Preliminary Analysis of Energy Consumption For Cool Roofing Measures

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Abstract

The spread of cool roofing has been more than prolific over the last decade. Driven by public demand and by government initiatives, cool roofing has been a recognized low cost method to reduce energy demand by reflecting sunlight away from structures and back into the atmosphere. By use of commonly available calculators, one can analyze the potential energy savings based on environmental conditions and construction practices. This article summarizes the results of a study based solely on simulation results from a new Oak Ridge Laboratory Roof Savings Calculator, which is currently in its beta version. The calculator's findings differ from the savings reported by other established cool roof studies.

History of Reflective Roofing

For more than 30 years, roof coating products have been available to the roofing market in the form of asphaltic-based mastics and coatings, emulsion coatings, fibered and non-fibered aluminum, acrylic coatings, polyurethanes, polyureas, epoxies, methyl methacrylates, and polyvinylidene difluorides, to name more than a few. For just as many years, modified bitumen membranes have existed in the form of mineral, smooth, foil-faced, and film-surfaced with base chemistries of SBS, APP, and a variety of other chemistries. There are single ply options (such as EPDM, TPO, KEE, and PVC) and metal options, most notably, standing seam solutions in a myriad of colors. Built up roofing systems with asphalt or tar, cold or hot applied, with aggregate or mineral surfaces are also prevalent. Each product has its specific advantages, performance attributes, economic impact, life-cycle expectations, and limitations.

Give these facts, product selection and design decisions can be highly complex and, in some cases, risky. It is therefore critical to work with industry experts, roofing professionals, and reputable companies when selecting a roofing solution. Furthermore, using independent agencies (like ASTM, UL, FM, CRRC, CCMC, DIE, etc.) or independent test laboratories to assist in verifying quality and performance helps to validate product claims and performance. New and existing qualifying agencies (such as IBC, USGBC-LEED, IgBCC, CEC, ASHRAE, etc.) help building owners and facility managers make appropriate decisions by offering design requirements and establishing building codes. Over the last decade, much of the development, design, and code alterations have focused on enhancing overall construction sustainability, the use of green product solutions, and an emphasis on cool roofing solutions.

The cool roofing initiative was the result of studies performed in the 1980's establishing a phenomenon known as the urban heat island effect. As best described, the urban heat island effect is the thermal property of metropolitan areas to remain hotter longer than areas of less building density as shown in Figure 1.

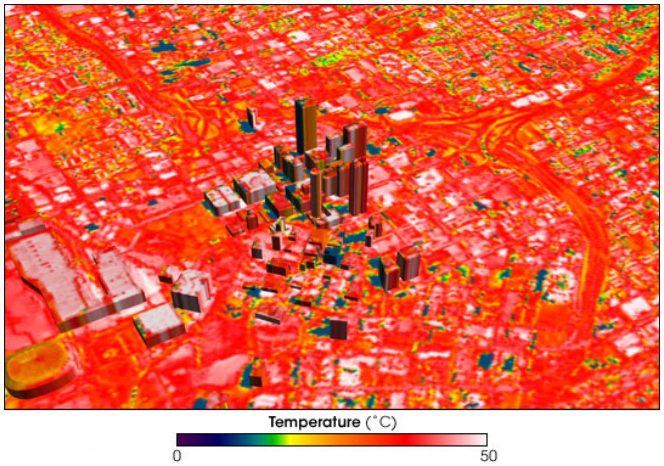


Figure 1. Thermal, infared image of downtown Atlanta, GA

The infrared photo shows that the occupied areas in and around downtown Atlanta stay hotter longer, not only affecting the nearby environment, but also driving up energy costs to cool the interiors of the building. Academic studies and discussions regarding how to solve these issues include creating more green space, replacing parking lots with grass surfacing, utilizing the roof top as a passive solar heater, additional shading for window designs, and finally the reduction in black surfaces by removing dark surfaced roofs, roads, and parking facilities and replacing them with more reflective surfaces.

Basis for Energy Savings – Energy Calculators

There are a variety of calculators available for public use. In most cases, users have the ability to input data for a broad group of variables including but not limited to location, facility use, HVAC efficiencies and type, product selection, reflectivity, emissivity, and level of insulation. Based upon the information provided, the calculator uses mathematical models that return energy usage based on specific climatic conditions for the selected location. The most common environmental conditions used in typical analysis are solar irradiance, cooling degree days, and heating degree days.

Cooling degree day is a measurement designed to reflect the demand for energy needed to cool a building to a baseline temperature of 65°F (approximately the zero house load temperature), while heating degree days relate to the amount of energy necessary to heat a building to 65°F. Maps shown in Figure 2 outline the cooling degree days and heating degree days for locations throughout the United States.

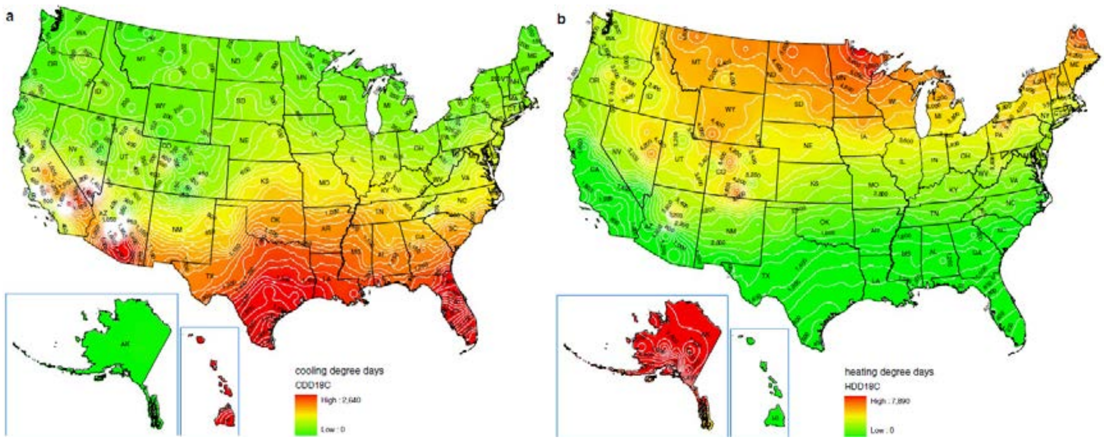


Figure 2. Maps of (a) annual cooling degree days (CDD18C), and (b) annual heating degree days (HDD18C) computed from NREL TMY2 typical meteorological year data (NREL 2007)

Intuitively, Houston (HDD=1500, CDD=3000) would spend more days cooling their buildings versus heating their buildings; conversely, in Minneapolis (HDD=8000, CDD=500), more days require heating versus cooling.

The solar irradiance is a measure of the amount of solar radiation that is received at a specific location. Again the climatic conditions are quite obvious. Hotter climates like Phoenix have higher solar irradiance than a more temperate climate like Chicago.

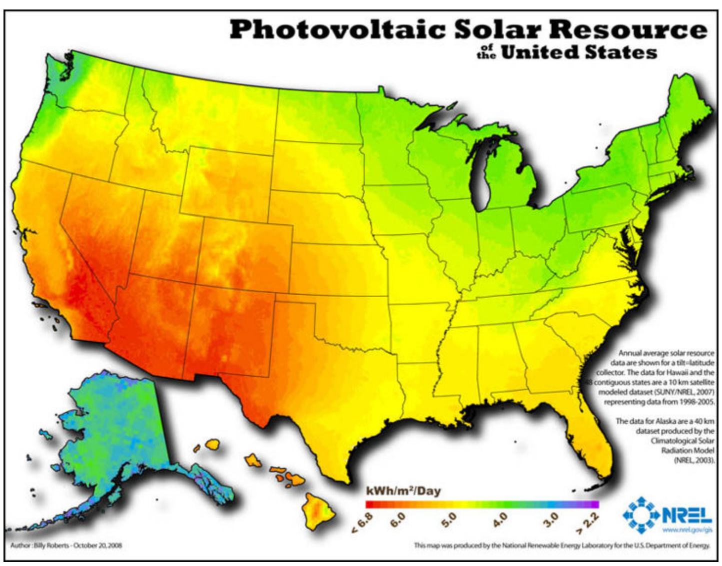


Figure 3. U.S. Direct Normal Solar Radiation

By combining such environmental factors with building-specific inputs (such as reflectivity, level of insulation, etc.), one can use the algorithmic simulation engines of these calculators to generate energy consumption figures. By systematically comparing different simulation conditions, one can calculate the potential savings created by making specific construction changes to the roofing system.

For the purposes of this discussion, the Roof Savings Calculator hosted at the Oak Ridge National Laboratory was used to establish all data. This, among several calculators, is a well-recognized standard in the industry and allows for input and manipulation of a wide range of the most common building-specific variables.

Environmental Legislation

Much of the country has appropriately adopted cool roofing practices by increasing insulation or increasing the use of reflective surfacing. For example:

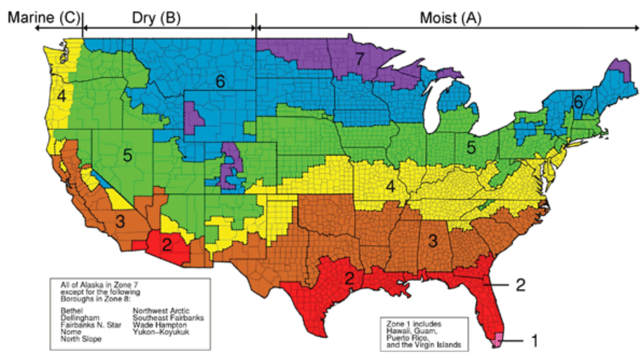


Figure 4. U.S. map of ASHRAE climate zones.

ASHRAE Standard 90.1 allows reduced insulation if cool roofing is used in Zones 1, 2, and 3. Cool roofing is defined as a reflectivity of 70% and an emissivity of 0.75 (SRI of 83). ASHRAE 90.2 Energy Efficient Design of Low-Rise Residential Buildings allows for reduced insulation for a reflectance level of 0.65 (SRI 75).

LEED provides credit for the use of reflective coatings (higher than 78 SRI) in all areas.

Many states, locations and power authorities provide credits, rebates, and incentives to utilize reflective systems. A lengthy list of these opportunities can be found on the CRRC (Cool Roof Rating Council) website at http://www.coolroofs.org/codes_and_programs.html#rebate.

You will note, upon the review of the information on the link above, that there are more than a number of temperate or cool climates that provide incentives (or requirements) for cool roofing, for example, Idaho, Ohio, Colorado, Illinois and Minnesota. It is important to note that consumers who choose reflective roofing solution may not receive the same financial benefit, as a result of energy savings, that they might in warmer climates.

Experimental Design

The following experiment represents a snapshot of a selected matrix of data for various building types and locations. This study is based solely on the beta version of the RSC v0.93. While DOE-2.1E and AtticSim ASTM Standard C 1340-04 have been validated with comparison to empirical data, the integrated RSC engine has not. Furthermore, it is known to have discrepancies with previous cool roofing studies, based on engines that didn't incorporate heat transfer through radiation within the attic assembly, which is yet to be reconciled.

In an effort to represent a variety of U.S. geographic locations, nine cities were selected. Both standard ASHRAE climate zone cities as well as several cities that have standing reflective roofing codes were included in the study. The selected list of cities can be seen in Table 1.

Table 1. Cities (weather data) used in this study.

City	ASHRAE Climate Zone	Standing Reflective Roofing Codes
Miami, FL	1A	
Austin, TX	2A	
Houston, TX	2A	
Phoenix, AZ	2B	Yes
Atlanta, GA	3A	
Los Angeles, CA	3B-CA	Yes
San Francisco, CA	3C	Yes
Kansas City, MI	4A	
Baltimore, MD	4A	
New York	4A	Yes
Chicago, IL	5A	Yes
Minneapolis, MN	6A	
Fargo, ND	7A	
Fairbanks, AK	8	

The building size selected was 40,000 ft2 and the type of facility used was classified as "office." Office was selected because it generally yields the highest return on energy savings when a reflective coating is employed. Heating and cooling costs were imported based on values taken from the U.S. Energy

Information Administration (December 2011). Values were input as shown in Figure 5 for creating the ensemble of simulations and analyze potential energy savings.

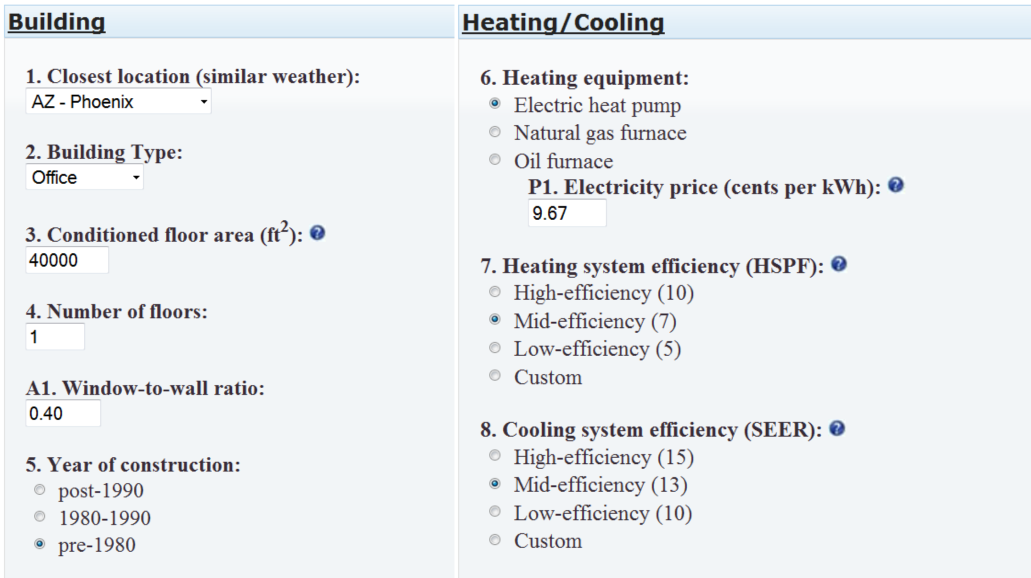


Figure 5. Screenshot of the Roof Savings Calculator input variables.

The final step in all cases was to enter non-variant data such as the base line data, which in all cases was:

- A Black (non-reflective) Built Up Roof System with 10% Reflectance and Emissivity of 0.90
- R-19 Insulation
- No Above-Sheathing Ventilation
- Low Slope (<= 2:12)
- No Radiant Barrier
- Duct Location in Conditioned Space

The data used represents the most common values for the U.S. building stock. The final step in this experimental design was the input of the higher reflectivity coatings and materials to conduct the energy savings calculations, relative to a common baseline built up roof. All data was compiled by Oak Ridge National Laboratory and reflects the calculated saving expected.

Table 2. Electricity and gas costs used in this study as retrieved from the U.S. Energy Information Administration database.

Location	Electricity, cents/kWh	Gas, $/1000ft3
New York	17.47	12.61
Los Angeles	15.14	9.21
Chicago	11.08	7.75
Houston	11.01	8.43
Miami	11.51	17.00
Phoenix	9.98	13.01

Kansas City	8.29	10.05
Minneapolis	10.37	7.76
San Francisco	15.14	9.21
Austin	11.01	8.43
Atlanta	10.06	14.23
Baltimore	13.44	11.85
Fargo	7.26	7.38
Fairbanks	16.55	8.43

Table 3. Comparison roof surface properties using listed products on the Cool Roofing Rating Council website. Calculated SRI is derived from the formulas found in ASTM E 1980, using calculation-3 with medium convection currents.

Description	Reflectance	Emissivity	SRI
BUR No Coating	10	90	6
Mineral Mod Bit	25	88	25
Single Ply	32	90	35
Mineral Mod Bit	33	92	35
Metal	35	82	35
Aluminum Coating over BUR	43	58	35
Mineral Mod Bit	45	79	55
Coating over BUR	49	83	55
Metal	49	83	55
Aluminum Coating over BUR	55	45	48
Mineral Mod Bit	63	88	75
Coating over BUR	63	86	75
Metal	63	84	75
Single Ply	64	80	75
Aluminum Coating over BUR	65	45	65
Metal (White)	70	85	85
Coating over BUR (White)	75	90	93
Single Ply (White)	76	87	94
Coating over BUR (White)	79	90	100
Mineral Mod Bit (White)	81	80	100
Single Ply (White)	82	79	100
Coating over BUR (White)	85	90	107
Single Ply (White)	85	87	107

Results

Table 4 below describes the results as derived through the use of the Roofing Savings Calculator (RSC) beta version 0.93. Given the lack of empirical validation, savings according to the old DOE Roof Calculator is provided in Table 5.

Table 4. Annual energy cost savings (in US dollars) over a 10% reflective built-up roof based on Roof Savings Calculator

Description	Reflectance	Emissivity	SRI	New York	Los Angeles	Chicago	Houston	Miami	Phoenix	Kansas City	Minneapolis	San Francisco
BUR Aggregate	10	0.90	19	0	0	0	0	0	0	0	0	0
Mineral Modified Bitumen	25	0.88	25	-398	60	-219	-33	36	-50	-224	-255	-208
Aluminum Coating Aged	55	0.45	48	67	505	78	255	265	300	128	74	162
Aluminum Coating	65	0.45	65	-132	915	21	408	524	438	33	-63	-87
White Metal	70	0.85	85	-2090	1216	-855	305	983	46	-963	-1339	-1914
White Coating Aged	75	0.90	93	-999	1518	-330	637	1235	406	-489	-737	-1426
White Single Ply Aged	76	0.87	94	-1097	1504	-389	615	1235	350	-546	-811	-1504
White Coating	85	0.90	107	-1195	1073	-410	778	1540	471	-599	-935	-1906
White Single Ply	85	0.87	107	-1277	1674	-463	744	1515	410	-648	-994	-1950
Mineral Modified Bitumen	33	0.92	35	-602	328	-299	-2	226	-2	-328	-396	-446
Mineral Modified Bitumen	45	0.79	55	-639	554	-301	96	359	96	-323	-418	-479
Mineral Modified Bitumen	63	0.88	75	-1117	1165	-460	180	876	180	-559	-770	-1204
Mineral Modified Bitumen	81	0.80	100	-1374	1574	-528	323	1333	323	-689	-1013	-1841
Metal	35	0.82	35	-1287	-32	-636	-45	-29	-45	-554	-698	-107
Metal	49	0.83	55	-1623	-453	-729	18	340	18	-704	-938	-741
Metal	63	0.84	75	-1934	985	-808	51	755	51	-864	-1192	-1488
Single Ply	32	0.90	35	-313	293	-146	34	204	34	-172	-218	-282
Single Ply	64	0.80	75	-767	1170	-276	287	837	287	-363	-530	-890
Single Ply	82	0.79	100	-1113	1632	-380	433	1355	433	-544	-839	-1631
Coating	43	0.58	35	81	262	61	175	133	175	101	72	154
Coating	49	0.83	55	-413	759	-142	228	508	228	-189	-277	-426
Coating	63	0.86	75	-716	1203	-236	331	873	331	-335	-496	-899
Coating	79	0.90	100	-1076	1604	-358	432	1353	432	-532	-812	-1608

Table 5. Annual energy cost savings (in US dollars) over a 5% reflective built-up roof based on DOE Roof Calculator

Description	Reflectance	Emissivity	SRI	New York	Los Angeles	Chicago	Houston	Miami	Phoenix	Kansas City	Minneapolis	San Francisco
BUR Aggregate	5	0.90	0	0	0	0	0	0	0	0	0	0
Mineral Modified Bitumen	25	0.88	25	120	80	-80	440	1040	720	200	-40	-120
Aluminum Coating Aged	55	0.45	48	520	400	360	1000	1760	1240	640	360	200
Aluminum Coating	65	0.45	65	560	440	280	1240	2320	1600	760	320	120
White Metal	70	0.85	85	400	280	-360	1440	3480	2360	680	-160	-360
White Coating Aged	75	0.90	93	400	280	-440	1600	3880	2640	680	-240	-440
White Single Ply Aged	76	0.87	94	400	320	-440	1600	3880	2640	720	-200	-440
White Coating	85	0.90	107	440	320	-520	1840	4440	3000	800	-280	-520
White Single Ply	85	0.87	107	480	360	-480	1800	4360	2960	800	-240	-480
Mineral Modified Bitumen	33	0.92	35	160	120	-200	640	1600	1080	280	-80	-200
Mineral Modified Bitumen	45	0.79	55	280	200	-80	880	1960	1360	440	0	-120
Mineral Modified Bitumen	63	0.88	75	360	240	-320	1320	3160	2160	600	-160	-360
Mineral Modified Bitumen	81	0.80	100	480	360	-360	1720	4000	2720	800	-160	-360
Metal	35	0.82	35	200	160	-40	640	1480	1000	320	0	-80
Metal	49	0.83	55	280	200	-160	960	2280	1560	480	-40	-200
Metal	63	0.84	75	360	280	-280	1280	3080	2080	600	-120	-320
Single Ply	32	0.90	35	160	120	-160	600	1480	1000	280	-80	-160
Single Ply	64	0.80	75	400	280	-240	1320	3040	2080	600	-80	-280
Single Ply	82	0.79	100	480	360	-360	1720	4000	2720	800	-160	-360
Coating	43	0.58	35	400	320	240	760	1400	960	480	240	120
Coating	49	0.83	55	280	200	-160	960	2280	1560	480	-40	-200
Coating	63	0.86	75	360	240	-320	1280	3120	2120	600	-120	-320
Coating	79	0.90	100	400	320	-480	1680	4080	2760	720	-240	-480

The results were not surprising: in the climates where CDD's greatly exceeded HDD's, a reflective surface was financially preferable to a non-reflective surface. Conversely, in cooler or moderate climates where HDD's were in excess of CDD's, a less reflective surface provided the best financial savings. For each surface condition, the savings over a specified standard of an aggregate surfaced BUR with 10% reflectance and 0.90 emissivity (for a calculated SRI of 6) is listed in Table 5.

Much of the data indicated that either minimizing the SRI or maximizing the SRI would provide the maximized savings benefit as seen in Figure 6. Cubic curve-fitting equations used in this study were calculated using the Cubic Equation Calculator. Higher-resolution and data analysis would further indicate that the local optimums exist while demonstration buildings could be used to validate this behavior.

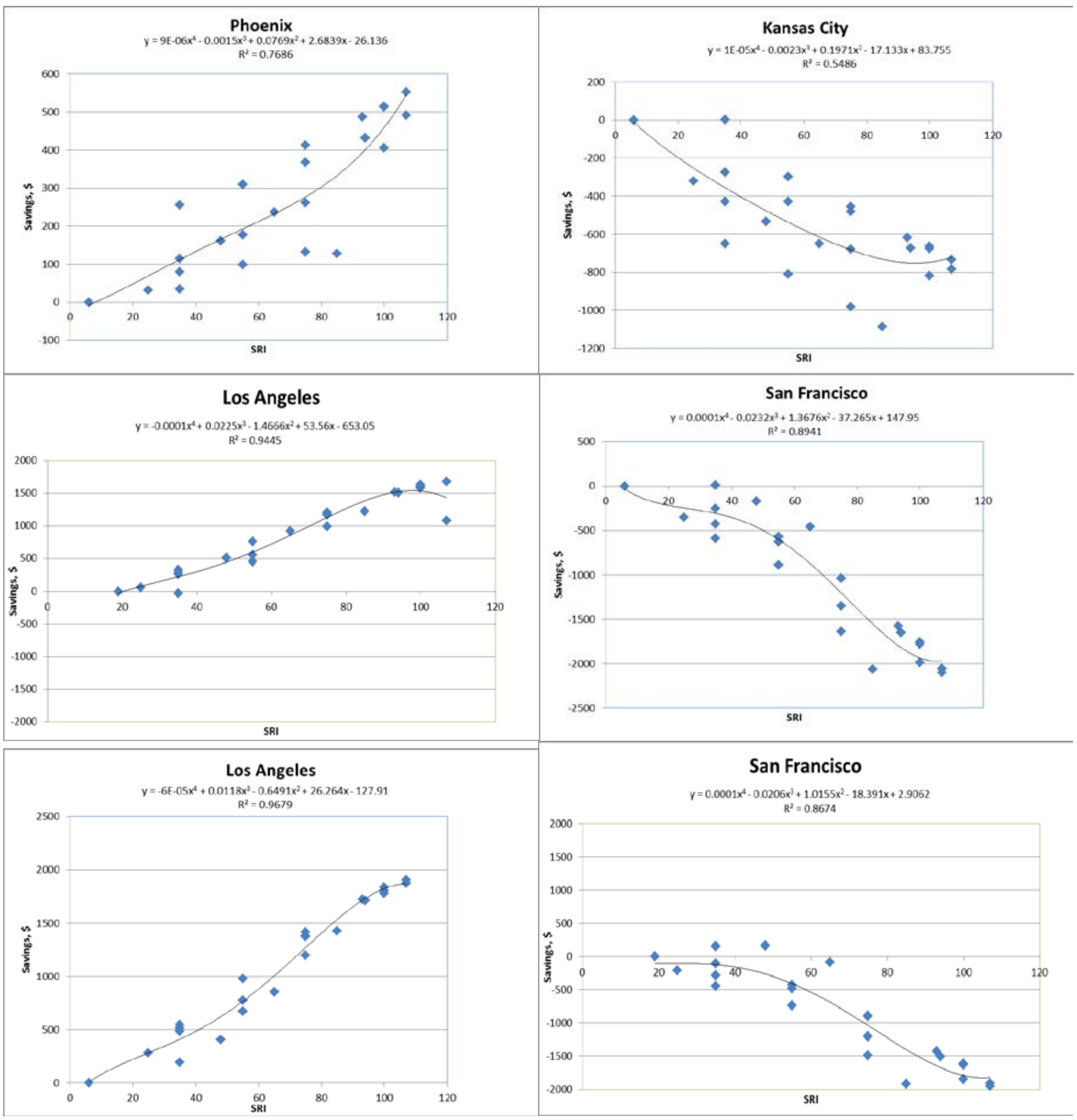


Figure 6. Cost savings over a 10% reflective built up roof for several cities as a function of SRI. Curves for Kansas City (a) and Phoenix (b) show opposing slopes to the relationships of SRI to savings. Several curves show localized maximums for performance such as those for Los Angeles (c) and San Francisco

(d). The anticipated behavior at the extrema of SRI values for heating- or cooling- dominated climates is shown in (e)-(f).

Based on the previous analysis comparing savings to 10% reflectance and 90% emissivity, we established SRI values for maximum savings performance. Specifically where curves indicated a minimum desired SRI, a value of six was used. For observations where a maximum SRI appears to be optimal, a 107 value was used.

Table 6. Maximized energy savings and SRI for the best observed material system (BOMS) at each location.

Location	Observed Optimized Condintion	Trend Desired SRI	Maximum Observed Savings, $	Best Observed System	Related SRI
Atlanta	Minimized	6	45	Aluminum Coating over BUR	35
Austin	Maximized	107	499	Coating over BUR (White)	107
Baltimore	Minimized	6	2	Aluminum Coating over BUR	35
Chicago	Minimized	6	0	BUR No Coating	6
Fairbanks	Minimized	6	0	BUR No Coating	6
Fargo	Minimized	6	0	BUR No Coating	6
Houston	Maximized	107	863	Coating over BUR (White)	107
Kansas City	Minimized	6	2	Aluminum Coating over BUR	35
Los Angeles	Maximized	107	1905	Coating over BUR (White)	107
Miami	Maximized	107	1686	Coating over BUR (White)	107
Minneapolis	Minimized	6	0	BUR No Coating	6
New York	Minimized	6	0	BUR No Coating	6
Phoenix	Maximized	107	553	Coating over BUR (White)	107
San Francisco	Minimized	6	10	Aluminum Coating over BUR	35

If we examine the difference between the HDD's and CDD's for each location, versus the Optimized SRI (O-SRI), we find that there appears to be a logical break between areas where a highly reflective system would be desired and where lower SRI products would be more appropriate.

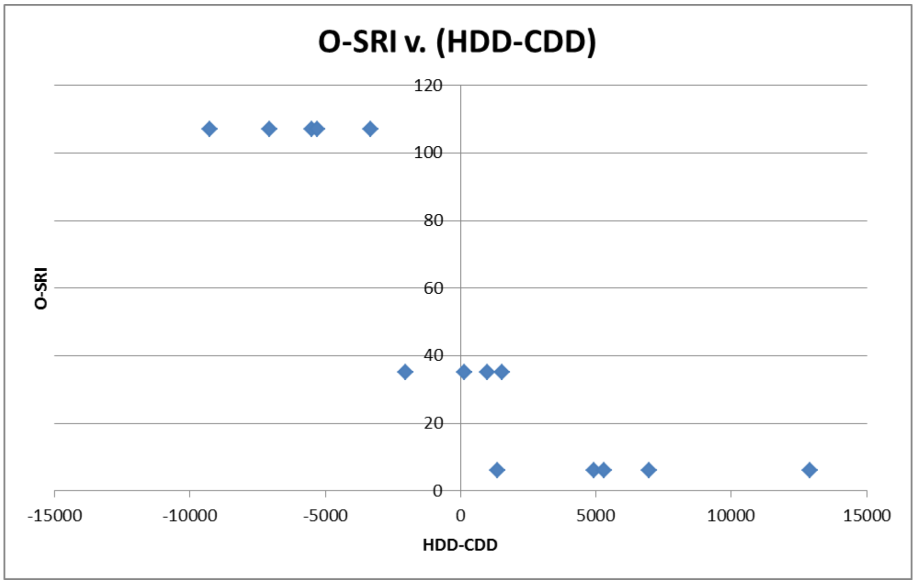


Figure 7. Optimized SRI (O-SRI) as a function of difference betwee HDDs and CDDs for a given location.

There appears to be a logical break between areas where a highly reflective system would be desired and where lower SRI products would be more appropriate, as shown in Figure 7. This break occurs based on climatic conditions at the transition between a dominance of HDD over CDD. For conditions where HDD's are in excess of CDD's (or where the CDD's are greater than HDD's by more than 3000), the optimum SRI is below 40. Conversely, in areas where CDD's are in excess of HDD's, an SRI in excess of 100 is desirable. This would seem intuitive, but is critical in understanding the function and benefit of alternative surfaces.

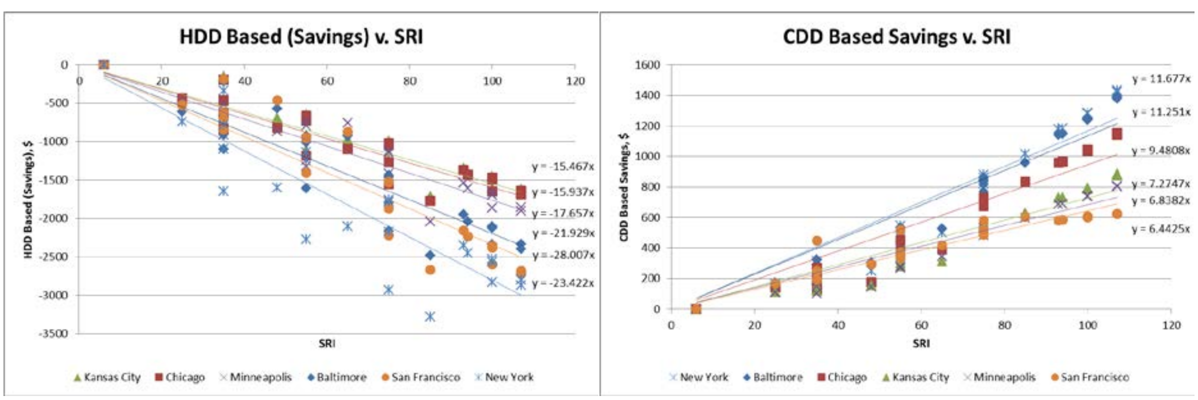


Figure 8. Energy savings and losses as a function of SRI for several cities.

Examining the calculated energy savings (or losses) versus SRI for temperate climates, it can be seen in Figure 8 where the calculated slope of increased cooling savings is less than the slope of the calculated losses for heating demand. In temperate zones, the losses attributed to additional heating demand outweigh the benefit of cooling savings. Internal loading (common in office buildings or retail stores) can affect these results and the current modeling engine is rather conservative regarding internal load for such buildings.

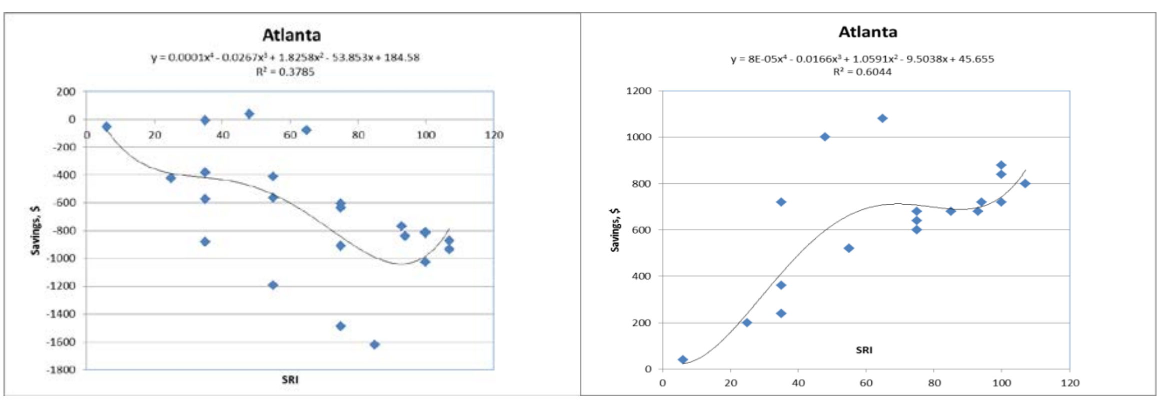
Alternative Calculations

Table 7. Comparison of the existing simulation-based DOE Roof Savings Calculator (RSC) and the previous, demonstration data-driven DOE Cool Roof Calculator

Location	Observed Optimized Condintion	Trend Desired SRI	Maximum Observed Savings, $	Best Observed System	Related SRI	Slope Difference
Atlanta	Maximized	107	1080	Aluminum Coating over BUR	65	Reversed
Austin	Maximized	107	2680	Coating over BUR (White)	107	Same
Baltimore	Maximized	107	1000	Single Ply White/Coating over BUR (White)	103.5	Reversed
Chicago	Modal	64.95	360	Aluminum Coating over BUR	48	Same
Fairbanks	Modal	42.68	680	Aluminum Coating over BUR	48	Same
Fargo	Modal	40.58	160	Aluminum Coating over BUR	48	Same
Houston	Maximized	107	1840	Coating over BUR (White)	107	Same
Kansas City	Maximized	107	800	Coating over BUR (White)	107	Reversed
Los Angeles	Maximized	107	440	Aluminum Coating over BUR	65	Same
Miami	Maximized	107	4440	Coating over BUR (White)	107	Same
Minneapolis	Modal	47.05	360	Aluminum Coating over BUR	48	Same
New York	Maximized	107	560	Aluminum Coating over BUR	65	Reversed
Phoenix	Maximized	107	3000	Coating over BUR (White)	107	Same
San Francisco	Modal	39.31	200	Aluminum Coating over BUR	48	Same

As a method of comparison, the same data set (including all cities and material types) was analyzed using the existing DOE Calculator that can currently be found on the Oak Ridge Website. The DOE Cool Roof Calculator compares a fixed black roof with 10% reflectance and 0.90 emissivity. The compiled data showed similarity but also showed some interesting differences.

Atlanta, Baltimore, Kansas City and New York exhibited contradicting trends between the two calculators. The RSC would indicate that a minimized SRI would be appropriate for the four cities, while the DOE Calculator would favor a maximized SRI value for energy efficiency.



9(a) New DOE (RSC) **9(b) Previous DOE Calculator**

Figure 9. Differences between the new and old roof calculators for Atlanta, GA.

The DOE calculator indicated localized maximums as previously described. Two cities, New York and surprisingly Los Angeles, showed localized peaks at 65 SRI.

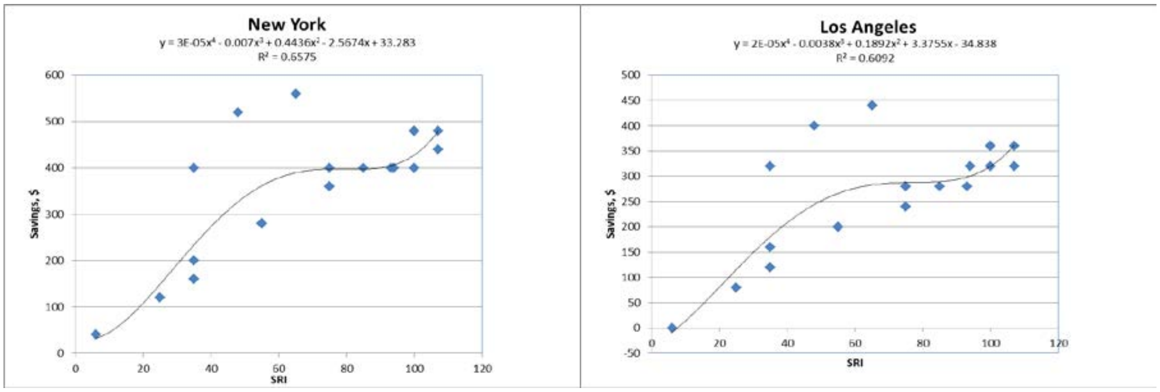


Figure 10. Localized, optimal SRI values for New York and Los Angeles

Conclusions

Cool roofing in the form of reflective surfacing can provide benefit in any climate as a result of:

- Potential reduction in energy costs as a result in reduction in cooling costs
- Reduction in the Urban Heat Island Effect (including increased safety from heat-related illness)
- Reduction in Roof Top Temperature, reducing the rate of aging of the overall roofing system
- Reduction of the strain on power demand related to facility air conditioning
- Increased reflectance of the earth surface to mitigate climate change

However, it is important to note that based on acceptable industry standard calculations in the current business environment, static reflective roofing does not provide an energy cost savings in cooler or temperate climates. In fact, it can be detrimental to overall energy costs to employ roofing with high SRI values. Clients should consider a broad range of solutions when selecting the environmental surfacing and should not be misled by potential savings. Using available tools, building owners, architects, and facility managers can select the appropriate and best product for overall function.

A complete set of data and charts can be obtained by visiting http://gartalk.garlandco.com/Industry-Trends. The Roof Savings Calculator (RSC) used in this study is in beta version, known to have differences in reported savings compared to established cool roof studies, and is undergoing software and empirical validation during FY13.

Glossary

APP	Attactic Polypropylene
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning
ASTM	American Society for Testing and Materials
CCMC	Canadian Construction Materials Centre
CEC	California Energy Commission
CRRC	Cool Roof Rating Council

EPDM	Ethylene Propylene Diene Monomer (M-Class)
FM	Factory Mutual
IBC	International Building Code
IgBC	International Green Building Code
KEE	Ketone Ethylene Ester
PVC	Polyvinyl Chloride
SBS	Styrene Butadiene Styrene
TPO	Thermoplastic Polyolefin
UL	Underwriter Laboratories
USGBC-LEED	United States Green Building Council – Leadership in Energy and Environmental Design

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