Energy Efficient
ROOF DESIGN

This Walgreens in Marathon, Florida has a cool roof supplied by Stevens Roofing Systems.

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Successful roof asset management relies on disciplined preventative maintenance to maximize the service life and, ultimately, a well thought out replacement design. When reroofing becomes necessary, the design professional may recommend technology that has a "turn of the century" legacy or materials that became popular since the 1960s. There is no single solution that meets the complicated matrix of performance options each project will require. Therefore, a trade-off of features must be considered that most closely meets the designer's goal.

When discussing the process a designer uses to select the most appropriate roof system, one quickly sees how issues of slope, foot traffic, deck type, regulatory compliance, maintainability, and personal experience drive the thought process. Designers have not had to creatively contend with energy efficiency since the oil embargoes of the 1970s. That shock quickly resulted in each state developing an energy conservation guideline for all structures that were heated and/or mechanically cooled. Code compliance was complicated by a "patchwork quilt" of state energy code mandates.

Industry and Government Energy Conservation Programs

Leadership in building energy conservation has come slowly since the first energy shocks from manufactured oil shortages. However, there have been several important efforts that, when taken together, begin to form a national policy. Work by the Department of Energy and Environmental Protection Agency has resulted in the Energy Star® Program. The American Society of Testing Materials (ASTM) is developing a Solar Reflectivity Index of common building materials. Cool Communities and NASA have raised the Urban Heat Island issue and offered suggestions for its mitigation. The three Model Building Codes have adopted a de facto National Energy Code.

Other work focuses on environmental issues in the use of white and black roof surfaces. The Urban Heat Island is a condition in urban areas where the temperature in the developed city center is up to 6 degrees warmer than the surrounding forested rural areas. Dark construction materials absorb the sun's energy and convert it into heat. That heat energy is radiated back into the neighborhood, increasing cooling costs and adding to air pollution problems.

The National Energy Code

The ASHRAE 90.1 standard, entitled "Energy Standard for Buildings, Except Low-Rise Residential Buildings," was developed in 1972 to serve as an energy standard for the design of commercial buildings. It specifies the minimum requirements for the envelope, lighting, HVAC, and service water heating components. The intent is to implement a single standard that covers nationwide construction. The standard also allows for design trade-off of envelope components to meet the total energy efficiency of the structure. In other words, if walls are not in compliance because of increased window treatments, the roof efficiency can be increased to bring the structure into compliance.

A multi-residence structure in Key West, Florida, shows use of high reflectivity materials by Stevens Roofing Systems.

The Energy Policy Act of 1992 (EPACT) requires all states to adopt an energy code at least as stringent as ASHRAE 90.1. Under the terms of EPACT, the Department of Energy will undertake its own analysis of the revised 90.1 standard to determine if the federal government should adopt the equipment efficiency levels specified therein as national levels for covered products.

The 90.1 standard has generally increased the amount of roof insulation when compared with the older state energy codes. In Atlanta, for example, the old Georgia State Code was met using an R-10 roof assembly, while the ASHRAE standard requires an R-13.85.

ASHRAE 90.1 1999 Standard

The ASHRAE standard is meant to be a living document, undergoing periodic revisions since its 1972 introduction. The 1989 revision has undergone a substantial review and benefited from an extended period of public comment. It was voted out of committee in 1999 and accepted by ASHRAE that same year. The document was published and released to the public in February of 2000. Among the more important roofing-related revisions are:

- Application to building additions and renovations.
- A simplified building envelope section.
- High albedo roof treatments and insulation trade-off.

A high albedo roof, typically white in color and smooth-surfaced, reflects most of the sun's energy from the structure before it is converted into heat energy.

Existing Buildings

One of the more significant adjustments in the 1999 version was the change in scope of Standard 90.1 to include modifications made to existing buildings. This change was made to ensure that the requirements for modifications to existing buildings were the same as for new buildings. The project committee recognized that, in many code jurisdictions, Standard 90.1 was already being applied to existing buildings. The committee considered the impact of this change and worked with consulting engineers and user groups to craft appropriate language for all alterations and additions.

Envelope

The envelope section was completely revised and now contains all of the minimum requirements for both opaque surfaces and fenestration in one table for each of the 26 specific climate zones. This represents a major simplification for the envelope criteria. The criteria have been expanded to include additional assemblies. For the first time, Standard 90.1 contains a true prescriptive option that does not require calculation on the part of the designer. Pre-calculated assemblies are included in Appendix A, and the designer can select the appropriate R-value for the insulation to show compliance. Of course, calculations may still be done to establish the U-factor for a specific assembly if the designer so desires.

Design Options

For the first time the designer can use the solar reflectivity of the roof surface (in addition to insulation R-values) to comply with Sunbelt energy code requirements. This approach was first enacted in the 1995 Georgia White Roof Amendment to the ASHRAE 90.1 1989 standard.

Since most cooling costs are associated with electric fuel and the most common heating fuel is natural gas, high albedo roofs show an economic benefit in northern climates. On a cost-per-BTU basis, electric fuel can be five times the cost of natural gas. It is in the Sunbelt that a combination of high albedo roof surfaces and roof insulation has been shown to be most effective. High albedo roofing lowers cooling energy costs and can mitigate Urban Heat Island conditions. Insulation can maintain a comfortable interior temperature during winter months and cool nights.

The 90.1 1999 Standard builds on the Georgia amendment by extending it across the southern region of the country. By codifying the benefits of a high albedo roof treatment, two important issues are settled: energy savings produced by the solar reflectivity of roofing are proven to be real, and the savings have been quantified.

Perhaps the most frequently asked question was whether the savings continued when the roof became dirty. The Department of Energy and numerous research laboratories confirm the savings are real and can be of long-term benefit.

In non-residential construction, most roof selection decisions are made by absentee owners. Since by definition an absentee owner doesn't benefit from reductions in cooling energy costs, the installed cost drives most decisions. Because the use of a white roof treatment is typically more expensive than black-surfaced roofing, the absentee owner was discouraged from using high albedo roofing by its slightly higher installed cost. Standard 90.1 1999 allows designers to reduce the cost of insulation when a high albedo roof is installed, thus reducing the installed cost. The 90.1 standard acknowledges both insulation and surface color as effective energy conservation tools.

Reductions in roof insulation R-value may be taken for projects in locations that have a relatively mild winter. The 90.1 1999 standard establishes the threshold of 3600 Heating Degree Days (base 65) as the baseline for designers reducing the amount of insulation used in high albedo roof assemblies. These locations have the primary utility costs in mechanically cooling the structure during summer, not in winter heating. The expression "Heating Degree Days" is a measurement of the severity of winter.

Figure 1 shows the four Climate Zones where a reduction can be made in the insulation used in high albedo roof assemblies. The adjustment is the allowable increase in the U-value of the roof assembly. An increase in the U-value is the same as a reduction in the R-value of the roof assembly. (U-value is the reciprocal of the total R-value of the assembly.)

Typical Insulation Reduction

Heating Degree Day Range	Representative City for Each Climate Zone	Adjustment
0-900	Miami, FL	23%
901-1800	San Diego, CA	17%
1801-2700	Dallas, TX	15%
2701-3600	Atlanta, GA	12%

Figure 1

Designing for Energy Efficiency

The ASHRAE 90.1 1999 standard sets the stage for more sophisticated designs of roof assemblies, allowing the most efficient combination of surface color and insulation to achieve either installed cost savings or operating cost savings. Fine tuning the roof design allows the requirements of an absentee owner to be met while the occupant benefits from lower operating costs.

The May 1995 issue of *Interface* journal contained an article titled "Energy Efficient Roof Design" that proposed a methodology for making roof energy analysis. This protocol can be used to estimate the installed and operating costs for roofing in the different ASHRAE climate zones. A comparison can be made between identical roof assemblies that have black and white surfaces. The analysis can determine how much additional insulation R-value is required under a black-surfaced roof to make it equal in energy efficiency to a white roof. A black roof was considered as the "baseline" condition, and added costs for lightening the roof's color had to be calculated.

Cost for Color and Insulation R-Value	
Product Type	**$ Insulation cost/R s.f.**
Expanded polystyrene (1 pcf)	0.02
Isocyanurate	0.04
Extruded polystyrene	0.05
Wood fiber	0.07
Glass fiber	0.09
Perlite	0.09
$ Cost of Lightening Color s.f.	
White membrane	0.15
Gravel in bitumen flood coat	0.30
White acrylic coating	0.50

Figure 2

The suggested methodology for examining the economic trade-off is as follows:

1. Calculate the estimated cost for two identical assemblies where the only variable is the surface color of the roofs. The ASHRAE 90.1 1999 standard R-values are used for the roof assembly.
2. Determine how much additional R-value would be necessary in the dark-surfaced roof assembly to provide equivalent energy efficiency to the lighter-surfaced roof.
3. Calculate the cost of the additional R-value needed as part of the dark-surfaced roof. Calculate the cost of a light color for the white system. Refer to *Figure 2* for estimated costs or use local market costs for greater accuracy.
4. To determine the job cost, multiply the cost-per-R or the added cost for a white surface by the roof area. The cost difference provides an estimated savings for insulation vs. color.
5. A financial analysis can complete the review by examining the Return on Investment (ROI), Net Present Value (NPV), or other recognized financial modeling technique.

Assumptions for the Energy Analysis

If we consider a new construction project and compare a white-surfaced roof to the same assembly with a black-surfaced roof, the impact of color on heating and cooling costs can be evaluated. The U-value of the roof assembly is based on the 90.1 standard for each location. The following factors are used in the analysis:

1. 50,000 sf (4,647 sm) roof area
2. 10-year analysis term
3. 75ºF (24ºC) inside air temperature
4. 70ºF (21ºC) inside winter temperature
5. $0.10 per KWH cost of electricity for cooling
6. $ 0.58 CCF (hundred cubic feet) cost of natural gas for heating
7. Five percent yearly inflation rate in energy costs
8. White roof reflectivity stabilizes at 60%, and the black roof stabilizes at 30% after the first year
9. Roof insulation R-value is one component in the total R-value for the roof assembly

The following examples for a building located in Miami, Florida (*Figure 3*), and Atlanta, Georgia (*Figure 4*), show R-values for roof insulation and surface color according to the 90.1 1999 Standard. The first energy cost column uses the same insulation R-value for a white and black roof and shows the energy cost difference. The second energy cost column shows the change in energy cost savings by taking the insulation trade-off allowed by the ASHRAE standard, comparing a white and black roof. Note the high albedo roof shows cost savings in each condition.

Miami, Florida Comparison				
Detail	**Insulation R-Value**	**Energy Cost****	**Adjusted R**	**Energy Cost**
Black*	12.22	$197,788	12.22	$197,778
White	12.22	$100,188	9.15	$130,166
Savings		$97,600		$67,612

* The energy analysis determined that the black-surfaced roof needs an additional R-12.98 (R-25.2 total) to make it equivalent in energy efficiency with a white-surfaced roof in Miami, Florida.
**10-year energy cost

Figure 3

Atlanta, Georgia Comparison				
Detail	**Insulation R-Value**	**Energy Cost****	**Adjusted R**	**Energy Cost**
Black*	12.78	$108,103	12.78	$108,103
White	12.78	$72,972	11.11	$182,952
Savings		$35,131		$25,151

* The energy analysis determined that the black-surfaced roof needs an additional R-6.68 (R-19.46 total) to make it equivalent in energy efficiency with a white-surfaced roof.
**10-year energy cost

Figure 4

Economic Analysis White vs. Black Over R-13.33 Roof Assembly (Inside Air to Outside Air)

MIAMI

12.98	Added insulation R-value needed under black roof
x 0.04	Cost per R for isocyanurate insulation
$ 0.52	Cost per sf for added insulation
x 50,000	Square foot of roof area
$25,950	Total cost for added isocyanurate insulation under the black roof
$0.15	Cost per sf for white surface membrane
x 50,000	Square foot of roof area
$7,500	Total cost for white surface membrane
$25,950	Total cost for added isocyanurate insulation
- 7,500	Total cost for white surface membrane
$18,450	Estimated savings with a white, high-albedo roof over a ten-year term

In Atlanta, the energy analysis still shows savings using a high albedo roof; however, the summer vs. winter condition is not as dramatic as in the Miami example. The savings are smaller, and the additional insulation needed to make the black and white roofs equivalent in energy efficiency is less than in the Miami example. This trend continues as the examples are cited in increasingly cooler climates.

Economic Analysis White vs. Black Over R-13.33 Roof Assembly (Inside Air to Outside Air)

ATLANTA

6.68	Added insulation R-value needed under black roof
x 0.04	Cost per R for isocyanurate insulation
$ 0.27	Cost per sf for added insulation
x 50,000	Square foot of roof area
$13,350	Total cost for added isocyanurate insulation under the black roof
$0.15	Cost per sf for white surface membrane
x 50,000	Square foot of roof area
$7,500	Total cost for white surface membrane
$13,350	Total cost for added isocyanurate insulation
- 7,500	Total cost for white surface membrane
$5,850	Estimated savings with a white, high-albedo roof over a ten-year term

Analysis Results

The economic impact in each design results in cost savings using high albedo roofing. When ASHRAE 90.1 1999 insulation adjustments are taken with the high albedo roof, there is an operating cost savings to the occupant, and the absentee owner reduces the installed cost of the roof system.

In Atlanta, the owner can eliminate approximately 50 percent of the cost difference between the white-surface, high-albedo roof and the black-surface roof. The Miami adjustment eliminates approximately 80 percent of the cost difference. The energy cost savings result because the cost of cooling is up to five times greater than the cost of heating, on a BTU basis.

Summary

The analysis protocol used in this article is intended to examine the economic comparison of white, high-albedo roofs and black-surface roofs. In the Sunbelt, a balanced combination of high albedo roof treatment with insulation R-value can provide significant economic benefits for both owner and occupant. The new ASHRAE 90.1 1999 Standard allows the design of the roof assembly to benefit both parties while maintaining code compliance. ■

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Global Hydrology and Climate Center, *www.ghcc.msfc.nasa.gov*
Studies of the Urban Environment and Urban Heat Island

JPS Stevens Roofing Systems, *http://www.stevensroofing.com*
Multiple links to websites featuring energy efficiency

National Aeronautical Space Administration (NASA)/
Marshall Earth Science, *www.ssl.msfc.nasa.gov/newhome/headlines/essd08may97_1.htm*
Project Atlanta Urban Heat Island

National Climatic Data Center, *www.ncdc.noaa.gov*
Information on climate, geophysical and oceanographic data.
Archived weather data for US locations.

Oak Ridge National Lab, *www.ornl.gov/roofs+walls*
Zip code R-value recommendations.
Moisture control in low slope roofs.

Pacific Northwest National Labs, *www.pnl.gov*
Review of the ASHRAE 90.1 energy efficiency standard

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US Department of Energy, *www.doe.gov*

Environmental Protection Agency, *www.energystar.gov*
Energy Star roof products program Tel: (888) STAR-YES

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Patrick L. Downey, RRC, CDT, is president of Merik Inc., an Atlanta-based roof consulting firm specializing in reroofing problem solving. Downey is an RRC and chair of the Bylaws Committee with RCI, where he has also been a speaker at Building Envelope Symposia and an instructor in the Advanced Roof Consulting courses. He is on the Board of Directors of the Atlanta Chapter of CSI from which he received the CSI Advancement of Construction Tech nology Award. Merik has developed and markets the ROOFCALC software, which addresses specialized areas of roof analysis. Downey has 22 years of experience in the construc tion industry, including a product development specialist with W. R. Grace Co. and national sales manager with Benoit Inc. and Semperit. He is on the Atlanta Steering Committee for Cool Communities and is past president of the Georgia Chapter of RCI.