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Demonstration of Energy Savings of Cool Roofs

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Executive Summary

The use of dark roofs affects cooling and heating energy use in buildings and the urban climate. At the building scale, dark roofs are heated by the summer sun and thus raise the summertime air-conditioning (a/c) demand. For highly-absorptive (low-albedo†) roofs the difference between the surface and ambient air temperatures may be as high as 90°F on a summer afternoon. While for less absorptive (high-albedo) surfaces with similar insulative properties, such as roofs covered with a white coating, the difference is only about 20°F (Berdahl and Bretz 1997). For this reason, "cool" roofs (which absorb little insolation‡) can be effective in reducing cooling energy use. Earlier studies have suggested that cool roofs incur no additional cost if color changes are incorporated into routine re-roofing and re-surfacing schedules (Bretz et al 1998 and Rosenfeld et al 1995).

There is a sizable body of measured data (primarily collected for residential sector) documenting energy-saving effects of cool roofs as shown in **Table EX.1**. Both measured data and simulations clearly demonstrate that increasing the albedo of roofs is an attractive (and cost-effective) way of reducing the net radiative heat gains through the roof and hence, reducing building cooling loads. To change the albedo, the rooftops of buildings may be painted with reflective coatings or covered with a new light-colored material. Since most roofs have regular maintenance schedules or need to be re-roofed or re-coated periodically, the change of the albedo should be done then. In that case, the cost would be limited to the incremental cost associated with the high-albedo material. In buildings and climates with significant air-conditioning use, increasing the albedo of roofs will reduce energy use and produce a stream of savings immediately.

Why this project?

The question then is why reflective roofs are not used as widely as expected. One can offer a few answers:

1. For building owners and managers, the primary function of a roof is to protect the building. Energy savings are perceived as a secondary issue. The cost associated with repair and maintenance of a leaky roof far exceeds the energy saved by changing the reflectivity of the roof.
2. For existing buildings, the compatibility of a reflective roofing material with the existing roof is important. Many types of building materials, such as tar roofing, are not well adapted to painting. Although such materials could be specially designed to have a higher albedo, this would be at a greater expense than painting. Additionally, to maintain a high albedo, roofs may need to be re-coated on a regular basis. The cost of a regular

† When sunlight hits a surface, some of the energy is reflected (this fraction is called the albedo = a) and the rest is absorbed ($1-a$). Low- a surfaces become much hotter than high- a surfaces.

‡ INcoming SOLar radiATION.

maintenance program could be significant.

3. A third factor is the durability of the albedo of the material. As a reflective roofing material is weathered and collects dust, its reflectivity and hence its capability to save air-conditioning energy decreases.
4. Building owners and architects like to have the choice as to what color to select for their rooftops. This is particularly a concern for sloped roofs.
5. Most existing data are documenting savings for homes. For flat-roof low-rise commercial buildings that offer significant savings potentials, energy-saving data are scarce.
6. Finally, the lack of information and incentives for building owners and roofing contractors can be an important factor.

This project was designed to address some of the questions regarding the implementation of reflective roofs in a few commercial buildings. The objective of this project was to work with developers, industry, businesses, and utilities to develop and carry out up to three demonstration cases, in commercial buildings, to show effectively the impact of cool materials on building cooling energy use.

There were three target audiences for this demonstration: technical staff, corporate facility managers, and the general public. The technical audience is interested in valid scientific observations which further our knowledge about white roof coatings and energy savings. To meet this audience's expectations the instrumentation used on these buildings was comprehensive, including monitoring of air-conditioning electricity use, temperature measurements throughout the ceiling, plenum, and rooftop layers, and a weather tower to measure solar radiation, wind speed, air temperature, and humidity at each site.

The corporate facility managers and engineering and maintenance staff of the individual buildings need to be educated about the performance of light-colored roofs. The buildings chosen for this study were selected partly because they were facilities belonging to large corporations with hundreds of buildings under their control. The hope here was to educate key corporate personnel about the value of white coatings, stimulating their use on other buildings and spreading the word by example. Since the facilities managers were paying for their own coatings, we hoped to demonstrate cost-effectiveness, ease of application, and durability.

To educate and inform the general public about the environmental and energy-saving benefits of cool roofs, the buildings were also chosen for the high volume of people passing through them each day. Information kiosks were located conspicuously in each of the buildings. These kiosks introduced the concept of cool roofing and its role in saving energy and reducing pollution. In addition to the kiosks in each building, pages on the World Wide Web were published with the results of the demonstrations for the cyber-public.

Results

In this project we monitored air-conditioning electricity use, plenum, indoor, and outdoor air temperatures, roof surface temperature, and other environmental variables in three buildings in California:† two medical office buildings in Gilroy and in Davis and a retail store in San Jose. The following is the summary of findings.

Reduction in roof surface temperatures

In the Davis building, coating the roof with a reflective coating increased the roof albedo from 0.24 - 0.60. The roof surface temperature on hot sunny summer afternoons before coating was applied reached 175°F but only 120°F after coating. In the Gilroy building, coating the roof increased the roof albedo from 0.25 - 0.60; the roof surface temperature was reduced from 170°F - 120°F. In the San Jose building, coating the roof increased albedo from 0.16 - 0.60 and the roof surface temperature decreased from 175°F - 120°F. **Figure EX.1** is an infra-red photograph of the edge of the roof coating at Gilroy at the time of application.

Air-conditioning electricity savings

Summertime standard-weekday average daily air-conditioning savings are highlighted in **Table EX.1**, where electricity use was reduced by 18% (6.3 kWh/1000ft²) in the Davis medical office building, 13% (3.6 kWh/1000ft²) in the Gilroy medical office building, and 2% (0.4 kWh/1000ft²) in the San Jose retail store. The most savings were seen in the Davis building since of the three buildings its roof system was least resistant to heat transfer (i.e. primarily R-8 rigid insulation) and it had an unvented return plenum. The Gilroy building utilizes similar shell construction and internal load characteristics as in the Davis building, but with two significant differences: R-19 fiberglass ceiling insulation and large passive roof vents; experienced about 25% less relative savings than in the Davis building. The air-conditioning electricity use in the San Jose retail store is internal-load driven, and the roof system contributes relatively little to the whole-building load, and thus the savings were least in this building (even though Δa was higher than in the medical office buildings). It has a well-ventilated plenum, which efficiently exhausts to the outdoors any heat that is transferred through a radiant barrier attached under the roof.

Experience in having the roofs coated

There were many unexpected difficulties in getting the rooftops coated with high-reflectance coatings. In this project the cost of the coatings were paid by the facility itself, and the coatings were applied by roofing contractors instead of by project personnel. One of the difficulties was associated with selling the coating based on its cost-effectiveness. Based on the projected energy savings of these coatings alone (2 - 5¢/ft²) a roof coating is not very cost-effective. If the

† We also subcontracted the Florida Solar Energy Center to carry out a similar demonstration project in Florida. The results of that effort are reported separately in Parker et al 1997.

coating can be used to lengthen the life of the roof and avoid replacement costs, it becomes much more economically attractive. Other difficulties arose in working with facility managers and roofing contractors. Neither group has much experience with or knowledge of high-reflectance coatings, leading to a hesitance to adopt this new technology. These people are also extremely busy, so scheduling meetings and work can be challenging. A set of information to collect and guidelines for coating costs were developed to help streamline the process of coating rooftops.

Display kiosk

Display kiosks were designed to explain cool-roof coating theory and to display real-time measurements of weather conditions, roof surface temperature, and air-conditioning electricity use to visitors of the buildings. They were situated in the lobby or a central area of each building so patrons would have easy access to them and could then learn about the cool-roofing project underway. **Figure EX.2** is a photo of the display kiosk in operation in the San Jose building.

Table EX.1. Monitored summertime daily air-conditioning electricity savings from cool-roof research in single-story residential and commercial buildings in California and Florida.

location	building type	1000ft ²	roof system description			daily a/c savings	
			insulation	duct location	Δ albedo	kWh/1000ft ²	%
California							
Davis	medical office ^(a)	31.7	R-8	cond. space	0.36	6.3	18
Gilroy	"	23.8	R-19	plenum	0.35	3.6	13
San Jose	retail store ^(a)	32.9	rad. bar.	plenum	0.44	0.4	2
Sacramento	school ^{(b)(c)}	1.0	R-19	ceiling	0.60	4.4	46
Sacramento	residence ^(b)	1.8	R-11	crawl space	0.59	1.3	63
Florida							
Cocoa Beach	residence ^(d)	1.2	none	attic	0.53	12.7	43
Cocoa Beach	"	1.3	none	attic	0.39	10.8	26
Cocoa Beach	"	1.3	R-11	attic	0.52	7.9	25
Merritt Island	"	1.7	R-11	attic	0.44	6.8	20
West Florida	"	0.9	none	none	0.53	6.2	25
Miami	"	1.4	R-11	attic	0.30	5.9	15
Cape Canaveral	"	1.4	R-11	attic	n/a	5.4	22
Cocoa Beach	"	1.5	R-19	attic	0.42	2.9	13
Merritt Island	"	1.8	R-25	attic	0.51	2.2	11
Palm Bay	"	1.5	R-19	attic	0.44	2.1	10
Palm Bay	"	1.8	R-19	attic	0.42	0.5	2
Cocoa Beach	strip mall ^(e)	12.5	R-11	plenum	0.46	0.7	25

a This report.

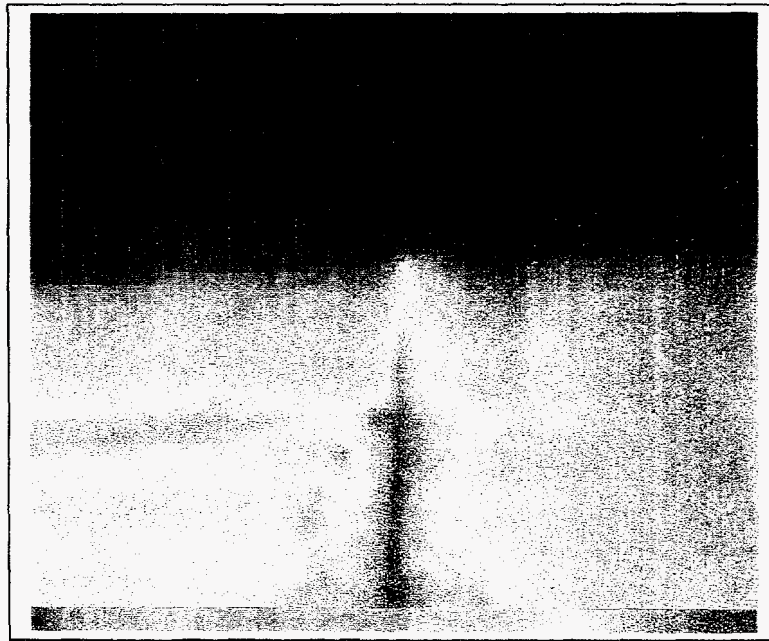
b Akbari, H., et al. 1997. *Peak Power and Cooling Energy Savings of High-Albedo Roofs*. Energy and Buildings. vol. 25, no. 2, pp. 117-126.

c Two identical school bungalows.

d Parker, D., et al. 1998. *Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings*. ASHRAE Transactions, vol. 104, pt. 1.

e Parker, D., et al. 1997. *Demonstration of Cooling Savings of Light Colored Roof Surfacing in Florida Commercial Buildings: Retail Strip Mall*. Florida Solar Energy Center Report FSEC-CR-964-97.

dark seams
→



coated

uncoated

100

degrees Fahrenheit

180

Figure EX.1. Infra-red photograph of roof-coating edge at Gilroy.



Figure EX.2.
Kiosk in operation at
the San Jose site.