Aging and Weathering of Cool Roofing Membranes

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ABSTRACT

Aging and weathering can reduce the solar reflectance of cool roofing materials. This paper summarizes laboratory measurements of the solar spectral reflectance of unweathered, weathered, and cleaned samples collected from single-ply roofing membranes at various sites across the United States. Fifteen samples were examined in each of the following six conditions: unweathered; weathered; weathered and brushed; weathered, brushed and then rinsed with water; weathered, brushed, rinsed with water, and then washed with soap and water; and weathered, brushed, rinsed with water, washed with soap and water, and then washed with an algaecide. Another 25 samples from 25 roofs across the United States and Canada were measured in their unweathered state, weathered, and weathered and wiped.

We document reduction in reflectivity resulted from various soiling mechanisms and provide data on the effectiveness of various cleaning approaches. Results indicate that although the majority of samples after being washed with detergent could be brought to within 90% of their unweathered reflectivity, in some instances an algaecide was required to restore this level of reflectivity.

Introduction

The solar reflectance or albedo of a roof's surface affects roof temperature, air temperature above the roof, and the heating and cooling energy use in buildings (Akbari and Konopacki, 1998). Lighter colored roofing membranes, including those covered with high-albedo, low-absorptance, white coating materials, reflect incident solar energy, enabling them to stay cooler in the sun than low-albedo roofing materials. Young (1998) and Akbari and Konopacki (1998) found that cool roofing membranes can reduce building cooling energy use by 10% to 50%, that can result in savings of \$10 to \$100 per year per 100 m^2 roof surface. In cities, cool roofs can reduce summertime air temperature of their surroundings by 1-2 K (Akbari and Konopacki, 1998; Young, 1998; Pomerantz et al., 1999 and Akbari et al., 1999).

Cool materials for low-sloped roofs are characteristically white with smooth surfaces (Eilert, 2000). But the albedo of light-colored roofing materials changes, because of aging, weathering, and discoloration—which results from weathering. In this paper, we present data from two independent series of tests carried out at Lawrence Berkeley National Laboratory (LBNL) and National Research Council (NRC) in Canada. The LBNL study included measuring the spectral solar reflectance of 15 weathered roofing membranes from eight cities across the United States. The study also investigated the effect of four cleaning treatments in restoring the reflectance relative to its original levels. The NRC study also included measuring the solar reflectance of 25 weathered roofing membranes from 25 cities across the United States and Canada. But only the effects of two cumulative cleaning processes in restoring the solar reflectance were measured. All membranes were produced by the same manufacturer.

Effects of Light Colored Roofs

Roof temperature strongly influences air temperature inside and outside of buildings. Solar absorptance, thermal emittance, convection coefficient, and heat conduction through a roofing membrane, all affect the roof surface temperature (Pomerantz et al., 1999). Consequently, lighter colored (reflective), cool roofs reduce the demand for indoor cooling by controlling the temperature from the outside and therefore heat flow into buildings.

The reduction in annual electricity use resulting from the application of cool roofs is greatest for buildings in areas with short cold seasons, because cool roofs have the potential to increase heating energy demand during extended cold periods (Levinson et al., 2005). However, significant annual net energy savings have been calculated for northern locations such as Chicago, Salt Lake City, and Toronto, through the implementation of heat island reduction strategies (Akbari and Konopacki, 2004; Konopacki and Akbari, 2002).

Recognizing the potential energy savings that could be achieved through the use of reflective roofing materials, the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE) introduced the Energy Star Roof Products Program in 1999. Energy Star labeled membranes must meet defined minimum reflectivity levels according to their intended applications (low and high slope). Looking to curb energy demand, beginning in 2005, the State of California will prescribe the use of cool roofs on low-sloped non-residential buildings in their Title 24 Energy Code.

The reduced temperatures of reflective roofing surfaces, in turn, keeps air blowing over the roof and downwind from the buildings cooler (Taha, 1996). In large metropolitan areas, this contributes to a reduction in the urban heat island which reduces smog formation and the greenhouse effect (Akbari et al, 1990, 1999, 2001; Akbari and Konopacki, 1998; Pomerantz et al., 1999).

The United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) recognizes these benefits by awarding a point for the use of highly reflective and emissive roof materials in their green building rating system. The City of Chicago is looking to introduce an urban heat island ordinance that would call for the use of high reflectance roof materials beginning in 2008.

Typically, all non-metallic materials absorb the sun energy in the ultraviolet (UV) band (0.30-0.40 μm). Ultraviolet light is characterized as the major factor in aging and material degradation. Although the aging is primarily caused by UV absorption, the degradation process is highly temperature dependent. For the same UV absorption, the higher the temperature and temperature fluctuations through a day, the faster the material degrades. Reflective surfaces, by keeping the surface temperature low during the sunlit hours that result in less diurnal thermal expansion and contraction, may have a longer useful life.

Cooler roof surface temperatures have also been found to improve the performance of roof insulation. The thermal resistance of insulation materials installed immediately below a black membrane has been found to be up to 30% lower than advertised, when measured at peak summertime temperatures in Austin, Texas (Konopacki and Akbari. 2001).

Effect of Aging and Weathering

The durability and solar reflectance of high albedo, cool roofs is affected by weathering (Paroli et al., 1993). Precipitation, dust and air pollutant depositions can degrade the solar reflectance of cool roof materials (Eilert, 2000). Over a period of several years, light colored roofing surfaces are typically expected to lose about 20% of their initial solar reflectance. Aged roofing membranes show a greater increase in absorptance on short wavelengths than long wavelengths (Berdahl et al., 2002).

Berdahl et al. (2002) indicated that the soil deposited on the surface of roofing membranes is made up of elemental carbon, hydrocarbons and other deposits that along with the soil further reduce the reflectivity of the membranes. Soiling and accumulation of carbonaceous particles is a serious problem in or around urban centers that are exposed to higher levels of fossil fuel combustion. Since carbonaceous aerosols can travel fast in the mixing atmosphere, they can spread to both urban and rural places to create a similar effect.

Methodology

To investigate these and other related phenomena, this study was carried out on 15 membranes from eight locations that have been weathered for five to eight years and additional membranes from 25 other locations (Whelan et al., 2004), exposed 15 to 22 years. Solar (0.3 – 2.5 μm), UV (0.3 – 0.4 μm), visible (0.4 – 0.7 μm), and near-infrared (0.7 – 2.5 μm) reflectances were analyzed.

Sample Description

The LBNL received weathered membranes (about 30-cm square) from 15 roofs while the NRC received membranes from 25 roofs. All samples contained at least one hot air welded seam. The bottom flap of material within the overlap was protected from weathering (but may still have been exposed to some elevated temperatures) and is thus labeled "unweathered." The roofing membranes were made of about 1.2-mm to 1.5-mm thick polyvinyl chloride (PVC). The top half of most of the samples was white from the use of a rutile-phase titanium dioxide (TiO_2) pigment, while a few were very light gray in color. The 15 LBNL roof membrane samples were collected from eight locations where they had been installed for five to eight years (see Table 1). The 25 NRC roof membrane samples were from various locations in the United States and Canada, and had a top surface which was light gray in color. Buildings selected for sampling were chosen based on owner willingness to allow sample removal, and geographic and climate location.

Measurement Protocols

Although some membranes received at LBNL were more soiled than others, all the samples appeared to be in good mechanical condition when the measurements were taken. For each sample, the most heavily soiled spot of each membrane was exposed to the different cleaning treatments.

The cleaning process was made to replicate natural and professional cleaning of the roofs, as given in Table 2. The unweathered samples refer to the part of the sample that was underneath the weathered part (i.e., in the overlap) and was assumed to have the optical properties of new membrane. The weathered samples were the soiled exposed samples. On each sample, we carried out a progression of four cleaning processes. First, each sample was dry wiped to simulate the effect of the dust removal by wind. After the measurements of the dry wiped samples, they were rinsed with running water to simulate the effect of rain. Samples were also washed with detergent and sodium hypochlorite (NaClO) and sodium hydroxide (NaOH) solution (algae cleaners) to simulate the effect of professional cleaning. The unweathered and uncleaned samples were handled in such a way so as not to alter the conditions under which they were collected. For each of the wet cleaning treatments, the sample was allowed to dry before the spectral reflectance measurements were taken.

For the samples received at the NRC, specimens taken from two different areas (1 and 2) of the "as received" top (weathered) sheet were analyzed before and after cleaning. Cleaning was achieved by using water and a cloth to wipe off the dirt. No detergent or algaecide was used. One to two specimens from the bottom sheet (underlap) without cleaning were analyzed. In some cases, two specimens were analyzed before and after cleaning. This was done to check for differences in the solar reflectivity values between the two areas or between the dirty and clean top surface of the bottom sheet.

All samples were analyzed using a Varian Cary-5 UV-Vis-NIR spectrophotometer equipped with a total integrating sphere (ASTM 1996). Spectral reflectance measurements were weighted according to the ASTM G 159-98 to obtain the overall solar reflectance (ASTM, 1998). This standard is a combination of an editorial revision of tables E 891 and E 892 to make the reference solar spectral energy standard harmonious with ISO 9845-11992. The ASTM G 159 states that the conditions chosen for these tables "are representative of average conditions in the 48 contiguous states of the United States. In real life, a large range of atmospheric conditions can be encountered, resulting in more or less important variations in the atmospheric extinction. Thus, considerable departure from the present reference spectra might be observed depending on time of the day, geographical location, and other fluctuating conditions in the atmosphere."

Tables 1 and 3 summarize the weighted average solar reflectance values for the samples received at the LBNL and NRC.

Results

The results of the LBNL measurements are summarized in Table 1 and Figures 1 and 2. The samples can be divided in two groups: Group A with the unweathered solar reflectance of about 0.80 (see Figure 1) and Group B with unweathered solar reflectance of about 0.63 (see Figure 2).

The solar reflectance of the weathered samples in Group A ranged from 0.32 to 0.71 with a median of 0.55 (see Figure 3). With wiping, the solar reflectance improved to 0.42 to 0.75 with a median of 0.69. Rinsing with water improved the solar reflectance to 0.59 to 0.75 with a median of 0.71. Further washing with detergent improved the solar reflectance to 0.65 to 0.80 with a median of 0.77. And washing with an algae cleaner practically restored the solar reflectance of the samples to their unweathered values (the range was 0.77 to 0.82 with a median of 0.80). The solar reflectance of the unweathered samples ranged from 0.79 to 0.82 with a median of 0.80.

There were only four samples in Group B. The solar reflectance of these unweathered samples was 0.63 (see Figure 4). The solar reflectance of the weathered samples in Group B ranged from 0.48 to 50. Wiping and rinsing with water improved the solar reflectance to 0.59 to 0.62, practically approaching the solar reflectance of the unweathered samples.

The results of the NRC measurements are summarized in Table 3 (see also Figure 5). The weighted average solar reflectance for the unweathered (bottom) and weathered (top) surfaces of the gray colored samples ranges from 0.29 to 0.55. As should be expected, surfaces display a higher reflectance value after cleaning. The top side of the bottom (unweathered) sheet also showed higher solar reflectance than the weathered side of the top sheet. Only 10 surfaces (bottom and/or top) out of the 25 tested have slightly over 0.5 solar reflectance. Based on previous work done at the NRC, bottom flaps can be used as a reference material when no original material is available. In most cases, the bottom flap retains most, if not all, of the original properties. It was decided that this would also be done for the reflectivity data. However, in some cases, the bottom flap was found to be dirty and had to be cleaned. It is speculated that the bottom flap may have picked up dirt at the time of installation simply from the environment.

In summary, it is interesting to note that a simple cleaning with water and cloth allowed the samples to regain a substantial part of their original reflectivity.

Conclusion

The experiments conducted at the LBNL suggest that for the PVC roofing materials studied that are not covered with algae, wiping and rinsing with water (simulating the annual cleaning by rain) have restored the solar reflectance of the sample to at least 80% of the solar reflectance of the unweathered samples. For samples with algae, washing with detergent and algae-cleaners has practically restored the solar reflectance of the weathered roofing membranes to the solar reflectance of the unweathered membranes.

The solar reflectance measurements from the NRC indicated that with a few exceptions, all roofs have a weighted averaged solar reflectance of less than 0.6. There was no unweathered material available at the time of the analysis. Hence, no final conclusions can be drawn about the effect of weathering on solar reflectance of the roof material analyzed. However, as in the case of the samples analyzed by the LBNL, at least 70%, and as much as 100%, of the initial reflectivity was regained by simply washing the PVC membranes with water (no cleaning detergent).

Thus, if high reflectivity is critical to the roof owner, then it would be recommended that the regular maintenance protocol include power washing the membrane on a frequency to be determined according to the roof's requirements.

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Table 1: Location, Length of Time Since Installation, and Solar Reflectance of Weathered and Cleaned Samples, Studied at the LBNL

Sample			Solar Reflectance					
Sample No.	Location	Date of Installation	Uncleaned	Wiped	Rinsed	Detergent-Washed	Algae-Cleaner Washed	Unweathered
Group A (white)								
1	Springfield, MA	09/22/1995	0.54	0.68	0.70	0.77	0.82	0.80
2	Springfield, MA	05/31/1995	0.55	0.73	0.72	0.76	0.77	0.82
3	Lancaster, OH	03/28/1995	0.59	0.76	0.75	0.80	0.81	0.81
4	Heath, OH	04/01/1995	0.57	0.72	0.72	0.78	0.79	0.80
5	West Hampton, NJ	05/01/1995	0.71	0.71	0.71	0.73	0.77	0.79
6	West Hampton, NJ	02/04/1993	0.69	0.69	0.71	0.72	0.77	0.81
7	Plantation, FL	11/04/1994	0.35	0.43	0.64	0.65	0.79	0.82
8	Plantation, FL	11/04/1994	0.32	0.42	0.59	0.68	0.80	0.79
11	Solano Beach, CA	09/20/1992	0.38	0.47	0.71	0.78	0.82	0.81
12	Solano Beach, CA	09/20/1992	0.52	0.65	0.69	0.80	0.80	0.81
13	Alpharetta, GA	04/01/1995	0.45	0.59	0.66	0.69	0.79	0.80
Group B (very light gray)								
9	Gardena, CA	10/25/1995	0.50	0.58	0.60	0.62	0.63	0.63
10	Gardena, CA	10/25/1995	0.49	0.60	0.61	0.63	0.63	0.63
14	Bethesda, MD	04/28/1995	0.50	0.59	0.59	0.63	0.64	0.63
15	Fredericksburg, VA	11/06/1995	0.48	0.60	0.62	0.63	0.64	0.63

Note: The cleaning process was cumulative. All samples went through a cleaning process progression of dry wiping, rinsing with water, washing with detergent, and washing with algae cleaners.

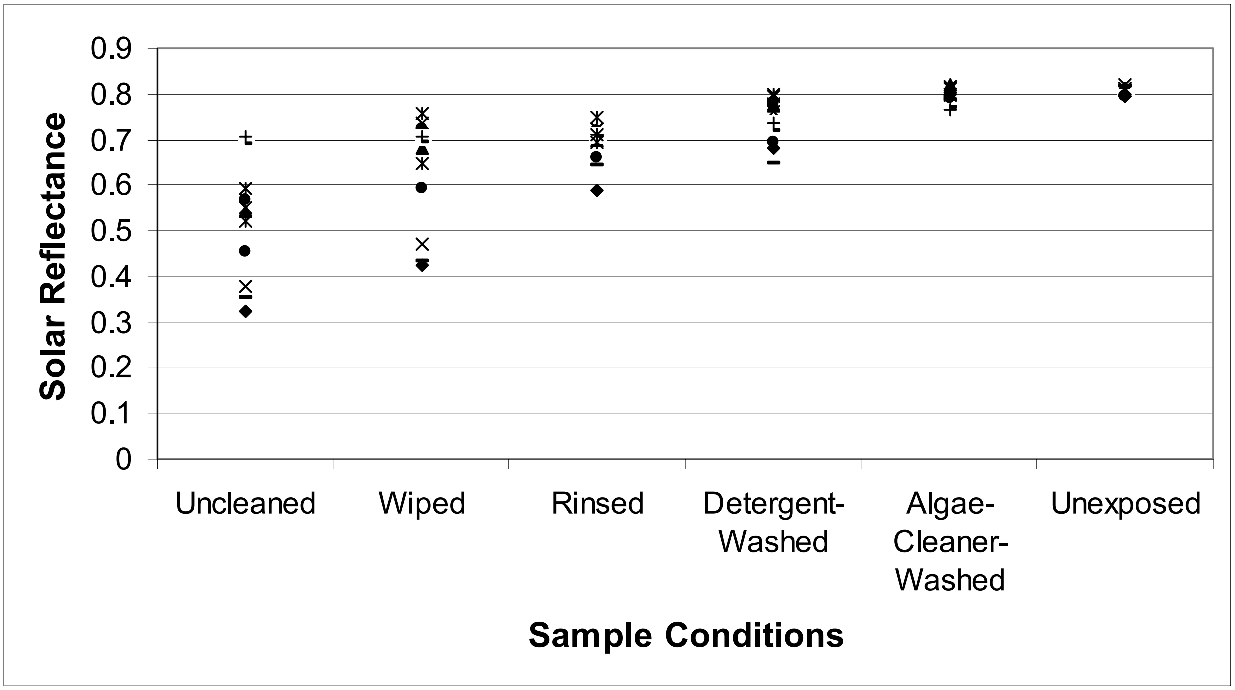
Table 2: Cleaning Processes

Sample	Cleaning Process	To Replicate
Unexposed	None	**Unweathered, aged condition**
Uncleaned	None	**Weathered, aged condition**
Wiped	Wiped with dry cloth	**Effect of wind and sweeping**
Rinsed	Rinsed with running water	**Effect of rain**
Detergent-Washed	Phosphate-free household detergent with brush	**Professional cleaning**
Algae-Cleaner Washed	Sodium Hypochlorite (NaClO) and Sodium Hydroxide (NaOH) solution, with brush	**Professional cleaning**

Table 3: Weighted Average Solar Reflectance of Samples Studied at the NRC

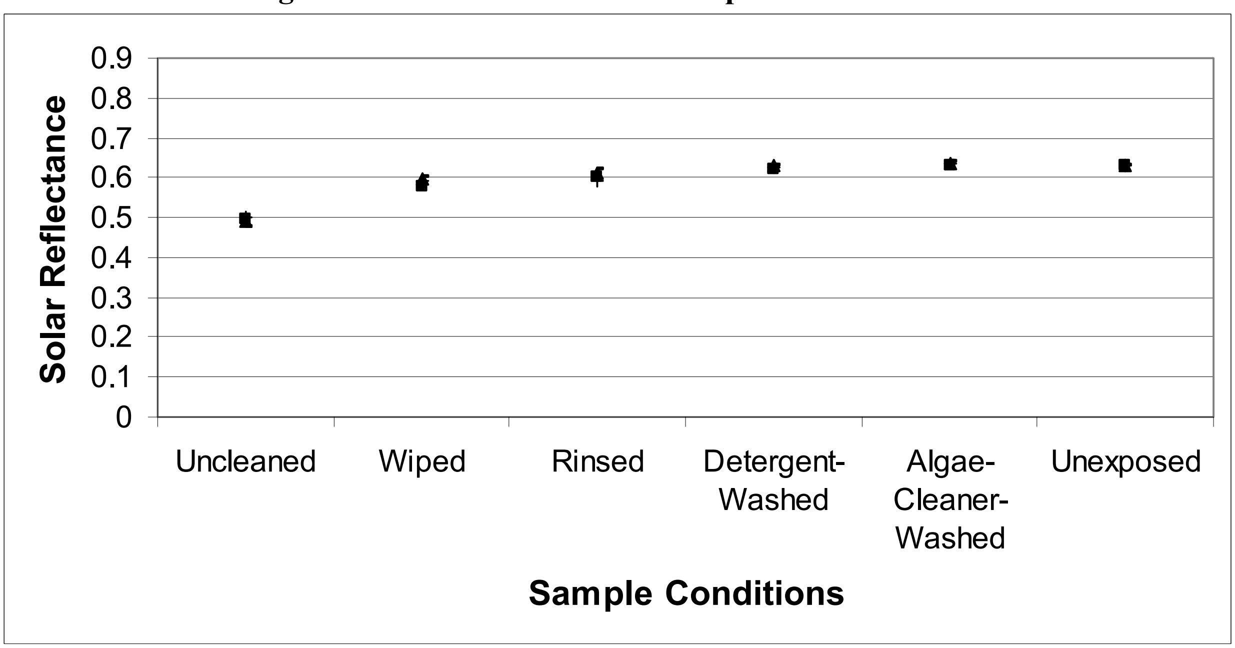
Sample			Solar reflectance		
Sample ID	Location	Year Installed	Top: Uncleaned	Top: Washed and Wiped	Bottom: Unweathered
1D	Canton, MA	1979	0.48	0.50	0.52
2A	Wenham, MA	1984	0.32	0.41	0.55
2D	Wenham, MA	1984	0.39	0.44	0.51
3A	Woburn, MA	1983	0.39	0.41	0.48
4B	Dickson, TX	1984	0.40	0.45	0.49
5B	Tyler, TX	1981	0.41	0.46	0.50
6A	Euless, TX	1984	0.42	0.49	0.51
7A	City of Industry, CA	1979	0.44	0.50	0.53
8A	El Segundo, CA	1982	0.39	0.43	0.50
9B	Mountain View, CA	1983	0.40	0.45	0.52
10B	Lacey, WA	1982	0.40	0.43	0.51
11B	Ft. Steilacoom, WA	1983	0.45	0.47	0.52
12A	Atlanta, GA	1986	0.42	0.48	0.50
13A	Jacksonville, FL	1982	0.41	0.47	0.52
14A	Appleton, WI	1985	0.38	0.44	0.49
15B	Mt. Prospect, IL	1981	0.33	0.39	0.49
15D	Mt. Prospect, IL	1981	0.50	0.52	0.54
16A	Park Ridge, IL	1984	0.35	0.42	0.50
17B	Hackensack, NJ	1986	0.35	0.41	0.50
18A	Englewood, NJ	1985	0.39	0.43	0.48
18C	Englewood, NJ	1985	0.32	0.37	0.48
19A	Iowa, IA	1982	0.34	0.4	0.49
20B	Davis, CA	1981	0.47	0.49	0.52
21A	Haileybury, ON	1981	0.48	0.49	0.55
21C	Haileybury, ON	1981	0.44	0.47	0.51
22A	Hamilton, ON	1984	0.34	0.38	0.51
24A	Oakville, ON	1977	0.43	0.46	0.48
25A	Sarnia, ON	1984	0.37	0.43	0.50

Figure 1: Solar Reflectance of Samples 1-8 and 11-13



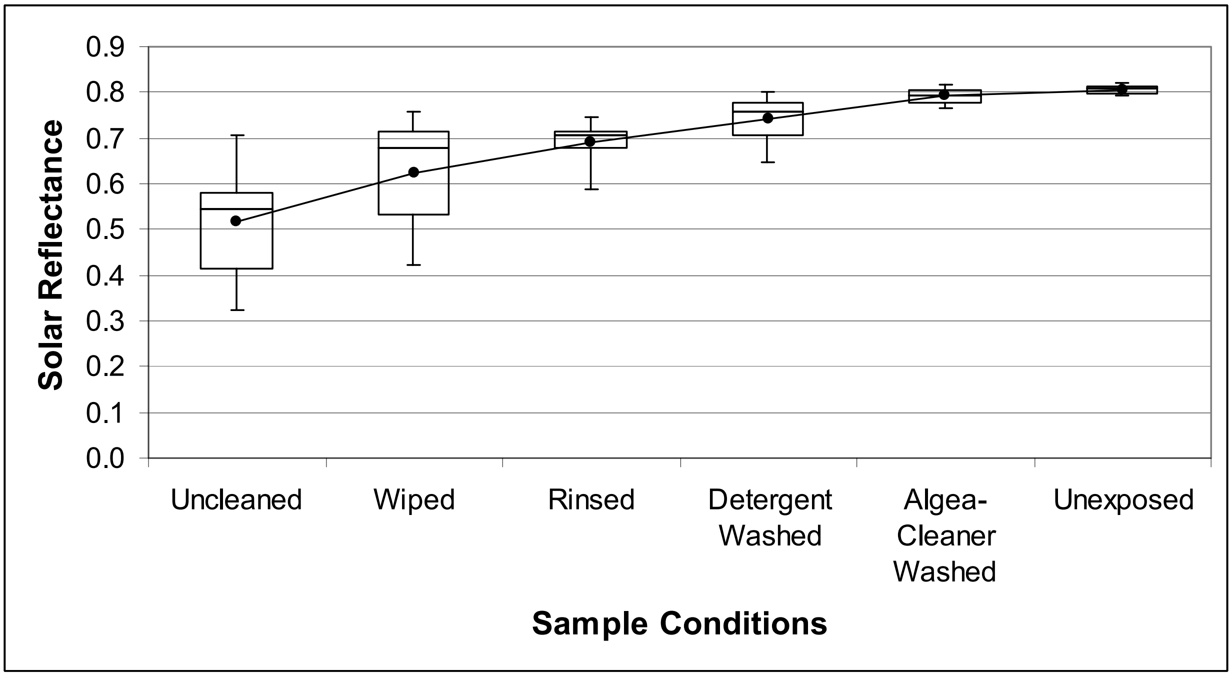
Values are Hemispherical Solar reflectance calculated with air mass 1.5

Figure 2: Solar Reflectance of Samples 9-10 and 14-15



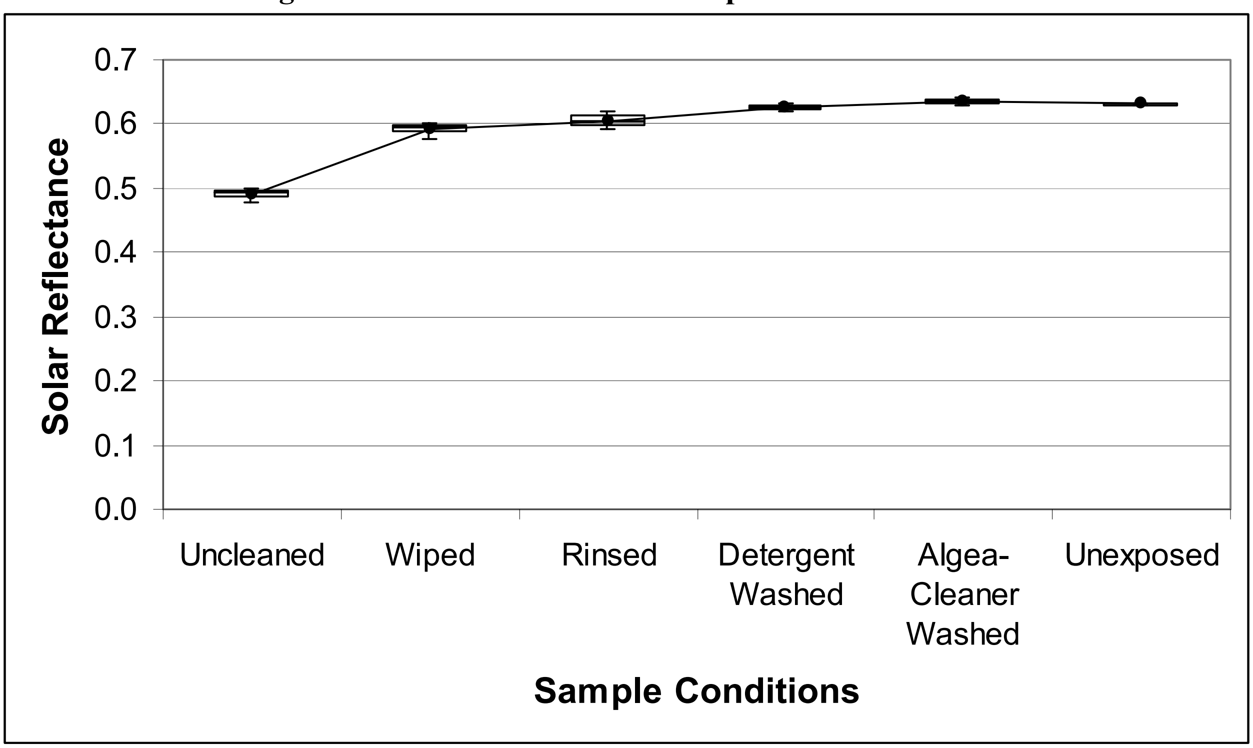
Note: Values are hemispherical solar reflectance calculated with an air mass of 1.5

Figure 3: Solar Reflectance of Samples 1-8 and 11-13



Note: The data show the minimum, 25th quartile, 50th quartile (median), 75th quartile, and maximum solar reflectance of the samples. The solid line shows the average reflectance of all samples.

Figure 4: Solar Reflectance of Samples 9-10 and 14-15



Note: The data show the minimum, 25th quartile, 50th quartile (median), 75th quartile, and maximum solar reflectance of the samples. The solid line shows the average reflectance of all samples.

Figure 5: Solar Reflectance of Samples Analyzed at the NRC