation of the reflective surface finish. In order to achieve an optimal level of reflectivity over the service life of the roof, several strategies should be employed, both during installation and over the service life of the roof.

During installation. The key to maximizing long-term reflectivity during installation involves minimizing the effects of roof traffic. All roofing crew members should wear clean, non-marring shoes, and all construction debris should be removed promptly. Because each and every installation activity may increase the potential for surface degradation, the building designer or installer should consider the use of a pre-assembled roofing membrane that reduces both the time required for installation and the potential to mar the surface during installation.

During use. Just as during installation, the key to maximizing long-term reflectivity during use also involves limiting the effects of roof traffic. To accomplish this, access to the roof should be controlled and limited only to qualified maintenance personnel. And just like the original roofing crew, all maintenance personnel should wear clean, non-marring shoes. Finally, the roof surface should be inspected after storms for damage, and all roof drains should be maintained free of debris that could allow water to accumulate and discolor the roof surface.

For More Information

For the building owner or designer looking to install a reflective roof in the near future, this article should serve as a useful starting point. However, additional information providing a more in-depth look at the issues raised in this article also may be useful. The following documents, all freely available via the internet, are recommended for an expanded understanding of heat islands and the benefits of reflective roofing:

- **EPA Heat Island Home** (http://www.epa.gov/heatisland/index.htm). The U.S. Environmental Protection Agency offers a comprehensive overview of the dynamics of urban heat islands and the role that reflective roofs can play in mitigating their effects.
- **LBL Heat Island Group** (https://heatisland.lbl.gov/). Much of the research work conducted on heat islands by Lawrence Berkeley National Laboratory is available at this site.
- **Global Cool Cities Alliance** (http://www.globalcoolcities.org/). The Global Cool Cities Alliance (GCCA) was launched in 2010 to accelerate a worldwide transition to cooler, healthier cities. Its website offers extensive information about urban heat islands and how cool roofs and cool pavements can help. Especially useful is the GCCA's Cool Roof and Cool Pavement Tool Kit (http://www.coolrooftoolkit.org/read-the-guide/).
- **Recent *Building Envelope* Articles.** Several articles recently published in *Building Envelope* are referenced in this article and provide important information about some of the key issues and opportunities associated with reflective roofs.
  - **Reducing Peak Energy Demand: A Hidden Benefit of Cool Roofs**. This article, published in the spring 2015 edition, provides a detailed review of the peak demand charges currently applied to commercial utility bills and how the use of reflective roofs can reduce these costs. (http://www.buildingenvelopeonline.com/articles/85002-reducing-peak-electrical-demand-hidden-benefit-of-cool-roofs?v=preview)
  - **Roofs and Condensation: A Practical Approach for the Design professional**. This article, published in the summer 2015 edition, provides a comprehensive review of the issue of condensation and reflective roofs and offers detailed recommendations for the building designer to avoid the potential for roof condensation in the design and installation of any roofing system. http://www.buildingenvelopeonline.com/articles/85187-roofs-and-condensation?v=preview

Notes

*Because cool roofs tend to lose some level of reflectivity as they age, the overall energy savings would likely be less than the percentage calculation shown.

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