LBNL-51895

Cool Roofs as an Energy Conservation Measure for Federal Buildings

A document prepared for the
Federal Energy Management Program of the
U.S. Department of Energy

Haider Taha and Hashem Akbari
Heat Island Group
Lawrence Berkeley National Laboratory
Berkeley, California 94720

April 2003

TABLE OF CONTENTS

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Federal Energy Management Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LIST OF TABLES

GLOSSARY

Albedo (α): For a flat surface, albedo is hemispheric- and wavelength-integrated reflectivity. Thus whereas reflectivity (see below) is the ratio of reflected to total incident radiative flux at a particular wavelength, albedo, by definition, encompasses a range of wavelengths of interest. In this document, we are interested mostly in solar albedo with an integral over the portion of the solar spectrum between about 0.3 and 3.0 μm. In this report, the terms “albedo” and “solar reflectance” are used interchangeably.

Absorptivity: The ratio of radiative flux absorbed at a certain wavelength to the total incident radiative flux.

Emissivity: The ratio of radiative flux emitted at a certain wavelength and temperature to that emitted by a black body under the same conditions.

Emittance: This is emissivity integrated over a certain wavelength range of interest.

Reflectivity: The ratio of radiative flux reflected at a certain wavelength to the total incident radiative flux.

Solar reflectance: In this document, it is defined as reflectivity integrated over the solar spectrum.

Solar absorptance (a): In this document, it is defined as absorptivity integrated over the solar spectrum.

SUMMARY

The objective of this document is to develop initial estimates, for the Federal Energy Management Program, of the potential benefits of cool roofs on federal buildings and facilities as well as to extrapolate the results to national scale. In this document, regression equations are provided for use in estimating the energy and cost savings of cool roofs in specific federal building types and selected locations. In addition, the equations are also applied on a national basis to estimate nationwide savings. This will provide FEMP with a rationale for encouraging the use of this technology.

Thus along with this document, a preliminary spreadsheet "calculator" was devised to help FEMP estimate potential energy and cost savings of cool roofs (the calculator is on the floppy disk attached to this document). Entries in this calculator can be constantly updated as more region- and building-specific information becomes available. This document and companion calculator thus represents an initial step towards longer-term modeling of the potential benefits and implementation of cool roofs in FEMP facilities. In such possible future studies, specific Federal buildings may be analyzed and studied.

Based on the companion calculator, and for an average nation-wide insulation level of R-11 for roofs, it is estimated that nationwide savings in energy costs will amount to \$16M and \$32M for two scenarios of increased roof albedo (moderate and high), respectively. These savings correspond to about 3.8% and 7.5% of the base energy costs for FEMP facilities and include the increased heating energy use (penalties) in winter. This document also uses the cost of conserved energy (CCE) as a metric for assessing the cost effectiveness of cool roofs on Federal buildings. To keep the CCE under \$0.08 kWh^{-1} as a nationwide average, the calculations suggest that the incremental cost for cool roofs should not exceed \$0.06 ft^{-2}, assuming that cool roofs have the same life span as non-cool roofs. However, cool roofs usually have extended life spans, e.g., 15-30 years versus 10 years for conventional roofs, and thus the costs of re-roofing must be accounted for. When this is done, the cutoff incremental cost to keep CCE under \$0.08 kWh^{-1} can be much larger.

Incremental cost is defined in this document as the extra cost incurred because of selecting a cool roof instead of a non-cool version of the same. Of course, CCE varies significantly with building, location (state), and roof type. Thus a nationwide average, such as given above, may only give an order of magnitude indication. In addition to CCE, this document also provides a glimpse into generic results for residential and non-residential buildings from past studies that can be used to provide general indications as to the potential benefits of cool roofs in Federal buildings.

1. INTRODUCTION

Over more than a decade, several studies, both experimental and numerical, have shown that cool roofs can reduce air-conditioning energy use (ACEU) by up to 50% depending on location, climate, building type, and thermal integrity of the building envelope. On a nationwide basis, including both residential and commercial building types, Akbari *et al*. (1993, 1997) estimate savings in the order of $750M per year in cooling energy bills. On a building scale, studies suggest significant energy savings and improvements in thermal comfort. For example, Parker *et al*. (1998) report savings of 13000 kWh yr^{-1} in ACEU (10% reduction) and a peak demand reduction of 35% in a Florida school building when its roof albedo was increased from 0.23 to 0.67. Parker et al. (1995) also report average savings (averaged over 9 monitored homes) of 7.4 kWh day^{-1} (19% reduction) and 0.4 kW (22% reduction) in peak demand, when their roof albedos were increased.

In California, Akbari *et al*. (1997) report savings of 2.2 kWh day^{-1} (80% reduction) in ACEU and peak demand reductions of 0.6 kW (25% reduction) when a cool roof was applied to a home in Sacramento. In a school bungalow in that same city, savings were 3.1 kWh day^{-1} (35% reduction) and 0.6 kW (20% reduction). In another field monitoring study of non-residential buildings (commercial, museum, and hospice) in Sacramento CA, Hildebrandt *et al.* (1998) report cooling-energy savings of 0.35-0.68 kWh ft^{-2} yr^{-1} of treated roof as a result of using cool roofs. These savings correspond to reductions in the range of 17-39% in energy use.

Extensive DOE-2 energy modeling has shown significant savings from cool roofs in addition to other benefits. In most cases, the simulations even suggest that air-conditioners can be downsized as a result of implementing cool roof strategies. Of course, the actual benefits and disbenefits (e.g., heating penalty) will depend on the building type, loads, thermal integrity of the envelope, climate zone, and the level of modification (actual increase in roof albedo). In addition to energy benefits, cool roofs can have an indirect environmental impact, e.g., urban-scale cooling, reduced precursor air-pollutant emissions, and slower production of photochemical smog (Taha 1997, Taha *et al*. 1996,1999, 1992). Cool roofs also have structural advantages, for example, longer life spans and reduced maintenance needs (Bretz *et al*. 1997).

As a result of these demonstrated benefits, FEMP is looking into encouraging incorporation of cool roofs in Federal facilities, projects that it sponsors or in utility-financed energy retrofits. This document serves as an introductory blueprint for FEMP in formulating initial thinking about incorporating cool roofs in various aspects of its energy activities.

2. IMPACTS OF ROOF ALBEDO CHANGES

Dark roofs cause both direct and indirect effects, as explained in this section. Typical, dark roofing materials are efficient in absorbing incident solar radiation. For example, the majority of asphalt shingles typically have an albedo of between about 0.10 and 0.15. Roofing membranes, such as black single-ply roofing have a typical albedo of 0.06. Gravel roofs have albedos between 0.12 and 0.34, depending on the color of the gravel, but most tend to be around 0.15 (Taha *et al.* 1992). More recently, Konopacki *et al*. (1997) estimate that the average roof albedo for existing residential and commercial buildings in Atlanta GA, Washington DC, and Philadelphia PA, is 0.25.

Relatively dark roofs result in the direct effect of raising the roof temperature at a faster (larger) rate than reflective roofs. For example, Taha *et al*. (1992) show that light-colored roofs warm up at about 1/3 the rate of their dark counterparts. As a consequence, the hotter roofs transmit more heat into the building than cooler ones, assuming that the insulation levels and construction are similar. Also, the difference between the temperature of the roof surface and that of the overlying air can be as high as 45-55K (80-100°F) for dark roofs and as high as 10-15K (20-30°F) for cool roofs, assuming similar underlying materials. During certain times, the surface temperature of cool roofs can be very close to that of ambient air. In another study, Parker *et al*. (1998) report a decrease of up to 29K (52°F) in roof surface temperature (and 7K on average) when a cool roof was installed on a school building in Florida.

Dark roofs also cause the indirect effect of warming the air in contact with them faster than the air in contact with cooler surfaces (of course the rate of air warming is much lower than that of the roof surface). On a neighborhood or city scale, this effect can add up and generate an urban heat island (UHI) of some 1-2K as typical, and up to some 7K as extreme. It is estimated that 5-10% of the urban peak electric demand may be attributed to the UHI effect. For example, Rosenfeld *et al*. (1995) estimate that urban electric demand in certain warm U.S. cities increases by 2-4% for each 1K increase in daily maximum temperature above 15°C, in summer.

In this document, only the direct effects of cool roofs (as described above) will be discussed and quantified. But up to this point, these effects do not include impacts on lifetime of the roof. This additional benefit will be addressed later in this report.

3. EXISTING MARKET OF ROOFING SYSTEMS AND TECHNOLOGY OPTIONS

In general, roofs can be categorized as flat or low-sloped and as (steep) sloped, gable roofs. Roughly defined, low-sloped roofs are those with smaller than 10° grades. In 2001 for commercial buildings, three types of roof products (built-up roofing (BUR), modified bitumen, and single-ply membrane) accounted for 83% of sales dollars (including labor) in the $6.0B, 14-state western U.S. market for low-sloped commercial-building roofing (Western Roofing, 2001). The 14 western states include AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, TX, UT, WA, and WY. The remaining 17% of the market was made up of metal, asphalt shingle, tile, polyurethane foam, liquid applied coatings, and other materials. By roof area, BUR (27%), modified bitumen (26%), and single-ply membrane (22%) cover 75% of the western-region roof area. It may be reasonable to assume that the national roofing market bears resemblance to the 14-state market in terms of composition and makeup.

Nationwide, there are over 200 companies manufacturing roofing products, most of whom specialize in certain types of roofing. However, firms that manufacture asphalt-based roofing products, such as asphalt shingles, built-up roofing, and/or modified bitumen, are able to offer all three types of roofing systems. Companies that specialize in asphalt-based roofing have the largest sales volumes. Many roofing companies are eager to participate in the marketing of cool roofs. For example, the EPA Energy Star® roof program lists over 100 Roof Product Partners. The EPA program allows manufacturers to self-certify their products' performance criteria and thus an ample supply of eligible products should be readily available for low-sloped roofs, as summarized in **Table 1**.

Table 1: Selected cool-roof options for low-sloped roofs (Levinson *et al*., 2002).

	Solar reflectance	Emittance	Cost ($ ft^{-2})
Built-up Roof			1.2 – 2.15
with white gravel	0.30 – 0.50	0.80 – 0.90	
with gravel and cementitious coating	0.50 – 0.70	0.80 – 0.90	
smooth surface with white roof coating	0.75 – 0.85	0.85 – 0.95	
Single-Ply Membrane			1.0 – 2.05
white (EPDM, CPE, CSPE, PVC)	0.70 – 0.78	0.85 – 0.95	
Modified Bitumen			1.5 – 1.95
white coating over a mineral surface (SBS, APP)	0.60 – 0.75	0.85 – 0.95	
Metal Roof			1.8 – 3.75
white painted	0.60 – 0.70	0.80 – 0.90	
Asphalt Shingle			1.2 – 1.5
white	0.25 – 0.27	0.80 – 0.90	
Liquid Applied Coating			0.6 – 0.8
smooth white	0.70 – 0.85	0.85 – 0.95	
smooth off-white	0.40 – 0.60	0.85 – 0.95	
rough white	0.50 – 0.60	0.85 – 0.95	
Concrete Tile			3 – 4
white	0.65 – 0.75	0.85 – 0.90	
with off-white coating	0.65 – 0.75	0.85 – 0.90	
Clay Tile			3 – 4
Cement Tile			3 – 4
white	0.70 – 0.75	0.85 – 0.90	

Table 2 lists the available commercial-building low-sloped roofing technologies and their market shares in the 14 Western states region (Western Roofing, 2001). For each type, a description is provided along with estimated average costs and percentage of market. In **Table 3**, a listing of selected roofing product manufacturers is given (The Freedonia Group, 1997; Builder, 1995) along with its market share and a description of the product they specialize in.

Following that, **Table 4** lists estimated incremental costs for cool varieties of common low-sloped roofing products. Incremental costs are defined in this document as the additional costs for a certain roofing type that are incurred as a result of selecting a cool-roof version of it. Finally, in **Table 5**, the life expectancy of selected roofing materials is given (NRCA, 1998; Lufkin and Pepitone, 1997). Data from tables 1 through 5 are used in an example application using the companion calculator to assess nationwide costs and benefits of implementing cool roofs in FEMP facilities and buildings.

Table 2. Available commercial building low-sloped roofing technologies (Western Roofing, 2001 and Levinson *et al*., 2002).

Technology	Description	Cost[a] ($ ft^{-2})	WESTERN Sales	WESTERN Area[b]
Built-up Roof (BUR)	A continuous, semi-flexible multi-ply roof membrane, consisting of plies (layers) of saturated felts, coated felts, fabric, or mats, between which alternate layers of bitumen are applied. (Bitumen is a tarlike hydrocarbon mixture often including nonmetallic hyrocarbon derivatives; it may be obtained naturally or from the residue of heat-refining natural substances such as petroleum.) Built-up roof membranes are typically surfaced with roof aggregate and bitumen, a liquid-applied coating, or a granule-surfaced cap sheet.	**1.7**	**31%**	**27%**
Modified Bitumen	(1) A bitumen modified through the inclusion of one or more polymers (e.g., atactic polypropylene and/or styrene butadiene styrene).	**1.7**	**30%**	**26%**
	(2) Composite sheets consisting of a polymer modified bitumen often reinforced and sometimes surfaced with various types of mats, films, foils, and mineral granules. It can be classified into two categories: thermoset, and thermoplastic. A thermoset material solidifies or sets irreversibly when heated; this property is usually associated with cross-linking of the molecules induced by heat or radiation. A thermoplastic material softens when heated and hardens when cooled; this process can be repeated provided that the material is not heated above the point at which decomposition occurs.			
Examples	Styrene-butadiene styrene (SBS) is an elastomeric modifier containing high molecular weight polymers with both thermoset and thermoplastic properties. It is formed by the block copolymerization of styrene and butadiene monomers. These polymers are used as modifying compound in SBS polymer modified asphalt-roofing membranes to impart rubber-like qualities to the asphalt.		13%	
	Atactic polypropylene (APP) is a thermoplastic modifier containing a group of high molecular weight polymers formed by the polymerization of propylene. Used in modified bitumen as a plastic additive to permit heat fusing (torching).		17%	
Single-Ply Membrane	A roofing membrane that is field applied using just one layer of membrane material (either homogeneous or composite) rather than multiple layers. The principal roof covering is usually a single-layer flexible membrane, often of thermoset, thermoplastic, or polymer-modified bituminous compounds. Roofing membranes can be torch-applied or hot-mopped with asphalt during application.	**1.5**	**23%**	**22%**
Examples	Ethylene-propylene-diene monomer (EPDM) is the ASTM-designated name for an elastomeric single-ply roofing membrane containing a terpolymer of ethylene, propylene, and diene. EPDM is a thermosetting synthetic elastomer—that is, a macromolecular material that returns to its approximate initial dimensions and shape after substantial deformation by a weak stress and the subsequent release of that stress.		9.0%	
	Polyvinyl chloride (PVC) is a synthetic thermoplastic polymer prepared from vinyl chloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, fillers, and other modifiers. Flexible forms are used in the manufacture of sheeting and roof membrane materials.		6.3%	
	Thermoplastic olefin (TPO) is a blend of polypropylene and ethylene-propylene polymers. Colorants, flame-retardants, UV absorber, and other proprietary substances may be blended with TPO to achieve the desired physical properties. The membrane may or may not be reinforced.		6.3%	

Technology	Description	Cost[a] (\$ ft^{-2})	WESTERN Sales	Area[b]
	Chlorosulfonated polyethylene (CSPE) is a synthetic, rubber-like thermoset material, based on high molecular weight polyethylene with sulphonyl chloride, that is usually formulated to produce a self-vulcanizing membrane. It is best known by the DuPont trade name HypalonTM.		1.0%	
Metal	Metal roofs can be classified as *architectural* or *structural*.	**2.7**	**5.2%**	**2.8%**
Examples	Architectural (hydrokinetic-watershedding) standing-seam roof systems are typically used on steep slopes with relatively short panel lengths. They usually do not have sealant in the seam because they are designed to shed water rapidly. They do not provide structural capacity or load resistance, and their installation is less labor-intensive because they have a solid substrate platform that makes installation easier.		2.8%	
	Structural (hydrostatic-watershedding) standing-seam roof systems are versatile metal panel systems that can be used on both steep- and low-slope roofs .Most structural standing-seam systems include a factory-applied sealant in the standing seams to help ensure water tightness. These panel systems provide structural capacity and load resistance.		2.4%	
Asphalt Shingle	Asphalt is a dark brown to black cementitious material, solid or semisolid, in which the predominant constituents are naturally-occurring or petroleum-derived bitumens. It is used as a weatherproofing agent. The term asphalt shingle is generically used for both fiberglass and organic shingles. There are two grades of asphalt shingles: (1) standard, a.k.a. 3-tab, and (2) architectural, a.k.a. laminated or dimensional. Asphalt shingles come in various colors	**1.3**	**3.6%**	**4.2%**
Examples	Fiberglass shingles, commonly known as “asphalt shingles,” consist of fiber mats that are coated with asphalt and then covered with granules. Granules, a.k.a. mineral granules or ceramic granules, are opaque, naturally or synthetically colored aggregates commonly used to surface cap sheets and shingles.		3.6%	
	Organic shingles have a thick cellulose base that is saturated in soft asphalt. This saturation makes them heavier than fiberglass shingles, and less resistant to heat and humidity, but more durable in freezing conditions.		n/a	
Tile	Usually made of concrete or clay, tile is a combination of sand, cement, and water; the water fraction depends on the manufacturing process. Concrete tiles are either air-cured or auto-claved, whereas clay tiles are kiln-fired. Color is added to the surface of the tile with a slurry coating process, or added to the mixture during the manufacturing process.	**3.5**	**0.3%**	**0.1%**
Polyure-thane Foam (SPF)	A foamed plastic material, formed by spraying two components (Polymeric Methelene Diisocyanate [PMDI] and a resin) to form a rigid, fully adhered, water-resistant, and insulating membrane.	**0.7**	**2.5%**	**5.2%**
Liquid Applied Coatings	These are used as a surfacing on roofs of various types, especially built-up and metal roofs. They are available in different colors, and may be divided on the basis of reflectivity into black, aluminum, white, and tinted coatings.	**0.4**	**2.5%**	**9.2%**
Other	All other roofing materials that are not covered under the categories mentioned above.	**1**	**2.1%**	**3.1%**

a. LBNL estimates of the typical material and labor costs are approximate.

b. LBNL’s estimates of roof areas fractions are derived from product market shares and costs.

Table 3. Leading roofing product manufacturers (The Freedonia Group, 1997; Builder, 1995).

Company	Market Share	Leader In	Product Mix	Sales
Owens Corning	8%	asphalt-based roofing	multi-product building materials	local dealer/distributor and factory-direct
GAF Materials Corporation	7%	asphalt-based roofing	multi-product building materials	no information
France-based Saint-Gobain (via CertainTeed)	6%	asphalt-based roofing	multi-product building materials	local dealer/distributor
Jim Walter (via Celotex)	3-4%	asphalt-based roofing, coatings	multi-product building materials	local dealer/distributor
GS Roofing Products	3-4%	asphalt-based roofing	specialty	local dealer/distributor
Johns Manville	3-4%	asphalt-based roofing	multi-product building materials	local dealer/distributor and factory-direct
Carlisle Companies (via Carlisle SynTec)	3-4%	elastomeric roofing	multi-line rubber products; metal roofing	no information
Japan-based Bridgestone (via Firestone Building Products)	3-4%	elastomeric roofing	multi-line rubber products; building materials	no information
Tamko Roofing Products	<3%	asphalt-based roofing	specialty	local dealer/distributor
United Dominion Industries (via AEP Span and Varco-Pruden Buildings)	<3%	metal roofing	specialty pre-engineered buildings	no information
Gulf States Manufacturers	<3%	metal roofing	specialty pre-engineered buildings	no information
NCI Building Systems	<3%	metal roofing	specialty pre-engineered buildings	no information
Australia-based Boral (via US Tile and Lifetile)	<3%	tile	no information	local dealer/distributor
Clarke Group of Canada	<3%	cedar shingles and shakes; fiber cement roofing	no information	no information
Elcor (via Elk)	<3%	asphalt shingles	no information	local dealer/distributor
GenCorp	<3%	thermoplastic and rubber membrane roofing	no information	no information
Hood Companies	<3%	asphalt shingles and roll roofing	no information	no information
Redland of the UK (via Monier Roof Tile)	<3%	tile	no information	local dealer/distributor
Tremco	<3%	built-up and membrane roofing	no information	no information

Table 4. Incremental cost for cool varieties of common low-sloped roofing products (Levinson *et al*., 2002).

Roofing Product	Cool Variety	Cost Premium ($\$/ft^2$)
ballasted BUR	use white gravel	up to 0.05
BUR with smooth asphalt coating	use cementitious or other white coatings	0.10 to 0.20
BUR with aluminum coating	use cementitious or other white coatings	0.10 to 0.20
single-ply membrane (EPDM, TPO, CSPE, PVC)	choose a white color	0.00 to 0.05
modified bitumen (SBS, APP)	use a white coating over the mineral surface	up to 0.05
metal roofing (both painted and unpainted)	use a white or cool color paint	0.00 to 0.05
roof coatings (dark color, asphalt base)	use a white or cool color coating	0.00 to 0.10
concrete tile	use a white or cool color	0.00 to 0.05
cement tile (unpainted)	use a white or cool color	0.05
red clay tile	use cool red tiles	0.10

The values in the third column of **Table 4** represent increases in cost over that of conventional roofs of similar construction. For reference, the costs of conventional roof types are as follows (typical average values): 1.2-2.1 $\$/ft^2$ for built-up roofs, 1-2 $\$/ft^2$ for single-ply membrane, 1.5-1.9 $\$/ft^2$ for modified bitumen, 1.8-3.7 $\$/ft^2$ for metal roofs, 1.1-1.4 $\$/ft^2$ for asphalt shingles, and 3-4 $\$/ft^2$ for concrete tiles (Levinson *et al*., 2002).

Table 5. Life expectancies of roof materials (NRCA, 1998; Lufkin and Pepitone, 1997).

Roofing material	Life expectancy (yr)
wood shingles and shakes	15 to 30
tile	50
slate	50 to 100
sheet metal	20 to 50+
BUR/asphalt	12 to 25
BUR/coat and tar	12 to 30
single-ply modified bitumen	10 to 20
single-ply thermoplastic	10 to 20
single-ply thermoset	10 to 20
asphalt shingle	15 to 30
asphalt overlay	25 to 35

4. REPRESENTATIVE BUILDING TYPES USED IN THIS DOCUMENT

This document was prepared to provide an initial estimate of potential benefits of cool roofs on Federal buildings. The estimates are based on previous field work and numerical studies and resulting regression equations. Thus the results provided in this document rely implicitly on certain building types that were used in past modeling and analysis work. The combination of studies and building types used in the past forms the basis for an "in-house" knowledge database that can be drawn upon, e.g., in this document. In this section, generic building prototypes used past modeling and analysis efforts are briefly described, focusing on a generic "residential" and a generic "non-residential" building. In the future, specific Federal building types should be characterized and simulated based on detailed prototypes developed accordingly. For more information, see Konopacki *et al*. (1997).

4.1. RESIDENTIAL BUILDINGS

The representative prototypical residential building is a single-family structure with a floor area of 150m^2(~1610 ft^2). The roof material consists of ¼" asphalt shingle, ½" plywood, with an attic cavity and an R-11 insulation. The ceiling is ½" gypsum board. The walls are 1" stucco, with R-7 insulation and ½" gypsum. Windows have one pane of clear glass and a shading coefficient of 0.86. Occupancy of 3 people is assumed. Cooling is achieved with a packaged direct-expansion air-cooled system with a COP of 2.1 and a temperature set point of 25ºC (78ºF). Heating is done with either a forced-air natural gas furnace with 70% efficiency or an electric heat pump with a COP of 2.1. Both have a set point of 21ºC (70ºF) and a setback of 3.5ºC (6.5ºF). Equipment capacities vary depending on geographical area, building age, and climate.

4.2. NON-RESIDENTIAL BUILDINGS

The buildings include types such as offices, retail stores, schools, hospitals, nursing homes, and grocery stores. The typical floor area ranges from about 400 to 13000 m^2 (~4300 to 139700 ft^2) and the number of floors from 1 to 7. The roofing materials are mostly built-up roofs with ½ inch plywood, attic space, and an R-11 overall insulation level. Beneath that, there is either ½ inch gypsum or acoustic tiles. The walls are either a combination of stucco, plywood, insulation and gypsum, or a combination of concrete blocks (hollow or filled), insulation, and gypsum. The wall insulation is typically R-7. Windows are all one pane and clear, with a shading coefficient of 0.86. Internal loads and occupancy schedules vary from one region to another. Cooling is achieved mostly through packaged direct-expansion air-cooled systems with some buildings using hermetic centrifugal chillers with air-cooled cooling towers. A COP of 2.1 is assumed and an enthalpic ventilation scheme is adopted. The set point is at 26°C (78°F). Heating is done with forced-air natural gas systems and sometimes with electric heat pumps. The efficiency of the natural gas systems is 70% and the electrical heat pump's COP is 2.1. The heating set point is mostly around 21°C (70°F) with a set back of about 8°C (14ºF). When comparing results from a building that has a different COP than listed above, for example, the results should be adjusted by the ratio of the COPs.

5. REPRESENTATIVE WEATHER TYPES AND DATA USED IN THIS DOCUMENT

Table 6 only provides some examples of weather data sources and related characteristics as used in some of the relevant DOE-2 simulations done in the past to estimate the benefits of cool roofs. These are given here to provide an idea of the data types used for this application. Data sources include Typical Meteorological Years (TMY), Weather Years for Energy Calculations (WYEC), and related cooling or heating degree-days (CDD, HDD). Auxiliary information includes meteorological conditions such as cloud cover and latent enthalpy hours.

Table 6. Example weather types and sources used in past energy modeling work.

	Data format	HDD (18ºC)	CDD (18ºC)	Latent enthalpy hours	Mean sky cover
Atlanta	WYEC-2	3215	1602	4931	.495
Chicago	WYEC-2	6425	1105	2781	.492
Los Angeles	TMY	2238	1198	109	.588
Dallas	WYEC-2	2604	2649	7951	.536
Houston	TMY	1580	2883	18845	.480
Miami	WYEC-2	283	4011	27753	.506
New Orleans	TMY	1526	2610	17754	.511
New York	WYEC-2	5029	1076	1533	.465
Philadelphia	TMY-2	5297	1146	3168	.461
Phoenix	WYEC-2	1672	4044	967	.686
WDC	WYEC	4410	1494	3734	.472

6. IMPACTS OF COOL ROOFS ON ENERGY USE IN FEDERAL BUILDINGS

In this section, a method for evaluating the potential energy impacts of cool roofs in Federal buildings and facilities is addressed at two scales: 1) building scale and 2) nationwide estimates. In addition, some tabulated data are given for comparison reference in estimating potential benefits of cool roofs. Section 6.1 summarizes the building-scale calculations whereas section 6.2 summarizes the regional ones.

6.1 Building-Scale Calculations

This section provides a simplified tool, e.g., regression equations, that can be used to estimate the potential energy and cost savings from cool roofs in Federal buildings at given locations/climates (or at locations similar to any ones given in this document). The regression equations (Akbari *et al*. 1998) rely on a set of coefficients (C_i) that currently distinguish between residential and non-residential buildings and among a number of selected climates. Application of this tool at this time will require use of this limited information. However, if more detailed building types are sought in the future, or if new building- and location-specific data are developed, these coefficients could be updated and made more specific and used accordingly. Note that the results obtained from applying these equations represent the direct effect only, as defined earlier in this document. That is, they account only for the envelope (not air temperature) effects of cool roofs.

Thus this section provides the following:

1) A step-by-step description of how this tool can be used to derive savings estimates (6.1.1)
2) A general assessment of confidence and related margin of errors in using this tool (6.1.2)

3) Example application of this tool (6.1.3)

6.1.1. Application (step-by-step description).

Equations (1) and (2) can be used in an initial assessment of potential building-scale energy benefits. In theory, these equations could be used when specific building information is available, or in general when building prototype information is known but not specific to a certain building. Either way, the following steps should be followed in general:

CHART 1.

Specific building is known STEPS ↓	**Prototypical calculation (no specific building)** STEPS ↓
1. Calculate total roof area (the total area to which a cool roof will be applied)	1. Assume the most reasonable value for 'A' (the total floor area of the building) and estimate 'N' (the number of floors) or obtain it from Table 7. Divide A by N to estimate roof area. Or, alternatively, if possible, directly estimate or assume the roof area that will receive a cool roof
2. Identify building type (residential or non-residential), see NOTE 1, below	2. Identify building type (residential or non-residential), see NOTE 1, below
3. Determine the overall, effective U-factor (U) based on construction data and engineering drawings and specifications of the building in question, see NOTE 2, below	3. Estimate or assume some reasonable value for effective U-factor (U) based on building type and related information, see NOTE 2, below
4. Determine the initial absorptance (a) of the existing roof, via field-measurement, e.g., with a pyranometer or the like, or material specification.	4. Estimate or assume the absorptance (a) of the existing roof using entries from Table 10, column 2 (recall $a = 1 - \alpha$).
5. Identify the climate type or location of the building in Table 8, Column 1. If the location or climate of interest is not explicitly listed in Table 8, use Table 12 to "map" or select the State of interest into the corresponding climate type. That is, find your State in columns 1 or 3, and identify the matching entry in columns 2 or 4.	5. Identify the climate type or location of the building in Table 8, Column 1. If the location or climate of interest is not explicitly listed in Table 8, use Table 12 to "map" or select the State of interest into the corresponding climate type. That is, find your State in columns 1 or 3, and identify the matching entry in columns 2 or 4.
6. From Table 8, select the values of coefficients Co through C3 (from column 4 or 5) for the building type, location, and system (heating or cooling) as identified in steps 2 and 5 above.	6. From Table 8, select the values of coefficients Co through C3 (from column 4 or 5) for the building type, location, and HVAC system (heat or cool) as identified in steps 2 and 5 above.
7. Use the coefficients obtained in step 6 along with the U-factor and absorptance (a) obtained in steps 3 and 4 above, use them in equation (2) to compute F(i,j,k), see NOTE 4.	7. Use the coefficients obtained in step 6 along with the U-factor and absorptance (a) obtained in steps 3 and 4 above, use them in equation (2) to compute F(i,j,k), see NOTE 4.
8. Multiply the value of F(i,j,k) obtained in step 7 by the actual or assumed roof area obtained in step 1 above, to obtain energy use (E(i,jk)), see NOTE 4.	8. Multiply the value of F(i,j,k) obtained in step 7 by the actual or assumed roof area obtained in step 1 above, to obtain energy use (E(i,jk)), see NOTE 4.
9. Calculate energy costs. For electricity, multiply E by the local rate $/kWh and for gas, multiply E by the local rate for $/therm.	9. Calculate energy costs. For electricity, multiply E by the local rate $/kWh and for gas, multiply E by the local rate for $/therm. If the local rates are not available, use $0.08/kWh and $0.65/therm (national averages).
10. Repeat steps 4,7, 8, and 9 with a different value of (a) that corresponds to a cool roof to estimate the post-retrofit energy use as a result of implementing the cool roof on a building of interest. See NOTE 3. Then subtracts the post-retrofit use from the pre-retrofit use to get savings.	10. Repeat steps 4,7, 8, and 9 with a different value of (a) that corresponds to a cool roof to estimate the savings in energy use as a result of implementing cool roofs on a building of interest. See NOTE 3.

NOTE 1: In this application of the tool, the distinction is made generally between residential and non-residential buildings. Obviously, this can be improved upon in the future by addressing a large number of building types and categories. This of course will require an explicit study of specific federal buildings throughout the U.S.

NOTE 2: Some common value for the U-factor (for use in equation 2) are: 0.1734, 0.0726, and 0.0245 which correspond to insulation levels R3, R11, and R38, respectively. Note that U=1/R but the values above do not correspond exactly to each other due to nominal differences between R-value of insulation vs. U-value for the roof assembly.

NOTE 3: An example calculation is given in subsection 6.1.3, below.

NOTE 4: Steps 7 and 8 must be done twice; once for electricity and once for gas.

In applying equations (1) and (2), E(i,j,k) is annual energy use (kWh for electricity or therms for gas) for city/climate "i", building-type "j", and HVAC system "k". In equation (2), U is the overall U-factor of the roof construction and a is absorptance ($a = 1 - \alpha$). These values can be obtained or estimated as discussed above. The equations are (terms are defined below):

$$E(i,j,k) = F(i,j,k) \times A(j)/N(j) \quad \text{-------------} \quad (1)$$

$$F(i,j,k) = C_o(i,j,k) + C_1(i,j,k)\, a + C_2(i,j,k)\, U + C_3(i,j,k)\, U\, a \quad \text{-----------} \quad (2)$$

Where, depending on the way they are applied, E and F can be 1) annual electricity usage (kWh yr^{-1}), 2) annual gas energy use (therms yr^{-1}), or 3) net energy use (\$ yr^{-1}). In these equations, A(j) is the total square footage of the building (j) in question and N(j) is the number of floors for Federal building type (j) from **Table 7**. Of course, if A and N are actually known (building specific), or if roof area is directly known, then they should be used explicitly in the equations. The net energy costs are computed as Σ_k E(i,j,k).

Table 7. Assumed typical number of floors for Federal building types.

FEMP building type (j)	(N) # of Floors (assumed average)
Hospital	4
Housing	2
Industrial	1
Office	2.5
Prison	2
Other	2
R&D	2.5
School	1.5
Services	1
Storage	1.5
Utility	1

Table 8 (columns 4 and 5) provides the values of the regression coefficients for use in equations (1) and (2). In developing these coefficients, it was found that the corresponding R^2 values were better than 0.99 except for a handful of cases. These R^2 values are also listed in column 3 in the table. Note that the coefficients are exact for the locations given in column 1 of the table. For 'mapped' locations, e.g., from columns 1 and 3 in **Table 12**, a significant and unknown amount of error may be introduced. These issues should be considered very carefully when applying and using equations (1) and (2).

Table 8. Regression coefficients for equations (1) and (2).

1	2	3	4				5			
City/Climate (i)		R^2 Res/non-Res	Residential (j)				Non-residential (j)			
			C_o	C_1	C_2	C_3	C_o	C_1	C_2	C_3
Honolulu	cool	1.00/1.00	5.091	-.353	-7.328	37.579	5.21	.03	-2.617	21.384
	heat	0.96/0.94	-.0	.0	.004	-.003	-.0	.0	.01	-.007
Miami	cool	1.00/1.00	5.154	-.318	-5.334	39.364	5.169	.047	-1.723	23.238
	heat	0.99/1.00	-.001	.001	.082	-.065	.0	.001	.074	-.03
Tampa	cool	1.00/1.00	4.219	-.179	-3.558	32.583	4.5	.083	-1.152	20.056
	heat	0.99/1.00	.0	.004	.27	-.2	.003	.001	.222	-.085
Phoenix	cool	1.00/1.00	4.948	-.355	1.671	44.914	4.774	.078	1.276	29.219
	heat	0.99/1.00	-.0	.004	.502	-.401	.009	.001	.398	-.156
Lake Charles	cool	1.00/1.00	4.115	-.248	-3.361	36.687	4.211	.018	-1.379	22.002
	heat	1.00/1.00	.017	.004	.595	-.46	.012	.003	.396	-.162
San Diego	Cool	1.00/1.00	2.644	-.227	-6.598	30.033	2.904	.095	-3.837	18.416
	heat	0.97/1.00	-.009	.011	.428	-.4	.001	.002	.348	-.143
Fort Worth	cool	1.00/1.00	4.136	-.259	-.339	32.299	3.998	.049	.416	19.207
	heat	1.00/1.00	.036	.006	.864	-.611	.024	.003	.568	-.225
San Bernardino	cool	1.00/1.00	3.232	-.152	-3.308	35.228	3.481	.099	-2.329	23.352
	heat	0.99/1.00	.002	.008	.868	-.693	.014	.003	.69	-.28
Atlanta	cool	1.00/1.00	3.166	-.182	-4.422	31.908	3.304	.065	-2.547	19.618
	heat	1.00/1.00	.054	.006	1.15	-.754	.032	.003	.79	-.319
San Francisco	cool	1.00/1.00	1.731	-.224	-2.627	22.224	1.906	.035	-2.107	12.79
	heat	0.99/1.00	.011	.015	1.367	-1.210	.018	.003	.803	-.329
Amarillo	cool	1.00/1.00	3.202	-.273	-2.764	37.751	3.127	-.003	-1.581	19.015
	heat	1.00/1.00	.083	.008	1.57	-.998	.055	.004	1.056	-.0406
Portland	cool	1.00/1.00	2.066	-.065	-1.211	18.128	2.104	.048	-1.152	12.541
	heat	1.00/1.00	.095	.005	1.65	-.909	.045	.005	1.154	-.45
Seattle	cool	1.00/1.00	1.872	-.142	-2.377	18.024	1.829	.035	-1.591	11.824
	heat	1.00/1.00	.109	.008	1.942	-1.107	.05	.006	1.307	-.52
Boise	cool	1.00/1.00	2.688	-.162	-1.06	27.32	2.644	.046	-.64	17.271
	heat	1.00/1.00	.127	.005	2.028	-.1246	.073	.005	1.404	-.608
Vancouver	cool	0.99/1.00	1.722	-.01	-2.795	16.816	1.743	.035	-2.884	12.125
	heat	1.00/1.00	.119	.005	2.052	-1.13	.057	.005	1.413	-.557
Minneapolis	cool	0.99/1.00	2.342	-.038	3.306	15.862	2.464	.040	-1.107	13.382
	heat	1.00/1.00	.264	.001	2.502	-.88	.155	-.0	1.871	-.546
Halifax	cool	0.99/1.00	1.823	-.131	-1.305	19.955	1.875	.009	-2.197	13.594
	heat	1.00/1.00	.226	.006	2.696	-1.343	.122	.002	1.994	-.751
Bismarck	cool	0.99/1.00	2.403	-.020	1.131	20.015	2.375	.038	-1.123	14.146
	heat	1.00/1.00	.289	.0	2.88	-1.038	.179	.0	2.068	-.56
Anchorage	cool	0.99/1.00	1.537	.125	3.604	7.374	1.428	.067	-1.244	8.638
	heat	1.00/1.00	.337	-.005	3.253	-.988	.203	-.004	2.355	-.546
Edmonton	cool	0.99/1.00	1.898	.04	2.855	13.905	1.77	.074	-1.050	11.371
	heat	1.00/1.00	.340	-.001	3.392	-1.234	.222	-.003	2.423	-.654

In **Table 8**, the coefficients have the following units: A) for cooling, C_o and C_1 have units of kWh/ft^2, whereas C_2 and C_3 have units of hr-F°, B) for heating, C_o and C_1 have units of 10^5 Btu/ft^2, whereas C_2 and C_3 have units of 10^5 hr-F°.

Thus if a climate of interest is not found explicitly in column 1 of **Table 8**, one needs to select a location that has a climate generally similar to the desired one. For this purpose, **Table 12** could be used in a *very approximate manner*, whereby a desired State (in columns 1 or 3) can be mapped into a location given in columns 2 or 4 which then correspond to entries in column 1 of **Table 8** above. Thence, the coefficients of the location of interest can be obtained from columns 4 or 5 in **Table 8**.

Once the heating and cooling energies have been computed, the costs can be obtained by using the local rates, i.e., the cost of kWh electricity and therms of natural gas. If these rates are unknown for the locality of interest, national averages could be used instead, e.g., \$0.08 kWh^{-1} and \$0.65 therm^{-1}.

6.1.2. Expected confidence interval/error margin

In column 3 of **Table 8**, values for the coefficient of correlation (R^2) are given for each region (columns 1), building type (columns 4 and 5) and HVAC system (column2) that were simulated in previous studies. These values are based on the simulations of Akbari et al. (1998) and all of them, except two entries, are equal to or better than 0.99. This would suggest that the application of equations (1) and (2) for the regions given in columns 1 of **Table 8** should involve a minimum or no error. These R^2 values relate to *simulated* results, not field observations or actual building-monitoring data. However, the main use of these results would be to find the *relative* change in energy use. Thus we recommend the use of equations (1) and (2) in a relative sense, to assess the order of magnitude of potential savings from application of cool roofs on Federal buildings, but not for computing the absolute energy use in such buildings.

When using equations (1) and (2), one must also consider that the entries in column 3 of **Table 8** are valid only with respect to the locations and climates given in the corresponding entries in column 1. When mapping entries from columns 1 and 3 in **Table 12**, these correlation factors are no longer valid and as a result, the error introduced into the calculations are unknown.

6.1.3. Example application of the tool

In this section an example calculation is given. Let's assume that we are evaluating the effectiveness of cool roofs on a hypothetical non-residential building (small office) in Huntsville, Alabama (the choice is arbitrary). The building has a total floor area of 18,000 ft^2.

Step 1. Since the building is hypothetical, we'll use the steps on he right side of **Chart 1**. Thus A=18000 ft^2 and from **Table 7**, N=2.5 (line 4). Thus A/N=7200 ft^2 (the estimated roof area).

Step 2. The building is an office (non-residential) thus we will use entries in column 5 of **Table 8**.

Step 3. Based on some information, let's assume that the roof construction has an effective insulation level corresponding to R-11. Thus U=0.0726.

Step 4. Again, since the building is hypothetical, no observational values from albedo or absorptivity are available. Thus we need to use **Table 10**. From column 2, the albedo is 0.20. Thus absorptivity is roughly, a = 1 - 0.20 = 0.80, which is the "base-case" value for the non-cool hypothetical roof.

Step 5. Since Huntsville, Alabama is not listed in column 1 of **Table 8**, we will need to look it up in **Table 12**. We can locate Alabama in column 3 of Table 12 and see that the representative climate for mapping is that of Atlanta (column 4 of **Table 12**).

Step 6. Thus the coefficients we need are those under Column 5 in **Table 8**, corresponding to Atlanta. The values are 3.304, 0.065, -2.547, and 19.618 for electricity and 0.032, 0.003, 0.79, and -0.319 for gas.

Step 7. Use the values of coefficients above in equation (2). For this example, the computed value for 'F' is 4.31 kWh yr^{-1} ft^{-2} for electricity and 0.0732 therms yr^{-1} ft^{-2} for gas.

Step 8. Find the total annual energy use by multiplying the results from step 7 by the roof area obtained in Step 1. Thus the annual electricity usage is 4.31 × 7200 = 31000 kWh yr^{-1} and annual gas usage is 0.0732 × 7200 = 527 therms yr^{-1}.

Step 9. Calculate the energy costs. Since local rates are not available for this example, we'll use the national averages. Thus the electricity cost is 31000 × 0.08 = \$2480 yr^{-1} and for gas, the cost is 572 × 0.65 = \$340 yr^{-1}. The total annual energy cost is thus \$2800yr^{-1}.

Now, we repeat steps 4, 7, 8, and 9 (these will be labeled 4', 7', 8', and 9' below) with a different albedo value to estimate the reduction in energy costs as a result of cool roofs. For this example, let us assume that the level of modification of roof albedo is high. Thus from **Table 10** (column 6), the new albedo for office building is 0.60 (of course if building-specific data are available, they should be used instead). Thus absorptivity = 1 – 0.60 = 0.40.

Step 4'. The new absorptivity for the cool roof is 0.40 (note that we assume the same construction and thus the same U-factor as in the base case).

Step 7'. The computed values for cool roof 'F' is 3.71 kWh yr^{-1} ft^{-2} for electricity and 0.081 therms yr^{-1} ft^{-2} for gas. Note that cooling energy use has decreased compared to the base case whereas heating energy use has increased.

Step 8'. Total annual electricity usage is 3.71 × 7200 = 26700 kWh yr^{-1} and annual gas usage is 0.081 × 7200 = 580 therms yr^{-1}.

Step 9'. Thus for the cool-roof scenario, the electricity cost is 26700 × 0.08 = \$2100 yr^{-1} and for gas, the cost is 583 × 0.65 = \$380 yr^{-1}. The total annual energy cost is thus \$2500yr^{-1}.

SAVINGS: Thus the net cost savings for this hypothetical building are \$2800 yr^{-1} - \$2500 yr^{-1} = **\$300 yr^{-1}**, which is a net reduction of **11%** in annual energy costs. Of course this is a relatively small building and the absolute savings are small accordingly. However, as will be discussed in Section 7, there are other savings from cool roofs, such as increased life span and avoided maintenance and replacement costs (which can be very significant). The **\$300 yr^{-1}** are only the energy savings.

6.2 Regional/National Scale Calculations

To estimate the potential nationwide energy benefits of cool roofs in Federal buildings and facilities, equations (1) and (2) are expanded further and recast as equations (3) and (4) below, as explained in this section. For this nationwide extrapolation exercise, the FEMP facility and Federal building type distribution information was obtained directly from FEMP (www.eren.doe.gov/femp/facilitydata). The information available from FEMP includes the number of buildings by category and the total square footage. No indication for number of floors is given. Furthermore, the data is segregated by U.S. regional breakdown, i.e., 1) Northeast, 2) Mid Atlantic, 3) Southeast, 4) Midwest, 5) Central, and 6) Western.

In order to use equations (3) and (4), certain information must be known (or assumed) as was shown in **Chart 1** above as well as some additional information. This includes 1) the typical average number of floors for each building category, 2) the saturation of HVAC equipment (heating and cooling systems) for each building type, and 3) the assumed albedo increase per building type. In addition to varying by building type, some parameters can also vary by state, location, and climate. Thus in the present calculations, some simplifying assumptions were made. In **Tables 9, 10, and 11**, some of these assumptions and information are given.

In **Table 9**, the assumed HVAC saturation for selected climates and Federal building types is given, for use in equations (3) and (4). For heating systems, the saturation is a sum of gas and heat pump systems. Also, since there is no exact match between FEMP building types (listed in this document) and previously modeled building types, the saturations given here are those corresponding to building types closest to the FEMP types. In **Table 9**, "c" is saturation of cooling equipment and "h" is heating equipment saturation (%). For housing and office categories the saturations given in **Table 9** are averages of old and new building types. HVAC saturation for heating equipment (where there are old and new buildings) is the total of gas and heat pump then averaged again over old and new building types.

Table 9: Saturation (%) of HVAC for Federal building categories and selected weather/cities.

FEMP building category ↓		Atlanta	Chicago	Los Angeles	Dallas	Houston	Miami	New Orleans	New York	Philadelphia	Phoenix	WDC
Hospital	Cool	100	86	100	40	40	100	40	51	51	100	100
	Heat	98	98	84	100	100	98	100	85	85	100	98
Housing	Cool	83	62	44	88	85	85	77	26	55	91	84
	Heat	100	100	100	100	100	100	100	100	100	100	100
Industrial	Cool	40	30	35	40	40	45	45	35	30	40	30
	Heat	40	60	50	40	40	40	40	50	50	40	50
Office	Cool	100	97	96	100	100	100	100	95	95	100	100
	Heat	100	100	100	100	100	100	100	100	100	100	100
Prison	Cool	60	60	30	60	60	60	60	30	40	60	60
	Heat	100	100	100	100	100	100	100	100	100	100	100
Other	Cool	100	97	96	100	100	100	100	95	95	100	100
	Heat	100	100	100	100	100	100	100	100	100	100	100
R&D	Cool	100	97	96	100	100	100	100	95	95	100	100
	Heat	100	100	100	100	100	100	100	100	100	100	100
School	Cool	99	74	63	95	95	99	95	85	85	98	99
	Heat	72	99	90	94	94	72	94	95	95	89	72
Services	Cool	71	69	85	79	79	71	79	69	69	69	71
	Heat	100	100	100	100	100	100	100	100	100	100	100
Storage	Cool	10	5	5	10	10	5	5	5	5	10	5
	Heat	15	20	15	10	10	10	10	20	20	10	15
Utility	Cool	10	5	5	10	10	5	5	5	5	10	5
	Heat	15	20	15	10	10	10	10	20	20	10	15

In Table 9, categories “hospital”, “housing”, and “school” have directly corresponding entries from previous research (for example, Akbari *et a*l 1998) that addressed these types. The remaining categories in **Table 9** had no equivalent entries. As a result, category “R&D” was assigned the same entries as “office”. Category “services” was assigned values from retail buildings (using new retail facilities from Akbari *et a*l 1998). All other remaining categories were estimated for the purpose of this document. The same applies to weather or state. Thus when calculating nation-wide potential energy savings with equations (3) and (4), each state from the FEMP inventory should be matched to the closest weather type from the list of cities that were studied in the past. This approach was followed in developing the companion spreadsheet calculator (it was also explained in Step 5 of **Chart 1**).

Table 10 gives estimates for feasible moderate (column 3) and feasible maximum (column 5) levels of increase in roof albedo per building type based on field and laboratory experience and in-house knowledge databases. The given values also factor in the effects of dirt accumulation and weathering and thus no cleaning maintenance is assumed. The value of absorptivity (a) is used in equations (3) and (4). Of course, $a = 1 - \rho$, for opaque building materials.

Table 10. Assumed roof albedo (α) and feasible increase (Δα)

1	2	3	4	5	6
	Typical base-case albedo (existing roofing market)	Feasible moderate increase in roof albedo	Feasible moderate new roof albedo	Feasible maximum increase in albedo	Feasible maximum new albedo
Hospital	.20	.20	.40	.40	.60
Housing	.20	.15	.35	.30	.50
Industrial	.30	.25	.55	.40	.70
Office	.20	.20	.40	.40	.60
Prison	.15	.20	.35	.40	.55
Other	.20	.15	.35	.30	.50
R&D	.25	.20	.45	.40	.65
School	.20	.15	.35	.30	.50
Services	.20	.20	.40	.40	.60
Storage	.15	.20	.35	.40	.55
Utility	.20	.25	.45	.50	.70

Finally, one last piece of information is needed before equations (3) and (4) can be used, and that is total roof area by building type across the states. The data obtained from FEMP is aggregated on a regional basis, as mentioned earlier in this document. In the spreadsheet calculator, the data is manipulated and recast on a State basis as shown in **Table 11**. The purpose of this step is to develop better means of correlating the facility square footage to weather data (using States as a surrogate for weather). Even though states are still large in area and can have varied weather and microclimates within, the present step is at least an improvement over the FEMP regional scales, which cannot be easily associated with weather types. Thus **Table 11** gives a weighting basis for further breaking down the data by FEMP building types and by state. Square footage given in the table is in thousands.

Table 11. Federal/FEMP building type square footage by State.

State ↓	Hospital (x1000)	Housing (x1000)	Industrial (x1000)	Office (x1000)	Prison (x1000)	Other (x1000)	R&D (x1000)	School (x1000)	Services (x1000)	Storage (x1000)	Utility (x1000)
FEMP Region: Northeast											
Massachusetts	3542	16739	608	12645	0	655	3779	3479	4656	3550	0
New Hampshire	367	2725	3	1600	0	372	154	277	3042	1022	0
New York	7868	19556	2384	30499	2	1592	4364	4641	9921	10569	0
Rhode Island	489	3917	0	1702	0	366	1400	1332	1642	2503	0
Connecticut	988	5189	708	3058	203	134	330	793	1311	459	0
Maine	148	3753	0	2749	0	292	3	432	2962	1016	0
Vermont	281	8	0	668	0	61	9	19	251	61	0
FEMP Region: Mid Atlantic											
DC	3313	4319	1432	41638	0	1842	4242	644	3726	2671	10
Delaware	438	2270	0	845	0	36	9	389	2230	637	0
New Jersey	2028	11588	11	9049	110	787	3593	2309	6714	12753	0
Virginia	3592	36386	2739	33835	353	4328	4085	7193	23054	26560	0
West Virginia	1029	240	6	1845	823	215	404	320	485	269	0
Maryland	5099	22879	2102	18161	23	2163	17505	6112	11869	8133	0
Pennsylvania	5202	6785	1889	17954	942	1190	2459	1770	10745	22649	0
FEMP Region: Southeast											
North Carolina	3019	13218	604	10543	280	1266	166	3129	11650	7920	0
Alabama	1405	2330	601	5253	537	105	3862	863	2051	1639	0
Georgia	3579	19051	91	21122	622	1401	1395	5635	13773	18442	0
Kentucky	2590	7446	7917	8152	1400	281	173	2312	4898	7378	0
Puerto Rico	536	51	0	583	0	25	36	102	10	42	0
South Carolina	2316	19788	2283	5917	0	468	566	2513	6524	4312	0
Florida	5509	27099	1084	14900	492	1342	6817	4236	22691	7502	0
Mississippi	1833	8655	5	4123	0	518	2901	2539	3522	2878	0
Arkansas	2893	5756	391	4029	17	249	605	681	3051	3669	0
Tennessee	2950	3049	3335	9156	234	1442	4600	2051	7265	12012	0
Virgin Islands	0	22	0	152	0	12	0	0	3	2	0
FEMP Region: Midwest											
Missouri	2583	9434	5151	12596	0	310	162	1591	2826	6559	0
Ohio	3981	4330	15701	14254	0	653	8107	1555	8617	14571	0
Wisconsin	2630	3981	2746	3379	417	115	778	639	1772	1658	29
Indiana	1352	5114	2997	6732	744	414	865	1180	4125	7357	0
Iowa	657	299	1382	2177	0	147	685	529	1135	2440	0
Illinois	4638	12856	3010	19277	246	821	3997	3628	6476	11325	0
Minnesota	2666	544	3018	4373	142	299	538	680	1518	1754	0
Michigan	2405	8551	45	7918	386	787	604	928	3978	1824	0
FEMP Region: Central											
Colorado	2734	12946	2056	10857	245	449	1399	4058	7748	8784	9
New Mexico	1617	12374	658	9613	0	939	8226	2137	6687	5289	0
Texas	9718	37408	8744	32241	1431	1777	2173	10232	30344	28212	3
Utah	818	3844	301	3529	0	305	524	457	8588	9625	0
Kansas	1745	13790	2878	7237	1020	435	78	1562	4803	7099	0
Louisiana	1952	11083	5157	8406	12	171	665	1440	6793	5639	0
Montana	359	2792	15	1833	0	1333	159	246	1110	780	344

North Dakota	765	10017	54	1247	0	1765	139	944	4052	2030	0
Oklahoma	1962	10300	2950	7381	359	547	531	3145	11688	14357	0
South Dakota	993	4558	0	2163	0	270	41	1361	2424	865	0
Wyoming	440	2882	1	7193	0	263	625	180	2957	684	0
Nebraska	1151	5029	2556	3353	0	788	239	202	2745	1088	0
FEMP Region: Western											
Alaska	1038	18068	46	6494	15	717	383	417	8211	5158	0
Arizona	2268	17629	695	6514	837	425	1270	2979	7376	6403	0
California	12090	86906	6407	52671	1158	8902	20462	13619	73140	68091	33
Washington	3807	15130	1651	30749	47	3443	1773	3604	15786	11317	0
Guam	0	0	0	9	0	0	0	0	0	0	0
Hawaii	1183	26300	72	9007	13	2142	74	1107	13872	10593	0
Idaho	460	2955	708	2194	0	321	1617	296	2163	1850	0
Nevada	493	4409	414	2375	62	190	67	297	3454	8856	0
Oregon	1169	1257	58	3643	0	317	505	360	1311	3714	0

Using values from all tables in this document, the nationwide energy use in Federal buildings is computed as follows, where in this case, “i” is the State, “j” is the building type, “k” is HVAC system type, and “S” is saturation of HVAC equipment of type “k”. “A” and “N” retain their earlier meanings.

$$E_n = \Sigma\ E(i,j,k) = \Sigma\ \{\ F(i,j,k) \times A(j)/N(j) \times S(i,j,k)\ \}\ \text{-----------}\ (3)$$

$$F(i,j,k) = C_o(i,j,k) + C_1(i,j,k)\ a + C_2(i,j,k)\ U + C_3(i,j,k)\ U\ a\ \ \text{-------------}(4)$$

Then the savings from cool roofs are computed by repeating the above calculations for a scenario with cool roofs and subtracting the total from the values of the baseline energy usage.

6.3 The spreadsheet calculator

A simple MS Excel spreadsheet was developed along with this document and can be found on the included floppy disk. The purpose of the “calculator” is to provide a simple tool for use by FEMP in estimating the potential building-scale and national impacts of cool roofs on energy use in FEMP facilities. The spreadsheet can produce results by building type, state, or nationwide basis. As region- and building-specific coefficients and numbers become available, as well as more specific energy costs, HVAC saturation levels, and so on, this calculator can be updated constantly. Currently, the spreadsheet assumes national average energy costs, that is, \$0.08 kWh^{-1} and \$0.65 $therm^{-1}$.

The spreadsheet is currently designed just to produce results for a first-cut assessment and can be improved upon, quite significantly in follow-on efforts. Currently, the calculator consists of the following components: 1) square footage of building types by state, 2) assumed typical number of floors per building type, 3) HVAC saturation per building type and state for heating and cooling equipment, 4) assumed existing roof albedo for building types as well as two levels of assumed increases in albedo (feasible moderate and feasible maximum), 5) energy rates (electricity and gas), 6) various coefficients for equations (3) and (4), and parameters for calculating the cost of conserved energy (CCE) which will be defined and explained in Section 7.

As mentioned earlier, to use the calculator initially, a mapping of climate types, cities, and states is needed. This is because past studies did not encompass every single US state. Some similarity therefore has to be assumed and used in the mapping. In the current state of the calculator, the following mapping of the regression coefficients from **Table 8** (for use in equations (3) and (4)) was done (see **Table 12**). That is, for the states shown in columns 1 or 3 of **Table 12**, the coefficients were those from the corresponding location in columns 2 or 4.

Table 12. Mapping of states and climate types.

1	2	3	4
FEMP State	Use coefficients from:	FEMP State	Use coefficients from:
Massachusetts	Halifax	North Carolina	Atlanta
New Hampshire		Alabama	
New York	Minneapolis	Georgia	
Rhode Island		Kentucky	
Connecticut		Tennessee	
Maine		Puerto Rico	Tampa
Vermont		South Carolina	
District of Columbia		Florida	Miami
Delaware		Virgin Islands	
New Jersey		Guam	
Virginia		Mississippi	Lake Charles
West Virginia		Louisiana	
Maryland		Arkansas	Amarillo
Pennsylvania		Missouri	
Wisconsin		Colorado	
Minnesota		Kansas	
Michigan		Oklahoma	
Ohio	Boise	New Mexico	Fort Worth
Indiana		Texas	
Iowa		Alaska	Anchorage
Illinois		Arizona	Phoenix
Montana		Nevada	
South Dakota		California	San Bernardino
Wyoming		Washington	Seattle
Nebraska		Hawaii	Honolulu
Idaho		Oregon	Portland
North Dakota	Bismarck		

Note that the mapping assumed in **Table 12**, while handy, can be a source of serious error, especially in calculating energy savings, CCE, and related econometrics. For example, there are no coefficients appropriate for the Northeastern U.S., thus the use of Minneapolis (column 2) to represent 15 states in that area (column 1) which can introduce significant errors. The same is seen, but to a lesser degree, with Boise, Atlanta, and Amarillo. Using San Bernardino as an average for California may also introduce errors. However, this represents all the available data thus far that can be used in formulating this initial “template” calculator. Obviously, there is room for significant improvements in data site-specificity.

An example application of the calculator is given in the following section (Section 7).

7. COST EFFECTIVENESS

In previous studies, the cost effectiveness of cool roofs was estimated via a number of parameters. These included 1) the annual decrease in cooling electricity consumption, 2) annual increase in heating electricity and/or gas, 3) net present value of net energy savings, 4) cost savings from downsizing cooling equipment, 5) the incremental cost for cool roofs, 6) peak cooling electricity demand reduction, 7) expenditure decrease from participation in a load curtailment program, 8) expenditure decrease from participation in a reflective-roof rebate program, and 9) savings in material and labor costs from extended life of roof surface and insulating materials.

In this study, a more direct way of evaluating the benefits is being proposed to assess the cost-effectiveness of cool roofs on FEMP facilities and buildings. This is the cost of conserved energy (CCE) used in conjunction with the present value of heating penalties. Of course this does not account for additional benefits from 4, 6, 7, and 8 above. Depending on use, it may account for item 9, above. This metrics is defined with the following three equations:

$$CCE = [\,\Delta I/\Delta E\,] \times [\,i / \{\,1 - (1+i)^{-n}\,\}\quad \text{--------} \ (5)$$

$$\Delta I = (\,A_r \times c_i\,) + pHP \quad \text{---------}(6)$$

$$pHP = A\ \{\,(1+i)^{n} - 1\,\}\ /\ \{\,i\,(1+i)^{n}\,\} \quad \text{---------}(7)$$

In these equations, ΔI is the additional cost (investment) incurred in upgrading to cool roofs and ΔE is the annual cooling energy savings (note that the cost of heating penalties is included in the term ΔI). "i" is the "interest" or compounding rate, n is the life span of the cool roof, A_r is roof area for a particular roof type and state, c_i is incremental cool roof cost for building type and state, and pHP is the present value of annual heating energy penalty (A) for each state and FEMP building type.

Of course, if no additional costs are incurred (no incremental costs) when selecting a cool roof instead of a conventional one (such as during construction or reproofing) then all savings are pure benefits and there is no need to calculate CCE. However, if incremental costs are incurred, then the CCE must be calculated to help in selecting the most appropriate cool roof options.

To provide an example, the calculator is used in this section to compute a nationwide assessment of CCE, assuming a rate (i) of 6%. In the example, it is also assumed that pHP varies according to roof and building types. In addition, the incremental costs of cool roofs with respect to non-cool ones are assumed as in **Table 13**, which is a modification of a combination of tables 4 and 5. Furthermore, **Table 13** was recast to match the FEMP building categories. Again, the assumptions made here are for the sake of using the calculator in exemplifying the potential CCE related to FEMP cool roofs program, but can be improved upon in the future.

Because only cooling energy is reduced (heating energy can increase) when cool roofs are applied, CCE is computed only for cooling energy (as $\$\ kWh^{-1}$) while including the heating energy penalty in the investment term ΔI (as an additional cost), as in equation (6). But because heating penalty is accrued annually over the life span of the cool roof, a present value of heating penalty (pHP) is calculated and included in term ΔI. **Table 13** lists assumed expected life spans and incremental costs for common cool-roof types (these are assumptions used in the example calculations). The numbers are obtained from averaging and combining numbers in **Tables 4 and 5**.

Table 13. Assumed incremental costs and life spans of cool roofs.

		Incremental cost over conventional $/ft^2		Total Life span (years)	
FEMP building type	Proposed cool roof version	low	high	low	high
Hospital	BUR with asphalt + cementitious coatings OR BUR with white gravel	0.05	0.15	12	25
Housing	Light-color concrete tile	0.00	0.05	10	20
Industrial	Metal roof with light-color paint	0.00	0.05	20	50
Office	BUR with asphalt + cementitious coatings OR modified bitumen	0.00	0.05	12	25
Prison	Light-color concrete tile	0.00	0.05	15	30
Other	BUR with asphalt + cementitious coatings	0.05	0.10	12	25
R&D	BUR with asphalt + cementitious coatings OR BUR with white gravel	0.10	0.20	12	25
School	BUR with asphalt + cementitious coatings OR BUR with white gravel	0.00	0.05	12	25
Services	Metal roof with light-color paint	0.00	0.05	20	50
Storage	Metal roof with light-color paint	0.00	0.05	20	50
Utility	Light-color concrete tile	0.00	0.05	20	40

Table 13 thus involves simplifying assumptions when matching roof types and costs with FEMP building types. In the calculator, the user can enter state-specific and building-specific information, roof types, life span, and costs, if these become available. But for the example exercise here, the generic values in the tables above will be used.

In **Table 13**, the “low” end of the range is assumed to correspond to “scenario 1” in the calculator (feasible moderate increase in albedo), whereas the “high” end of the range is assumed to correspond to “scenario 2” (feasible maximum increase in albedo). This implies that the whiter (cooler) the roof is, the more expensive it gets. This may not always be true but the assumption is used as such in the first example calculation provided here. Also, for this initial estimation, the incremental costs of cool roofs are assumed to be State-independent. State-by-state costs can be entered in the calculator when they become known in the future.

Clearly, FEMP should encourage use of cool roofs in new construction and during regularly scheduled re-roofing to keep incremental costs down. In estimating cost effectiveness, only the incremental initial cost of changing the albedo of the roof from a low value to a high value was considered in the present calculations (calculator). Additional expenditure would be required if a building owner wished to maintain the cool roof's albedo at its initial high level (e.g., ≥0.70). That additional cost has not been factored into the present analysis because the simulated energy savings are based on a degraded albedo that assumes no additional maintenance. And, of course, material and labor costs for roofing projects vary from one contractor to another.

Thus using the combinations of options in **Table 13**, as well as expected features and roof types per building types, the calculations in the first set yield a nationwide FEMP inventory average CCE of $0.069/kWh in scenario 1 and $0.094/kWh for scenario 2. Assuming a national average cost of $0.08/kWh, these calculations suggest that scenario 1 (moderate albedo increase) is beneficial if adopted by FEMP whereas scenario 2 (high albedo increase) may be on the borderline because of increased cost of more reflective cool roofs. However, this analysis may be misleading because of the assumptions made above regarding cool roof types. That is, expensive cool roof types were selected. In the second set of calculations (where cool roofs last roughly twice as long as non-cool ones), the CCE is 0 (actually negative). This means that cool roof strategies are extremely efficient due to saving energy and also because the avoided cost of materials for re-roofing the conventional non-cool roofs pays for itself enormously (without even accounting for labor costs)!

To provide more realistic estimates, a sensitivity analysis was performed to elucidate a range of CCE due to various albedo and cost combinations. For this analysis, the assumption was made that all roofs in the FEMP inventory have an average life span of 15 years in option 1, 30 years in option 2, and 45 years in option 3 (the latter is rather high but used here for a theoretical calculation). These are shown in **Table 14**. In addition, the assumption was that scenarios 1 and 2 above would represent a range of possible albedo increases. The roofs are also assumed to have a nationwide average R-11 insulation. With that in mind, a stepwise increase in the incremental cost of cool roofs was used in the sensitivity analysis. The results are summarized in **Table 14**. The light gray region highlight CCE ≤ $0.08 ft^{-2}, whereas the dark gray area shows regions where CCE becomes extremely prohibitive. Thus the sensitivity analysis suggests that the cutoff incremental cost in the first set of calculations is about $0.06 ft^{-2}.

Example results in **Table 14** are for general illustration purposes and not meant to be used directly since they involve various assumptions and non-linear changes in certain terms of the equations. Actual calculations must be performed on a case-by-case basis with region-specific information.

Table 14. Computed CCE for various combinations of roof life span and incremental costs.

	Nationwide average incremental cost for cool roofs ($/ft^2)	CCE ($/kWh) FEMP facilities nationwide average					
		15 years roof life span		30 years roof life span		45 years roof life span	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Without replacement of non-cool (base case) roof. That is, the non-cool roof has the same life span as the corresponding cool roof.		0	0	0	0	0	0
	.02	.08	.05	.06	.04	.06	.04
	.04	.13	.08	.10	.06	.09	.06
	.06	.17	.10	.13	.08	.12	.07
	.08			.17	.10	.15	.09
	.10					.18	.10

8. CONCLUSIONS

This document summarizes initial estimates for the potential benefits of cool roofs on Federal buildings and facilities. It provides a basis for building-scale estimations and an example calculation for nationwide impacts assessments. Along with this document, a preliminary spreadsheet "calculator" was devised to help FEMP estimate potential energy and cost savings of cool roofs. This document and companion calculator form the basis for a first step towards longer-term research and modeling to assess the detailed potential benefits of cool roofs in FEMP facilities and buildings.

Assuming an average nation-wide insulation level of R-11 for FEMP building roofs, the calculations in this document suggest nationwide savings in energy costs of $16M and $32M for two scenarios of increased roof albedo (moderate and high), respectively. The savings correspond to about 3.8% and 7.5% of the base energy costs for FEMP facilities and include the increased heating energy use (penalties) in winter. This document also shows that to keep the cost of conserved energy under $0.08 kWh^{-1} as a nationwide average, the affordable incremental cost for cool roofs for Federal buildings should not exceed $0.06 ft^{-2} if cool roofs have the same life span as non-cool roofs. If cool roofs have longer life spans than non-cool roofs (which is usually the case), then the costs of re-roofing non-cool roofs must be factored in. In this case, the cutoff incremental cost for cool roofs can be much larger to keep CCE under $0.08 kWh^{-1}. As mentioned in the document, there is a whole range of options in between these ends. This does not even account for labor costs associated with re-roofing of non-cool roofs. Thus there seems to be significant benefits from implementing cool roofs in FEMP facilities and buildings.

9. REFERENCES

Akbari, H. 1998, "Cool roofs save energy", ASHRAE Technical Data Bulletin, Volume 14, No. 2, January 1998, pp. 1-6.

Akbari, H., Konopacki, S.J, Eley, C.N., Wilcox, B.A., Van Geem, M.G., and Parker, D.S. (1998). "Calculations for reflective roofs in support of Standard 90.1", ASHRAE Technical Data Bulletin, Volume 14, No. 2, January 1998, pp. 56-67.

Akbari, H., Bretz, S.E., Taha, H.G., Kurn, D.M., and Hanford, J.W., 1997, "Peak power and cooling-energy savings of high-albedo roofs", *Energy and Buildings*, 25(2) (1997).

Akbari, H., Bretz, S.E., Hanford, J.W., Kurn, D.M., Fishman, B.L., Taha, H.G., and Bos, W. 1993, "Monitoring peak power and cooling-energy savings of shade trees and white surfaces in the Sacramento Municipal Utility District (SMUD) service area: Data analysis, simulations, and results", Lawrence Berkeley National Laboratory Report No. 34411.

Bretz, S., Akbari, H., and Rosenfeld, H., 1997, "Practical issues for using solar-reflective materials to mitigate urban heat islands"" Lawrence Berkeley National Laboratory Report No. 38170, Berkeley, California.

Builder, 1995, "Roofing". *Builder Magazine*, April 1995, pp. 255-257.

Building Energy Simulation Group (1990), "Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D, Lawrence Berkeley National Laboratory Report No. 19735, Rev.1, Berkeley, California.

Freedonia Group, 1997, "Roofing to 2001", The Freedonia Group Report 886, Cleveland, Ohio.

Hildebrandt, E.W., Bos, W., and Moore, R., 1998, "Assessing the impacts of white roofs on building energy loads", ASHRAE Technical Data Bulletin, Volume 14, No. 2, January 1998, pp. 28-36.

Konopacki, S., Akbari, H., Gabersek, S., Pomerantz, M., and Gartland, L., 1997, "Cooling energy savings potentials of light-colored roofs for residential and commercial buildings in 11 U.S. metropolitan areas", Lawrence Berkeley National Laboratory Report No. 39433.

Levinson, R.M, H. Akbari, and S. J. Konopacki, 2002, "Inclusion of cool roofs in non-residential Tilte-24 prescriptive requirements", PG&E Code Proposals, 2005 Title 24 Building Energy Efficiency Standards Update. A draft LBNL report.

Lufkin, P.S. and Pepitone, A.J., 1997, The Whitestone building maintenance and repair cost reference 1997, 3rd annual edition, Whitestone Research, Seattle, WA.

NRCA 1998, "Data on life expectancies of roofing materials used on homes", *Roofing, Siding, Insulation*, November (1998), pp. 44.

Parker, D.S., Sherwin, J.R., and Sonne, J.K., 1998, "Measured performance of a reflective roofing system in a Florida commercial building", ASHRAE Technical Data Bulletin, Volume 14, No. 2, January 1998, pp. 7-12.

Parker, D.S., Barkaszi, S.F., Chandra, S., and Beal, D.J., 1995, “Measured cooling energy savings from reflective roofing systems in Florida: Field and laboratory research results”, Proceedings, *Thermal Performance of the Exterior Envelopes of Buildings VI*, ASHRAE, Atlanta.

Taha, H., Konopacki, S., and Akbari H., 1996, “Impacts of lowered urban air temperatures on precursor emission and ozone air quality”, *Journal of the Air & Waste Management Association*, Vol. 48, pp. 860-865.

Taha, H., 1997, “Modeling the impacts of large-scale albedo changes on ozone air quality in the South Coast Air Basin”, *Atmospheric Environment*, Vol. 31, No. 11, pp.1667-1676 (1997).

Taha, H., Konopacki, S., and Gabersek, S., 1999, “Impacts of large-scale surface modifications on meteorological conditions and energy use: A 10-region modeling study”, *Theoretical and Applied Climatology,* Vol. 62, pp. 175-186 (1999).

Taha, H., Sailor, D., and Akbari, H., 1992, “High-albedo materials for reducing building cooling energy use”, Lawrence Berkeley National Laboratory Report No. 31721, UC-350.

Western Roofing, 2001, “The growing western roofing market”, *Western Roofing Insulation and Siding Magazine*, http://www.westernroofing.net.