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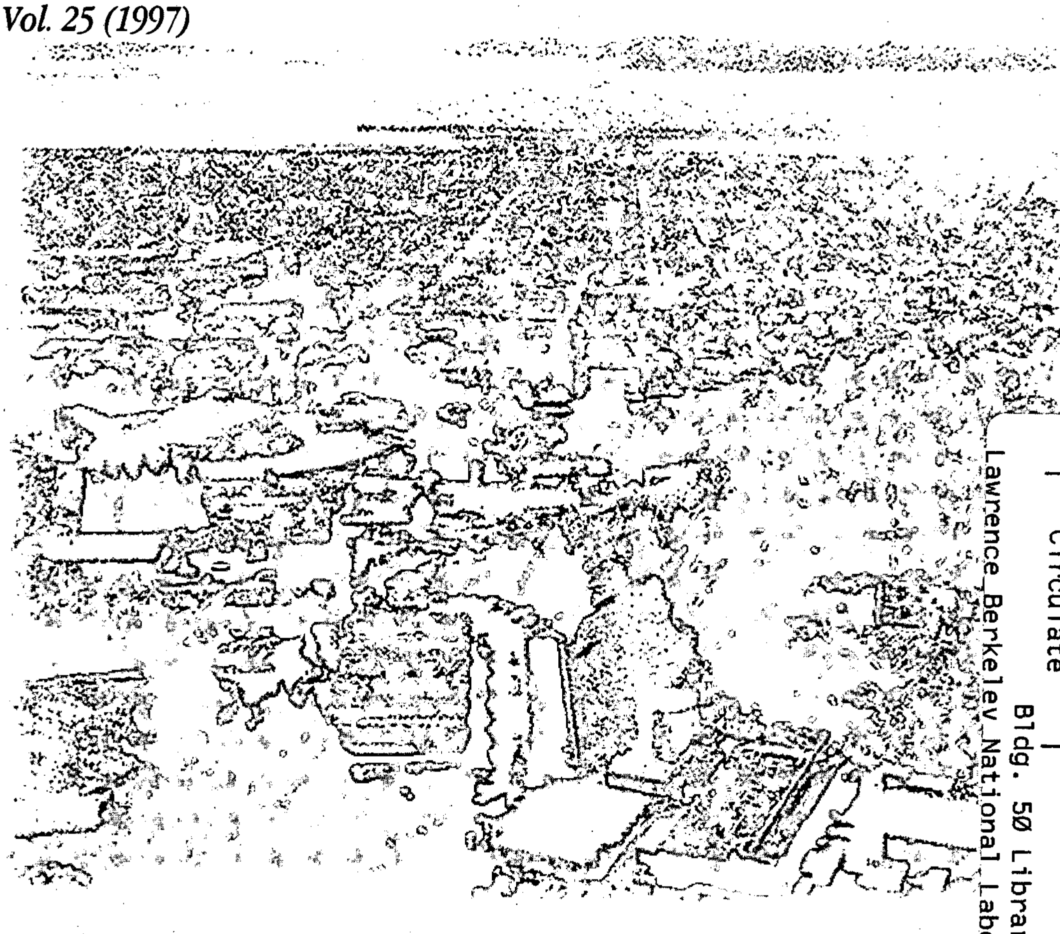

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ABSTRACT

Cooling energy savings of 10 to 70% have been achieved by applying high-albedo coatings to residential buildings in California and Florida. Since dirt accumulation can alter the performance of high-albedo roofs as an energy efficiency measure, we examined some high-albedo coatings at various stages of exposure to determine the magnitude of the effect.

We conclude that most of the albedo degradation of coatings occurred within the first year of application, and even within the first two months of exposure. On one roof, 70% of the drop in albedo for the entire first year occurred within the first two months. After the first year, the degradation slowed, with data indicating small losses in albedo after the second year. We use data from Akbari et al. (1993) to estimate the effects of weathering of white roofs on seasonal cooling energy savings and estimate a 20% reduction from first year energy savings for all subsequent years (2-10). Although washing the roofs with soap is effective at restoring albedo, calculations show that it is not cost-effective to hire someone to clean a high-albedo roof only to achieve energy savings. Instead, it would be useful to develop and identify dirt-resistant high-albedo coatings.

1. INTRODUCTION

High-albedo roof coatings can be used to reduce building cooling loads. By lowering the absorption of solar energy, high-albedo coatings reduce building surface temperatures, and heat-transfer to the building interior. The low surface temperature of a high-albedo coating also reduces the building's contribution to the urban heat island (Akbari et al., 1988). For many parts of the country, cooling energy savings are predicted to outweigh heating penalties, because winter solar gain is reduced by lower sun angles, shorter day lengths, cloudy weather, and snow on the roof. The ratio of cooling-load savings to heating-load penalties for an East Tennessee location with an R-2 insulation value roof section was approximately 2.1

to 1 (Byerley and Christian, 1994). Establishing this ratio for other areas of the country is complicated by the inability of modeling albedo change with many building simulation tools. Akbari et. al (1993) measured cooling energy savings 1.5 times those simulated with DOE-2.1e.

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 emissivity, and 3) maintain these properties for the service life of the coating.

This paper assesses the long-term performance of solar-reflective roof coatings and assesses the use of high-albedo building materials for cooling-energy and peak power savings. In addition to a review of previous research and standard measurement techniques, we present albedo measurements of roof coatings up to 15 years old, and implications of the results for cooling energy savings.

2. BACKGROUND REVIEW

2.1 *Roof Energy Balance*

The temperature of a roof is approximately equal to the sol-air temperature, T_{sa}, defined as

$$T_{sa} = T_o + (\alpha_s I_t - \delta R)/h_o \qquad (1)$$

where,

- T_o = outdoor air temperature, °C
- α_s = absorptivity of the surface for solar radiation (1- albedo)
- I_t = total solar radiation incident on the surface, W/m^2
- δR = difference between thermal radiation incident on the surface and surroundings and that emitted by a blackbody at the outdoor air temperature, W/m^2
- h_o = coefficient of heat transfer by long wave radiation and convection at the outer surface, $W/m^{2\circ}C$.

Changes in the emittance as weathering occurs are probably not significant, assuming the material has a high emissivity initially (this is true for most non-metals). Albedo, however, is likely to decrease if the initial albedo is high, 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 solubility. Microbial growth is more common in humid areas of the country, as implied by the perceptions of roofing contractors around the U.S.(Figure 1). Degradation, however, may 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).

[Figure 1 goes here.]

Roof coatings generally have been promoted for their ability to protect the roofing membrane from ultraviolet degradation. White roof coatings have the added benefit of reducing cooling load because of their reflectivity. Figure 2 is a photograph showing a black asphalt shingle roof that was coated with a high-albedo coating. Where the roof was not coated, the shingles cracked and shrank, partly because of thermal expansion and contraction and partly because of the UV blocking capabilities of the coating which protected the asphalt component of the shingle from degradation (Kirn, 1994).

[Figure 2 goes here.]

2.2 *Literature Review*

The effects of one year equivalent solar exposure on the albedos of five white elastomeric coatings were measured by Anderson (1992). The coating surfaces were tilted to minimize the effects of dirt accumulation. Since the changes in albedo seen on these coatings were minimal, we expect that for typical white coatings, most of the decrease in albedo is caused by the accumulation of airborne particles on the surface, and not from permanent degradation caused by sunlight (Byerley and Christian, 1994).

Under controlled conditions, in Florida, 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 membrane, a two-year-old white EPDM membrane, and a new, beige-colored EPDM membrane that was found to approximate the solar reflectance of a very dirty or oxidized white roof. The cooling-energy savings for a white membrane in reference to a black membrane on a 930 m^2 R-5 ft^2-h-degrees 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, bringing the savings down to $3.37/day. But the time it would take for the roof to reach a very dirty white is unknown.

Griggs and Shipp (1988) calculated effective solar reflectance values for black and white roofing membranes over a 75-week period of outdoor exposure in eastern Tennessee. Their calculations indicated that the white membrane's effective solar reflectance initially decreased from 0.8 to 0.7 during the first three months of exposure. A more gradual decrease to an effective solar reflectance of 0.55 continued to the end of the 75-week period.

Byerley and Christian (1994) monitored surface temperature, heat flux and solar reflectance of a white roof coating and a black EPDM in Tennessee over a 3.5 year period. During that time, solar reflectance of the white coating dropped from 0.80 to 0.59, with most of the decrease occurring during the first year (Byerley, 1993). In comparison, the solar reflectance of a white latex (acrylic) roof coating dropped from 0.56 to 0.43 in 1 year. They found washing to be effective, but did not quantify the resulting change in terms of solar reflectance.

2.3 *Methods of Measuring Albedo*

In this paper, we use the term albedo to refer to the integrated hemispherical reflectance between 0.28 and 2.8 micrometers (μm), a band that includes ultra-violet, visible, and near infrared radiation. Some clarification is needed for the term "albedo" as applied to a sloped roof. 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 received by a horizontal roof. 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 out-going radiation).

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 2.5μm. 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 (ASTM, 1992c).

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 (Berdahl and Bretz, 1994; Parker et al., 1993). Yarbrough and Anderson (1993) provide overall solar reflectance values for some high-albedo roof coatings. Their measurements indicate that coatings must be applied at a minimum critical thickness to obtain optimum solar reflectance. Of course, this minimum critical thickness depends on the coating. The implication is that a cost comparison of coatings should compare cost per unit thickness, which depends on percent solids by volume, rather than the cost per unit volume ($/gallon) comparison that is often used.

Field measurements of albedo typically involve the use of a radiometer for measuring the incident and reflected radiant flux. Our measurements are done in accordance with the draft Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field (ASTM E-06 Task Group, 1995a). We use a high precision pyranometer 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 is designed to minimize the effects of the pyranometer's shadow and radiation reflected by surroundings. 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 (about 4 meter in diameter). 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, which are based on surface reflectance of visible radiation. Roof coating manufacturers may claim reflectances of over 90%, citing various test methods that involve a visual comparison of a test sample and standard (ASTM, 1992a). These measurements are subjective and do not include the near infrared bands. And since nearly half the incoming solar flux lies in the near-infrared, reflectance measurements can be fairly different from full solar reflectance values.

2.4 *Standards for Measurements of Weathering*

Various types of weathering effects can be evaluated individually by standard test methods devised by American Society of Testing and Measurement (ASTM). All of these methods, however, rely on visual comparison with photographic reference standards. Such methods cannot be relied upon to provide information for energy efficiency purposes because the eye is not capable of judging the reflected flux. The method for evaluating microbial growth, however, may be adequate for identifying resistance to growth.

At this time, there are no standards for measuring albedo degradation. There are also no standards for assessing a coating's resistance to dirt pick-up or cleaning. Neither have there been evaluations of the ability of coatings to retain high-albedo and high emissivity (Yarbrough and Anderson, 1993). Kirn (1994) describes a method of comparing the weatherability of white roof coatings by soiling samples with iron oxide. Such a method of soiling could be combined with the ASTM E-903 method of calculating effective solar reflectance to produce laboratory measurements of relative weatherability. We note that when considering a decline in albedo, it is the absolute value that is important, not the percentage of the original albedo.

The Task Group under ASTM E-06 for Development and Exploitation of Cool Construction Materials has a draft Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low- Sloped Surfaces (ASTM E-06 Task Group, 1995b). The procedure recommended in that standard will allow a direct comparison of the steady-state temperatures (SSTs) of surfaces under the sun. A standardized method of evaluating the performance of high-albedo coatings will probably involve a standardized method of weathering.

3. METHODOLOGY

We used field albedo measurements to quantify the decline in solar-reflectance of high-albedo roofs over time. We also used laboratory measurements for albedos of freshly-prepared samples of these coatings. The following sections describe the methods we used, and the results, followed by a discussion of the implications for cooling-energy savings.

3.1. *Experimental Approach*

A field study of different roofs, each surfaced at a different time with one of three coatings as used to assess the effects of weathering on high-albedo roof coatings. 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 of measuring many roofs 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 as a basis for estimating the unpolluted albedos of the coatings.

3.2. *Selection of Roofs and Samples*

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

[Table 1 goes here.]

3.3. *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 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).

4. RESULTS

4.1. *Measured Decrease in Albedo over Time*

To facilitate data analysis, roofs were separated into categories of smooth, medium, and rough substrates. A rough substrate can result in a smaller surface albedo because of geometrical effects (multiple reflections) and because airborne particulates can accumulate in depressions on the surface. Figure 3 shows the effect of two months to six years of accumulation of environmental pollutants on the albedos 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.

[Figure 3 goes here.]

The estimated decrease in albedo during one year averaged 0.15 and ranged from 0.05 for sloped gravel roofs with Coating #3 to 0.23 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 few months. The cementitious coating on gravel exhibited the smallest and most gradual decrease in albedo. After one year of weathering, the trend for this combination indicated a decline in albedo of 0.03. After six years, it was 0.05, indicating that approximately three fifths of a six year albedo decline may 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).

We did not collect many data points for roofs that had been coated more than six years earlier. 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. Microbial growth varies according to the climate (see Figure 1).

4.2. *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 are able to estimate the impact of dirt accumulation on the long-term cooling energy savings. For our calculations, we use a linear approximation of the relationship between cooling-energy savings and albedo. According to the sol-air calculation shown in Section 2, 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.

Measured cooling-energy savings from increasing roof albedo at a house in Sacramento with an R-11 ft^2-h-° F/Btu roof, were 80% (270 kWh/year) (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 ($\delta A = 0.55$). The measured energy savings of 80% during the first summer include the effect of dirt accumulation on the roof, so the first year savings estimates are robust. In the second summer, the albedo of the roof had dropped to 0.61($\delta A = 0.43$). Thus, we estimate long-term cooling energy savings to be 20% lower than first year savings (64% cooling energy savings), because of a change in albedo.

At another site, where two buildings with R-19 ft^2-h-°F/Btu roofs were measured in parallel, a 34% cooling-energy savings (330 kWh/year) 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 post-first-year summers for these buildings also would have dropped by about 20% of first year savings (to 27% cooling-energy savings).

4.3 *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. 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.

[Table 2 goes here.]

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 surfaces were washed with soap, the albedo was restored to within 90% of the original value, indicating that the loss of albedo was not permanent, and was caused by dirt accumulation rather than by UV or hydrolytic degradation.

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 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 Cost of Conserved Energy (CCE) worked out to be ~70 ¢/kWh, far above the average cost of electricity to residential customers. Hosing off a roof, which produced an increase in albedo of 0.05, resulted in a CCE of ~60 ¢/kWh, for a one person-hour cost of $25. Although savings estimates are largely dependent on the climate and house characteristics, 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 is appropriate for other reasons 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 coating that are easier to clean with hosing only.

4.4 *Spectral Reflectance Measurements*

Results from the spectrophotometer with integrating sphere for the unexposed laboratory samples described in Table 1 and titanium dioxide pigment, 0.2 μm particle size, are shown in Figure 4. The standard solar spectral irradiance is shown in the background.

[Figure 4 goes here.]

As with the rooftop measurements, the purpose of the spectral measurements is not to compare reflectance values between coatings, because the samples vary in terms of thickness and substrate, as shown in Table 1. Note that this sample is far thicker than the recommended thickness of 24 mils. Coating #2 had a thickness of 1.0μm and was therefore exhibiting maximum reflectance for that coating, 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 of the roughness of the substrate, in addition to the sub-standard coating thickness.

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 consistent 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).

5. CONCLUSION

Our study shows that aging of high-albedo roofs is not a significant barrier to their application for building energy efficiency improvements. The albedo over the long term depends on the coating itself, the texture of the surface, the slope of the roof and the nearby sources of dirt and debris. From the roofs we measured, we estimate an average decrease in albedo of 0.15 in the first year, and much more gradual decline after the first year. Measured cooling-energy savings from other studies, however, include the effects of this decrease in albedo. After the second year, the incremental decrease in albedo can be small. We apply a 20% factor, reducing cooling energy saving estimates in Akbari et.al (1993) to 27-64% of total cooling after the first year.

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-lived. 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 long term exposure testing of high-albedo coatings.

This study was not designed to compare the relative weatherability of various coatings. Further studies are necessary to link coating type and surface physical characteristics with long-term reflectance. Coating comparisons require controlled conditions and perhaps 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 ability to maintain a high-albedo.

6. ACKNOWLEDGEMENTS

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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 goes here.]

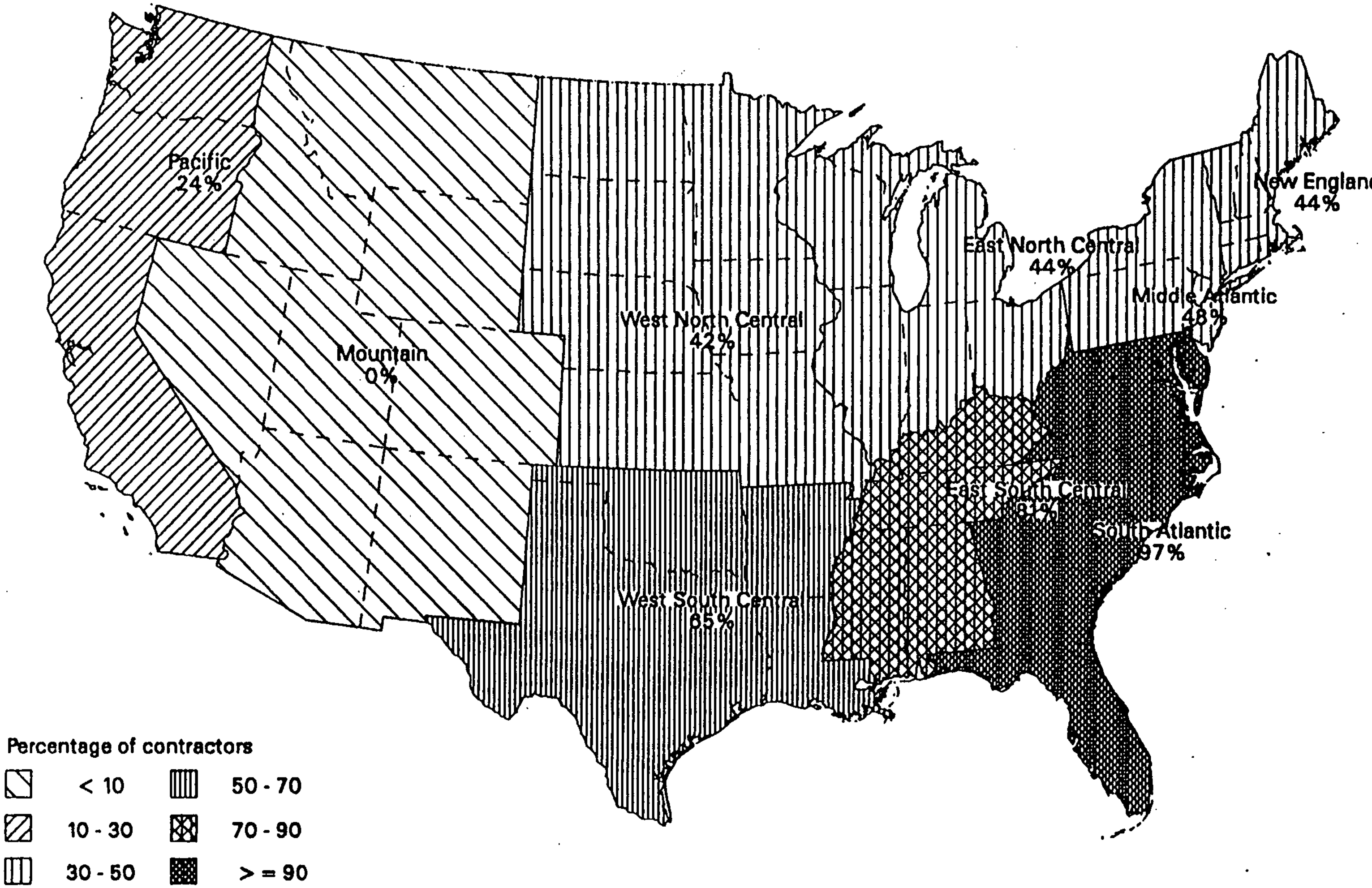

Figure 1. Percentage of Contractors Considering Algae Staining to be a Problem in Their Area. Source: "Gaining on the Algae Problem," Roofer Magazine, June 1995, pp. 21-24

Figure 2. Photograph showing an asphalt shingle roof that was partially coated with a high-albedo coating. The uncoated (dark-colored) shingles have contracted and cracked but the coated shingles have not. Courtesy of Bill Kirn, Rohm and Haas Company.

Table 1. *Roof Coating Samples for Hemispherical Spectral Reflectance Measurements*

Coating Number	Dry Film Thickness* mm	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 0.73kg/m^2, assuming a density of 1105 kg/m^2. Density was estimated from the manufacturer's information on the coating's formulation.

Table 2. *Albedo Restoration of Roofs Coated with 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

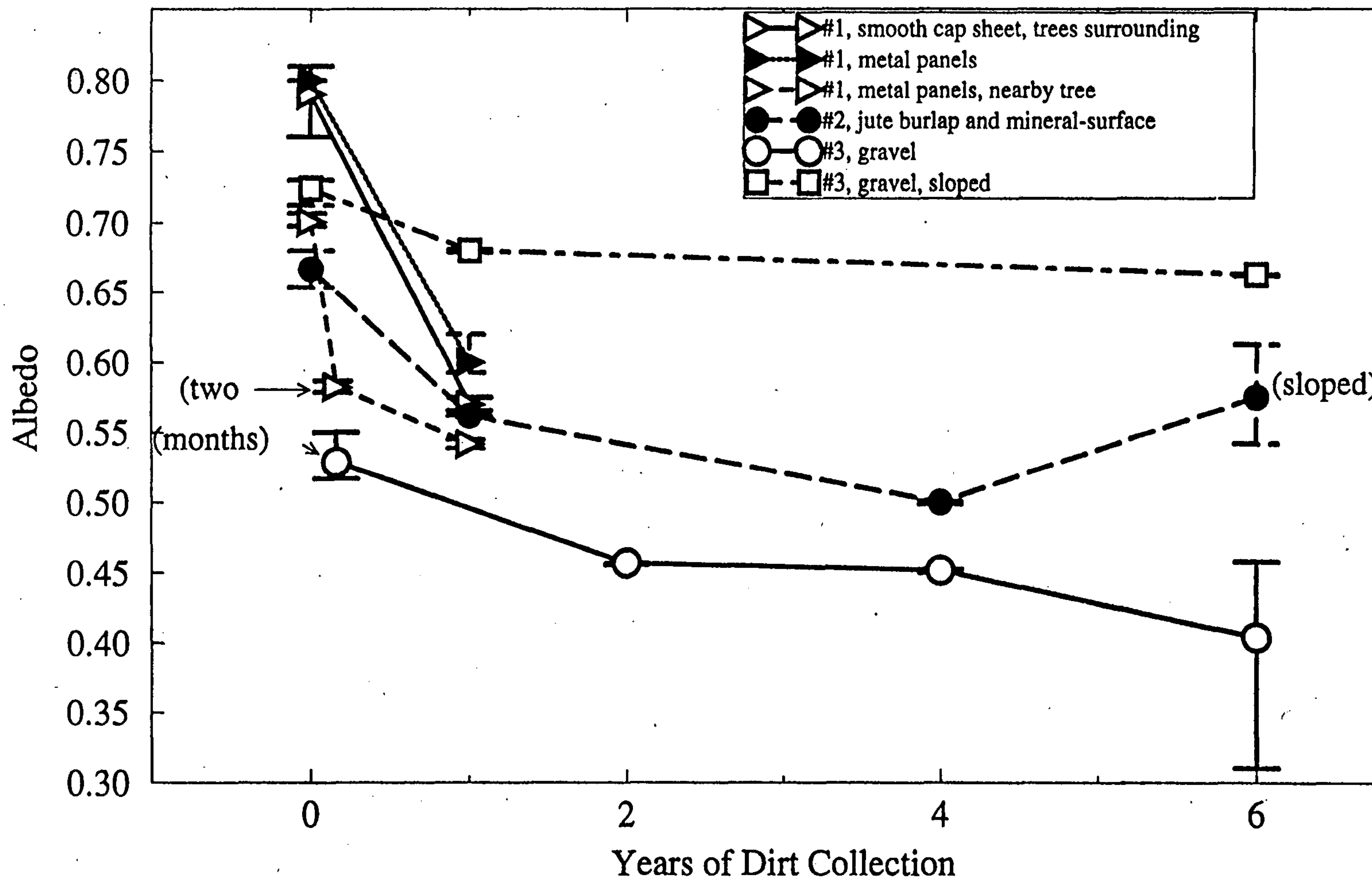

Figure ~~1~~ 3. Albedo vs. exposure for 3 roof coatings, on different substrates. Years of dirt collection are either years since the roof was coated or years since the last thorough washing. Roofs are flat, except where noted.

Figure 4. Spectral reflectance of five white roof coatings. Also shown is the shape of the solar spectrum (lower curve), which indicates how the solar energy is distributed over wavelength.

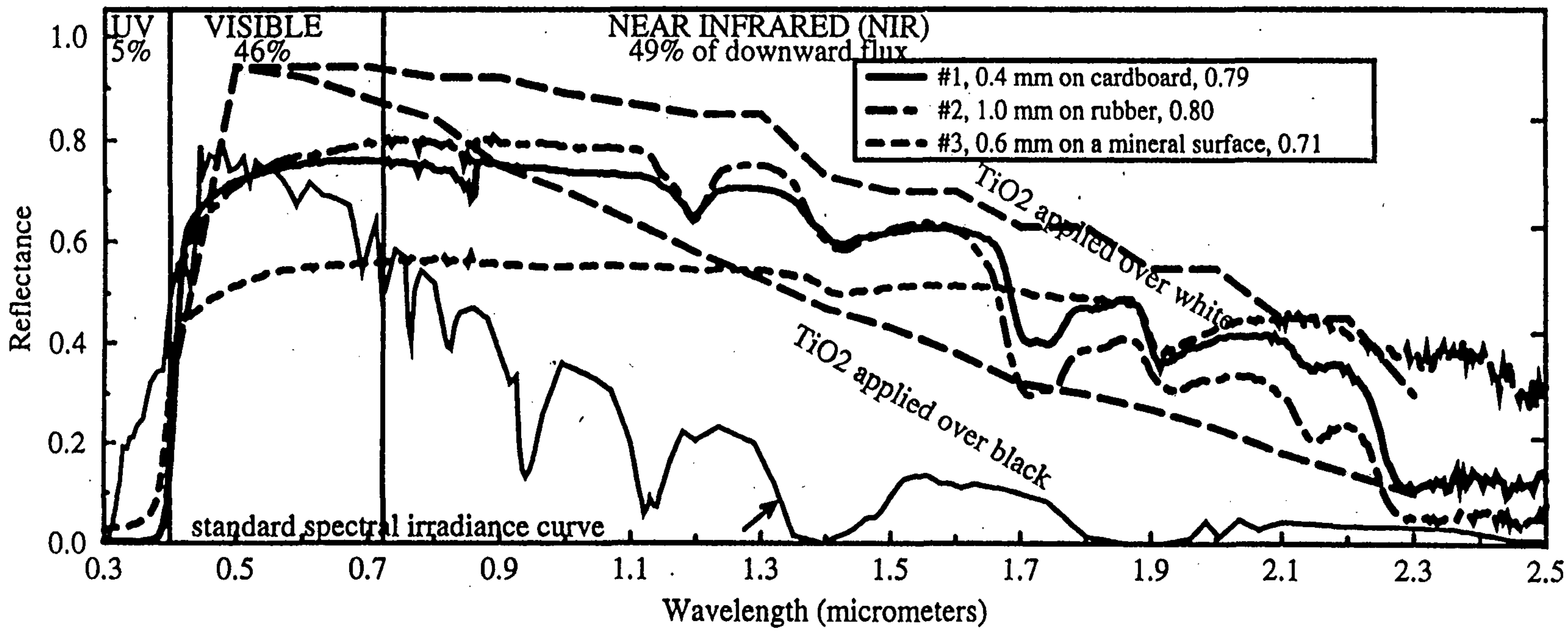
UV 5%
VISIBLE 46%
NEAR INFRARED (NIR) 49% of downward flux
#1, 0.4 mm on cardboard, 0.79
#2, 1.0 mm on rubber, 0.80
#3, 0.6 mm on a mineral surface, 0.71
TiO2 applied over white
TiO2 applied over black
standard spectral irradiance curve
Reflectance
Wavelength (micrometers)
1.0
0.8
0.6
0.4
0.2
0.0
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5

Figure 4

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

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