Durability of High-Albedo Roof Coatings

Sarah E. Bretz and Hashem Akbari, Lawrence Berkeley Laboratory

Twenty-six spot albedo measurements of roofs were made using a calibrated pyranometer. The roofs were surfaced with either an acrylic elastomeric coating, a polymer coating with an acrylic base, or a cementitious coating. Some of the roofs' albedos were measured before and after washing to determine whether the albedo decrease was permanent.

Data indicated that most of the albedo degradation occurred within the first year, and even within the first two months. On one roof, 70% of one year's albedo degradation occurred in the first two months. After the first year, the degradation slowed, with data indicating small losses in albedo after the second year. Measurements of seasonal cooling energy savings by Akbari et al. (1993) included the effects of over two months of albedo degradation. We estimate ~ 20% loss in cooling-energy savings after the first year because of dirt accumulation.

For most of the roofs we cleaned, the albedo was restored to within 90% of its initial value. Although washing is effective at restoring albedo, the increase in energy savings is temporary and labor costs are significant in comparison to savings. Our calculations indicate that it is not cost-effective to hire someone to clean a high-albedo roof only to achieve energy savings. It would be useful to develop and identify dirt-resistant high-albedo coatings.

Introduction

High-albedo roof coatings can be used to reduce building air-conditioning use and, if implemented at large-scale, might reduce summer urban temperatures. By lowering the absorption of solar energy, high-albedo coatings reduce building surface temperatures, and heat-transfer to the building interior. The lower surface temperatures also reduce the building's contribution to urban air temperature (Akbari et al. 1988). To maximize cooling energy savings, high-albedo roof coatings should 1) have high solar reflectance (both in the visible and near-infrared bands), 2) have high infrared emittance, and 3) maintain these properties for the service life of the coating.

This paper addresses the albedo durability of solar-reflective roof coatings, as part of a joint project between this laboratory and a utility to assess the use of high-albedo building materials for cooling-energy savings. A more detailed version of this paper that contains a review of research on coating durability appears as LBL No. 34974. Roof albedo measurements, with implications of the results for the use of high-albedo roof coatings for cooling-energy savings, are presented here.

Definition of Albedo

In this paper, we use the term albedo to refer to the integrated hemispherical reflectance within 0.28 and 2.8 micrometers (um). The term "albedo" as applied to a sloped roof is not a clearly defined parameter. Since a sloped roof receives some radiation that is reflected from surroundings and re-radiated by the ground, the spectral distribution of incoming radiation is different than that on a horizontal roof. The spectral distribution of radiation reaching the roof from surroundings can also be temporally variable. To estimate the albedo of sloped roofs in this study, we measured the hemispherical incident radiation as measured on a plane parallel to the roof surface, as close to the peak of the roof as possible (to minimize the detection of outgoing radiation).

Techniques for Measuring Albedo

Albedo can be measured in the field or the laboratory. Typically, laboratory measurements include the use of a *spectrophotometer* with an integrating sphere. This device is capable of measuring the spectral characteristics of a material over the solar region of the electromagnetic spectrum, from approximately 0.3 to 2.5 um. Spectral reflectance is measured in reference to a working standard that is highly reflecting and highly diffusing over the range of the solar spectrum, such as barium sulfate. Solar spectral reflectance is then calculated using a standard spectral irradiance distribution.

The advantage of albedo calculations based on laboratory measurements is that the laboratory measurements are more easily controlled than field measurements. Thus, it is easier to make comparisons between materials under similar environmental conditions. Such spectral reflectance data and infrared emittance data have been reported for a number of high-albedo roof coatings (Yarbrough and Anderson 1993; Parker et al. 1993). Measurements indicated that coatings must be applied at a minimum critical thickness to obtain optimum solar reflectance (Yarbrough and Anderson 1993). Of course, this minimum critical thickness depends on the coating. The implication is that a cost comparison should compare cost per unit thickness, which depends on percent solids by volume, rather than cost per unit volume.

Field measurements of albedo typically involve the use of a *radiometer* for measuring the incident and reflected radiant flux. We use a high precision *pyranomeler* that is sensitive to radiant energy in the 0.28 to 2.8 micrometer range. The pyranometer is mounted on a stand described in Taha et al. (1992). The stand LBL uses is designed to minimize the effects of the pyranometer's shadow and radiation reflected by surroundings. Uncertainties in the field measurements include the effect of the shadow of the pyranometer when it is facing down, error resulting from 1) radiation that is reflected by surroundings other than the surface in question, 2) solar incidence angle, and 3) nonuniformity of the surface. In contrast to the spectrophotometer, which measures the albedo of a small (~3 cm^2) sample, the pyranometer measures reflected radiation from a large area. A ratio of 1/10 between the pyranometer's height and the diameter of a test area is required for a view factor of 95% or better from the roof to the inverted pyranometer.

Measurements of solar albedo should not be confused with reflectivity measurements, based on surface reflectance of visible radiation. Roof coating manufacturers may claim reflectance of over 90%, citing various test methods that involve a visual comparison of a test sample and standard (ASTM 1992a).

Effects of Weathering

The performance of reflective roof coatings as an energy-efficiency measure is directly related to albedo. The temperature of a roof is approximately equal to the sol-air temperature, T_{sa}, defined as

$$T_{sa} = T_o + \frac{(1-A_s)I_t - ER}{h_a} \qquad (1)$$

where,

- T_o = outdoor air temperature, “C
- A_s = reflectivity of the surface for solar radiation (albedo)
- I_t = total solar radiation incident on the surface, W/m^2
- ER = difference between thermal radiation incident on the surface and surroundings and that emitted by a blackbody at the outdoor air temperature, W/m^2. E = hemispherical emittance of the surface.
- h_a = coefficient of heat transfer by long wave radiation and convection at the outer surface, $[W/m^2 °C]$

Changes in the emittance as weathering occurs are probably not significant, assuming the material has a high emittance initially. Albedo, however, is likely to decrease if the initial albedo is high, and increase if the initial albedo is low, because of surface accumulations and material degradation. Surface accumulations, such as dirt and microbial growth, may or may not be permanent, depending on their water volubility. Degradation, however, can modify the albedo permanently by inducing chemical change in the material. Insolation (particularly ultraviolet radiation), moisture (dew, rain, humidity), temperature (primarily the time-averaged temperature of the roof), and natural and anthropogenic pollutants (particularly aerosols and acid rain) are the major elements that degrade roof coatings (Anderson 1990). More detailed information on weathering can be found in papers on polymer degradation (Reeves 1975; Silberglitt and Le 1990), titanium dioxide (Braun 1987), combined effects of temperature, photodegradation, hydrolytic degradation and atmospheric pollutants (Griffin 1982; Pappas 1989).

Assessment of Weathering Effects: Temperature Measurements

Under controlled conditions, Backenstow (1987) measured temperature under roofing systems of various ages, including a new black Ethylene Propylene Diene

Terpolymer membrane (EPDM), a four-year-old black EPDM membrane, a new white EPDM, a two-year-old white EPDM, and a new, beige-colored EPDM that was found to approximate the solar reflectance of a very dirty or oxidized white roof. The difference in cooling-energy costs between a black and a white membrane on a 930 m^2 R-5 ft^2-h-°F/Btu roof was estimated at $4.56/day. About 26% of the savings would be lost if the roof were a very dirty white instead of new white.

Christian, Byerley, and Carlson also measured surface temperatures to assess aging effects on white roof coatings on nine roof systems in two climates.[1] They found the aging effect to be most dominant in the first year, leveling out in subsequent years. They also found surprising durability differences for the same coatings applied on different substrates or roof membranes.

Assessment of Weathering Effects: Albedo Measurements

The advantage of albedo measurements is that they are less sensitive than temperature measurements to environmental conditions such as windspeed, air temperature and solar intensity. Thus, albedo measurements of a surface obtained on different days can be compared. Air conditioning savings from albedo modifications can be estimated using meteorological data, by either calculation or computer simulation.

The effects of one year equivalent solar exposure on the albedos of five white elastomeric coatings were measured by Anderson (1992). Griggs and Shipp (1988) investigated changes in albedo for black and white membranes over a 75-week period of outdoor exposure.

Standard Measurement Techniques

There are various types of weathering effects. These effects can be evaluated individually by standard test methods. All of these methods, however, rely on visual comparison with photographic reference standards. Such methods cannot be relied upon to provide information for energy conservation purposes because the eye is not capable of judging the reflected flux. Less than half of the incoming solar flux is in the visible region. Also, visual methods are imprecise.

At this time, there are no standards for measuring albedo degradation. The ability of coatings to retain high-albedo and high emittance has not been evaluated (Yarbrough and Anderson 1993).

Methodology

To enhance our understanding of albedo degradation of reflective roofs, we conducted field experimentation to determine the magnitude of the effect. We also used laboratory measurements to understand the spectral distribution of the reflected radiation from fresh samples. The following sections describe the methods we used, and the results, followed by a discussion of the implications for cooling-energy savings.

Experimental Approach

One way to assess the effects of natural weathering on high-albedo roof coatings would be to monitor the albedo of a particular roof for several years. The time limits of this project, however, necessitated a survey of different roofs with a variety of ages. It should be emphasized here that there is an inherent variability in albedo measurements between different roofs and that cross-roof comparisons are not always valid. Each roof has a unique albedo, depending on the roughness and condition of the substrate and the thickness of the coating. Similarly, the change in albedo over time will vary inconsistently between roofs depending on the climate, the slope of the roof, the roughness and condition of the substrate, atmospheric pollution, nearby sources of dirt and debris, and the dirt resistance of the roof coating. Nevertheless, our methodology allowed us to estimate the rate of albedo degradation.

In addition to roof measurements, we measured the albedo of small samples of the same coatings in the laboratory. These samples were provided by the coating distributors.

Selection of Roofs and Samples

A list of high-albedo roof coating distributors was obtained. All of these distributors, and several additional ones, were contacted and informed of the study. They were asked to identify horizontal or gently-sloped high-albedo roofs of various ages that could be measured. Of the ten distributors contacted, three offered their assistance by contacting residents, accompanying us to the roofs, and providing necessary equipment. The measurement sites were identified in Sacramento, Vallejo, Concord, and Stockton, California. The coatings for this study included:

Coating #1 A white polymer coating, with an acrylic base.

Coating #2 A white acrylic-based coating.

Coating #3 A white cementitious coating. A dry mixture of white cement, titanium dioxide, and resin binders is combined with water at the site.

Horizontal and sloped roofs were identified. The sloped roofs in this study are gently sloped, with less than 25% incline. Information on the dry samples, provided by distributors are given in Table 1.

Instrumentation

Albedos were measured on clear days between 11:00 am and 4:00 pm, using a pyranometer and stand. The analog output from the pyranometer was converted to digital output with a readout meter that has an accuracy of better than ±0.5% and a resolution of 1 W/m^2. The meter was scaled to the sensitivity of the pyranometer by the vendor laboratory (Taha et al. 1992). The pyranometer was tested against another pyranometer of the same model and found to have a consistent deviation that was independent of sun angle. Because albedo measurements involve ratios of two readings, the deviation is not expected to affect the results reported here.

Laboratory measurements of hemispherical spectral reflectance were made with a double beam spectrophotometer with integrating sphere. The integrating sphere is a 150 mm diameter sphere surfaced with reflectance material that gives the highest diffuse reflectance of any known material or coating over the UV-VIS-NIR region of the spectrum. The calculation of solar spectral reflectance was made according to ASTM Standard Test Method E903-82 (1992b), by weighting reflectance output by a standard solar irradiance. Solar data were obtained from Standard Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37° Tilted Surface (ASTM 1992c).

Results

Effect of Dirt Collection on the Albedo of a White Roof

To facilitate data analysis, roofs were separated into categories of smooth, medium, and rough substrates. A rough substrate can lower surface albedo because of geometrical effects (multiple reflections) and because it can accumulate dirt faster than horizontal surfaces. Figure 1 shows the effect of two months to six years of dirt accumulation on the albedo of the roofs measured. Detailed descriptions of all the data and roofs in this study (including those that do not appear in the figure) are in Appendix A.

The error bars in the figure show the range of albedos that were measured for each data point. All spot measurements were repeated several times. Measurements that were repeated within minutes varied by ±0.01, or within 2%. The largest variation between measurements of the same spot was 0.03, or 5% of the average albedo of that spot. The time that elapsed between these particular measurements was over an hour.

Spatial variability in albedo is also different for each roof. In one case, we recorded a variation in albedo of ±0.03 (6%), on a 23 m^2 (250 ft^2) mineral-surfaced roof that had been coated with Coating #2 six years earlier. A smaller spatial variation in albedo of ±0.01 (2%) was measured on a 170 m^2 (1800 ft^2) roof that had been surfaced with Coating #1 a year before.

Table 1. Roof Coating Samples for Hemispherical Spectral Reflectance Measurements

Coating Number	Dry Film Thickness* mm	Dry Film Thickness* mils	Substrate Type	Equivalent Coverage (liters/m^2)	Cost at This Thickness ($/$m^2$)
1	0.4	16	cardboard	0.7	6.3
2	1.0	39	rubber	1.9	13.8
3	0.6	25	mineral cap sheet	1.6	0.7

* For Coatings #1 and #2, thickness was measured and the amount needed to cover a m^2 was calculated from percent solids by volume. For Coating #3, thickness was estimated from the manufacturer's estimate of 0.73 kg/m^2, assuming a density of 1105 kg/m^3. Density was estimated from the manufacturer's information on the coating's formulation.

In Figure 1, the opaque right triangles and solid line represent the albedos of a smooth roof with a 2% slope that was surfaced with Coating #1. The house was surrounded by trees that contributed to dirt build-up on the roof. The roof was measured days after it had been coated in 1991, and after a year of exposure in 1992. Then it was washed with a mop using soap and water to restore the albedo. In 1993, after a year of exposure, it was measured once more. The first year value on the graph represents an average of the 1992 and 1993 measurements.

The filled right triangles represent the albedos of a horizontal metal paneled roof, surfaced with Coating #1. The overlapping panels rose several centimeters in height at each edge of ~0.5 m panel. The texture of the roof may have affected the albedo measurements by blocking or scattering radiation.

The opaque right triangles with dashed line represent the albedo of a roof similar and adjacent to the one just described. The building was washed after one year and the albedo was measured again after two months and after another year. Although after the second year the coating was two years old, it had only had a year of dirt accumulation because of the washing. The albedo measured in the second year was similar to the albedo measured after the first year.

The filled circles represent albedos of roofs with medium-rough substrates surfaced with Coating #2. For these roofs, no initial albedo value was available so we used the average albedo of the roofs washed with a power-washer and soap. We assume that our estimated initial albedo is not more than 10% below that of a freshly coated roof. The roof substrates in this data set were jute burlap dipped in emulsion (data point 2), and mineral-surfaced cap sheet. The last measurement was taken on a 5% slope roof with a mineral-surfaced cap sheet, six years after it was coated.

The opaque circles in Figure 1 represent Coating #2 on horizontal roofs with gravel substrates. The first value was taken on a roof two months after the coating was applied, and some fine dust had settled on the surface. Given the drop in albedo in two months shown by the opaque triangles with a dashed line, the initial albedo of this roof was probably higher. The other three values were taken on roofs that had been coated in different years but were all on the same building. The six-year measurement is an average of two roofs, one of which ranged in albedo from 0.31 to 0.45 in different spots. These roofs were in poor condition when they were coated, which could affect albedo by decreasing durability. Also, heating, ventilating, and air-conditioning (HVAC) equipment on several roofs and poor drainage contributed to the dirt build-up.

Opaque squares represent albedos of gravel roofs surfaced with Coating #3. The initial value is an average of two roof measurements of horizontal roofs, but the other roofs had sloped portions. The decrease in albedo is most gradual for this combination of coating and roof type. It is unclear at this time whether the low dirt accumulation is because of the slope or properties of the coating.

The estimated decrease in albedo during one year averaged 20% and ranged from 0.04 (6%) for sloped gravel roofs with Coating #3 to 0.23 (28%) for a horizontal, metal paneled roof with Coating #1. The data indicate that most of the decrease in albedo occurs in the first year, possibly in the first two months. For the cementitious coating on gravel, after one year of weathering the albedo was reduced by an estimated 6%. After six years, it was

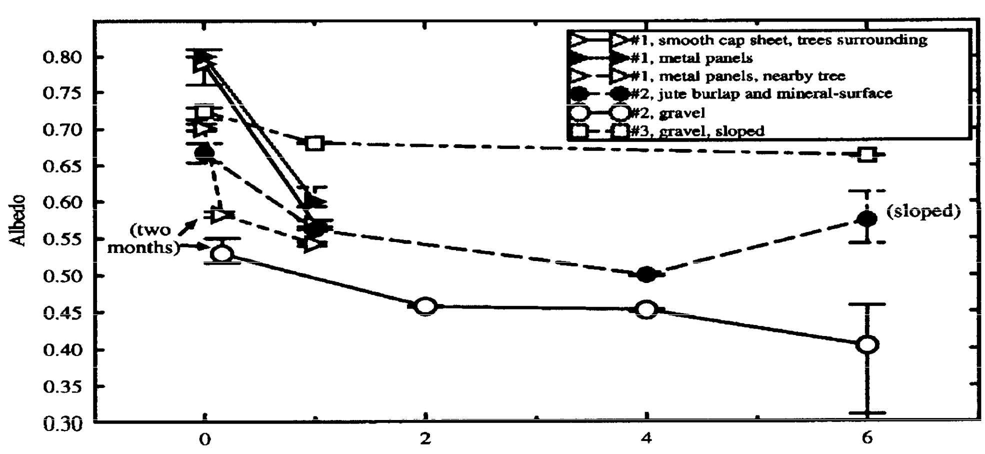

Figure 1. Albedo vs. Exposure for 3 Roof Coatings, on Different Substrates. Years on X-axis are years since the coating was new, or washed to within 90% of the original albedo (Roofs were flat, except where noted.)

8%, indicating that approximately three fourths of the decrease could occur in the first year. Measurements on one roof two months and one year after washing indicate that 70% of the first year albedo decrease occurred in the first two months (Measurement Nos. 2 and 3 in Appendix A).

Beyond six years, the pattern of albedo degradation is unclear. One spot that we measured, 15 years after it had been coated, had extensive microbial growth. The distributor informed us that in their service area such growth occurs after 10 years, at which point they offer a renewed warranty to the customer with recoating.

Two roofs with Coating #1 were identical and adjacent to one another, yet had different albedos. One of the roofs had an initial albedo of 0.80 that dropped to 0.57 after one year. The other roof had an initial albedo of 0.69 that dropped to 0.54 after a year of exposure. At that time, the roof was washed thoroughly and found to have an albedo of 0.70, consistent with the first measurement. After two months of exposure, it had dropped to 0.58. Although the initial albedos differed, the albedo of these two roofs were not significantly different after a year of exposure. Noticeable differences between the two roofs was that they were painted at different times (different conditions) and there was a tree located closer to the building with the lower albedo.

Implications for Cooling Energy Use

Since three buildings in this study were also monitored for their cooling energy consumption for another study (Akbari et al. 1993), we estimated the impact of dirt accumulation on the cooling energy savings. For our calculations, we use a linear approximation of the relationship between cooling-energy savings and albedo. According to Equation (1), the linear assumption is good for the relationship between albedo and surface temperature, an indicator of heat transfer through the roof. Extending the linear assumption to cooling energy savings is adequate for our purposes here.

At one house with an R-11 ft^2-h-^oF/Btu roof, measured cooling-energy savings from increasing roof albedo were 69% (2.2 kWh/day) (Akbari et al. 1993). The albedo of the original roof was 0.18. The energy savings were monitored over a summer period, at the beginning of which the albedo of the roof was measured at 0.73 (AA = 0.55). The measured energy savings during the first summer includes the effect of dirt accumulation on the roof. In the second summer, the albedo of the roof had dropped to 0.61 (AA = 0.43). Thus, we estimate cooling energy savings would have dropped about 20% because of a change in albedo.

At another site, where two buildings were measured in parallel, a 40% cooling-energy savings (4.6 kWh/day) was found from an increase in albedo to 0.7. Dirt accumulation was allowed to proceed during monitoring, at the end of which the albedo was 0.58. In the second year, the albedo had dropped to 0.53, 20% lower than the first-year average of 0.64. We estimate cooling-energy savings for the second summer would have dropped by about 20% (to 32% cooling-energy savings).

Effectiveness of Washing

Roofs surfaced with Coating #1 and Coating #2 were washed, using several methods. Most roofs were washed with soap and water, using a mop. Two roofs were washed with a power-washer (Measurements 8 and 17 in Appendix A), but because we had no original albedo measurements for these roofs we cannot estimate the washing effectiveness. Other roofs were divided into sections that were washed differently, for comparison between washing methods. For the roofs that were measured successively in 1991, 1992, and 1993, we can calculate the albedo restoration as the percentage of the original value (Table 2). The Measurement Number is used for reference in the text and in Appendix A.

The increase in albedo resulting from washing a roof was dependent on many factors, but was generally significant. Simply hosing off the roof was not as effective as using a mop and soap. When a mop was used, the albedo was restored to within 90% of the original value, indicating that the loss of albedo is not permanent.

Estimating the effectiveness of washing on restoring albedo for the other roofs in the study is less precise, because the initial albedo of each roof is unknown. As a base for comparison, we used the albedo of a similar roof measured two months after coating, multiplied by a correction factor of 1.2. The correction factor was based on the decrease in albedo on another roof after two months of exposure (Measurement 3 in Appendix A). Table 3 shows the estimated albedo restoration of these roofs. The measurements were made on rough roofs that were in poor condition prior to coating, which may have affected adherence of the coating, and exacerbated weathering. A few areas were stained by HVAC equipment located on the roof or by surrounding trees (Measurement Nos. 9 and 11 in Appendix A). With the method we used to clean the roofs, those with smooth surfaces were more easily cleaned than those with rough surfaces, which retained dirt.

The data collected in this study for the buildings monitored in Akbari et al. (1993) were used to calculate the cost of conserved energy of washing a high-albedo roof. Our estimates are based on an annual cooling-energy use

Table 2. Albedo Restoration of Roofs Coated with Coating No. 1

Meas. No.	Substrate Type	Pitch (%)	Age of Coating (years)	Dirt Collection (years)	Washing Method	Initial Albedo	Albedo Restoration (% of initial albedo)
NA	smooth cap sheet	2	1	1	hose off	0.79	81
21	smooth cap sheet	2	1	1	soap & mop	0.79	92
22	smooth cap sheet	2	2	1	soap & mop	0.79	96
2	metal panels	0	1	1	soap & mop	0.69	100

Table 3. Estimated Albedo Restoration of Flat Roofs with Coating #2
(These roofs were in poor condition prior to coating)

Meas. No.	Substrate Type	Age of Coating (years)	Albedo Restoration* (% of initial value)	Comments
9	rough (gravel)	2	78	HVAC equipment; discolored
10	rough (gravel)	4	83	
11	rough (gravel)	6	81	Poor drainage; discolored
12	rough (gravel)	6	83	HVAC equipment; discolored

* Albedo restoration through washing as percent of estimated original albedo of 0.64.

of 1000 kWh and the average change in albedo achieved through washing. Based on our experience, washing a 2000-square-foot roof would require four person-hours of work at an estimated cost of $25/person-hour. With a cost of $100 per roof, hiring someone to wash a roof by scrubbing with mop, soap and water, the CCE worked out to be ~70 cents/kWh. Hosing off a roof, which produced an increase in albedo of 0.05, resulted in a CCE of ~60 cents/kWh, for a one person-hour cost of $25. Although savings estimates are largely dependent on the climate and house characteristics, our data showed that the savings from washing a roof are only gained for one season. Thus, it is unlikely that washing a high-albedo or hosing off a roof will be cost-effective for most buildings. If washing does take place it should be done shortly before the summer. It would be useful to develop coatings that have dirt-resistance so that they do not require washing or hosing off, or coatings that are easier to clean with hosing only.

Spectral Albedo Measurements

Results from the spectrophotometer with integrating sphere for the small fresh samples described in Table 1 and titanium dioxide pigment, 0.2µm particle size, are shown in Figure 2. A standard solar spectral irradiance is shown in the background.

As with the rooftop measurements, the purpose of the spectral measurements is not to compare coating reflectance, because the samples vary in terms of thickness and substrate, as shown in Table 2. Coating #2 had a thickness of 1.0 mm and was therefore exhibiting maximum reflectance for that coatings, 0.80 (Anderson 1992). We suspect our samples of Coating #1 and Coating #3 are not exhibiting maximum reflectance. The sample of Coating #1 is slightly sub-standard thickness for roofs, while Coating #3 is below maximum reflectance because

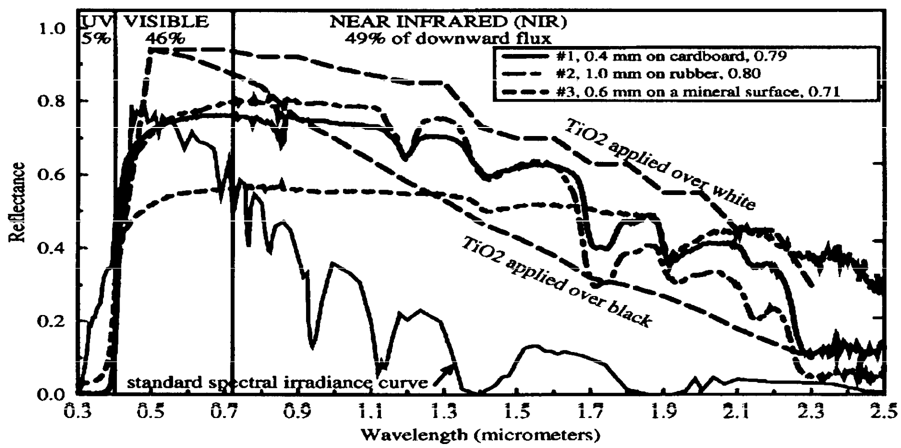

Figure 2. Spectral Reflectance Data for Three Roof Coatings and Titanium Dioxide (Lewis 1988) in the Solar Region of the Spectrum[2]

of the roughness of the substrate, and the thickness. The roofs surfaced with #3 in our field measurements had thicker coats.

All three coatings absorb in the UV region. This feature is common to titanium dioxide, a pigment that is used in many white roof coatings, including Coatings #2 and #3. Coating #3 does not have the same absorption features, as Coatings #1 and #2, although there is a small dip in reflectance at 1.4μm. Molecular groups containing hydrogen (e.g., OH^-) can cause absorption in the near infrared (Berdahl and Bretz, 1994). Commercial titanium dioxide pigments are often surface treated with aluminum hydroxide to improve various properties, such as dispersibility and durability (Lewis, 1988).

Future Research

The uncontrolled nature of this experiment, make it impossible to estimate the relative weatherability of various coatings. Further studies are necessary to link coating type and surface physical characteristics with albedo durability. Coating comparisons will require controlled conditions and long-term testing, so that all samples are exposed to the same weathering. It is possible that such comparisons will identify characteristics that promote dirt-resistance and high-albedo durability.

Before more albedo field studies are undertaken, measurement equipment need to be improved. With the present design, albedo measurements are time-consuming and require several participants. Because the pyranometer weighs 3.18 kg (7 lbs), the stand that holds it is unstable and unwieldy, especially for transport up and down ladders. We recommend that such measurements be done with either a lightweight pyranometer or albedometer. An albedometer has two sensors mounted back to back and thus increases the measurement speed. One commercially available albedometer weighs 0.85 kg (1.83 lb).

Conclusion

Our study has begun to address the aging characteristics of high-albedo roofs. The decrease in albedo depends on the coating itself, the texture of the surface, the slope of the roof and the nearby sources of dirt and debris. In general, the largest decrease in albedo can be expected to occur in the first year, at a reduction of about 20%. This decrease, however, is included in some of the reported cooling-energy saving measurements. After the second year, the incremental decrease in albedo can be small, lowering saving estimates by 10-20%.

In most cases, washing the high-albedo coatings returned the albedo to 90-100% of the estimated original value. Since dirt accumulation can occur in the first couple of months, the benefit from washing a roof is short term. Implications are that washing should be done shortly before summer, and that it is not cost-effective if one is only concerned with cooling-energy savings. The apparent differences between roof coatings found in this study indicate the need for quality testing and carefully controlled durability testing of high-albedo coatings that might be used for cooling-energy savings.

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Endnotes

1. Personal communication with Aaron Byerley, Mechanical Engineering Department, Mercer University, Macon, GA, 1993.

2. Also shown is a standard spectral irradiance curve for air mass 1.5. These data are useful for identifying absorption features of the coatings. Note that the coatings are applied at different thicknesses and to differing substrates. Apparent albedos appear in the legend.

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Appendix A: Albedo Data

Table A-1 contains the data that were collected during this study. The Measurement No. is used to identify the measurement in the text. Some measurements were taken on the same roof in different years: Measurement Nos. 1 to 4; 5 and 6; and 20, 21 and 22. These roofs were washed with mop, soap and water each year, so that there was never more than one year of dirt accumulation on them. Measurement Nos. 14 and 15, and 18 and 19 were taken on two parts of the same roof, where one part was flat and the other was sloped. Measurement Nos. 23 and 24 were taken on two parts of the roof: half that was newly coated and another half that had not been coated in 15 years. The first column in Table A-1 describes the texture of the roof surface, and the substrate type. Relevant information relating to the albedo measurement is listed in column four under "Comments." Years since last washing are listed as years since the roof was last coated or last washed with mop, soap and water.

Table A-1. *Solar Albedos of Roof Coatings at Various Ages*

Meas. No.	Substrate Type	Coating No.	Comments	Age of Coating (years)	Yrs. Since Last Washing	Albedo Dirty	Albedo Clean
			Horizontal Roofs				
1	rough (metal panels)	1	a tree was nearby	0	0	-	0.69
2				1	1	0.54	0.70
3				1.2	0.2	0.58	-
4				2	1	0.53	-
5	rough (metal panels)	1	adjacent to the above roof	0	0	-	0.80
6				1	1	0.57	-
7	rough (gravel)	2	dirt was visible on the surface	0.2	0.2	0.53	-
8	medium (jute and emulsion)	2	a power washer was used to clean the roof	1	1	0.56	0.65
9	rough (gravel)	2	roof was in poor condition before coating; staining from HVAC equipment located on the roof	2	2	0.46	0.50
10	rough (gravel)	2	roof was in poor condition before coating	4	4	0.45	0.53
11	rough (gravel and tar paper)	2	roof was in poor condition before coating; staining from HVAC equipment located on the roof	6	6	0.40	0.52
12	rough (gravel)	2	roof was in poor condition before coating	6	6	0.45	0.53
13	rough (gravel)	3		0	0	-	0.71
			Sloped Roofs and Varied-Sloped Roofs				
14	smooth (3-ply built-up with aluminum coating)	1	flat part of the roof	1	1	0.62	-
15			sloped part of the roof	1	1	0.65	-
16	medium (corrugated aluminum)	1	incomplete coverage of substrate due to substandard coating thickness	3	3	0.62	0.68
17	medium-rough (mineral surface cap sheet)	2	a power washer was used to clean the roof	4	4	0.50	0.65
18	medium-rough (mineral surface cap sheet)	3	flat part of the roof	6	6	0.54	-
19	rough (gravel)	3	sloped part of the roof	6	6	0.66	-
20	smooth cap sheet	1	surrounding trees dropped debris on surface; some staining	0	0	-	0.79
21				1	1	0.59	0.73
22				2	1	0.61	0.76
23	rough (gravel)	3	half of the roof was newly coated	0	0	-	0.73
24	rough (gravel)	3	microbial growth on the other half	15	15	0.30	-
25	rough (gravel)	3		1	1	0.68	-
26	medium-rough (mineral surface cap sheet)	2	dirt caught at strip edges	6	6	0.57	0.67