DIMENSIONAL STABILITY AND REFLECTIVITY OF FIELD-EXPOSED TPO ROOF MEMBRANES

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Keywords

TPO, seven-year, Alaska, Las Vegas, Seattle, Texas, linear dimensional stability change, reflectivity, water absorption, surface characteristics

Abstract

This paper summarizes some results from TPO roof membranes exposed for up to 10 years in different climatic regions of the western U.S. Properties such as linear dimensional stability of the seven-year samples were evaluated and compared with the unexposed membranes. The reflectivity of the unexposed three-, seven- and 10-year exposed samples also was evaluated in the laboratory using UV-VIS Near-IR and values compared with those available from the field.

In general, the analyses showed the linear dimensional stability did not change significantly up to seven years' exposure. The small variations observed in the membrane's linear dimensional stability were not significant and can be considered within the experimental error.

The reflectivity of some roof membranes increased slightly after cleaning the surface with a damp cloth a second time. Similar results were obtained in the field after cleaning the roof membranes using two cleaning methods. No reflectivity data is available for

"seven years exposed in Alaska" and all "10 years'" samples. Therefore, it was not possible to make any comparison for the membranes.

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Michael Ludwig is a senior building envelope technologist/technical lead at Building Envelope Technology & Research. Ludwig joined the company in 1998, shortly after it was founded, and continues to bring more than 30 years of broad-based experience in building envelope construction, detail design, roofing, waterproofing, wall cladding and fenestration issues, and technical consulting to the firm. Building Envelope Technology & Research clients benefit from his extensive knowledge and experience in low- and steep-slope roofing, below- and above-grade waterproofing, masonry, cement plaster (stucco), EIFS, metal, wood, synthetics and other wall cladding systems, as well as his comprehensive understanding of window and door assemblies, flashing systems, and sealant technologies and their installation sequencing requirements. Ludwig is an accomplished technical writer and editor and a skilled CAD draftsman.

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Paroli received his bachelor's degree in analytical chemistry from Concordia University, Montreal, and his doctorate in physical/inorganic chemistry from the McGill University, Montreal. Paroli is a chartered chemist with the Chemical Profession of Ontario. He is a member of the American Chemical Society, Chemical Society of Canada, International Union of Pure and Applied Chemistry, Spectroscopy Society of Canada, and Society for Applied Spectroscopy (U.S.). In addition, he is the past president of the Spectroscopy Society of Canada and the Canadian Thermal Analysis Society.

Introduction

TPO is a single-ply roof membrane typically composed of three layers: TPO polymer base, a polyester-reinforced fabric center (scrim) and a TPO compounded top ply. The first appearance of a "TPO-type" roofing product in the U.S. was around 1987. Three products offered by one company were listed in the EPDM section of the NRCA Roofing Materials Guide [1]. In 1991, another company entered the market with a product that reportedly had the benefits of EPDM and hot-air-welded seams. The product literature listed the membrane as being ethylene propylene (EP) elastomeric, thermoplastic alloy (ETA), containing no plasticizer. The membrane was reported to be an EP rubber with the unique alloy being 100 percent polymer. In 1993, still another company introduced a new product reported to have the weatherability of EPDM with the heat-weldability of a thermoplastic. Listed as an EP rubber, "the base product is made by a two-phase, in-reactor polymerization of monomers with a very specific catalyst. The elastomer phase is a non-vulcanized ethylene propylene which imparts the compound with flexibility and low temperature properties. The olefin phase imparts chemical and tear resistance, enhanced strength to the blend, and enables the product to be heat welded." The most current TPO into the market appeared in 1996 with an ethylene propylene rubber formulation [*2*].

It is well-known changes in material properties because of exposure can lead to membrane failure. Therefore, it is important for the roofing community to know how exposure to different climatic regions affects material properties such as linear dimensional stability and solar reflectance (albedo or reflectivity). Solar reflectance is a key characteristic of a roof membrane in terms of mitigating the urban heat island effect and helping reduce energy demands during warmer months. The higher the solar reflective value, the more efficient the product is in reflecting sunlight and heat away from the building [3–6]. New white TPO membranes usually have a reflective value greater than 80 percent, which exceeds the Environmental Protection Agency's (EPA's) ENERGY STAR® performance levels set at 65 percent when new and 50 percent after three years' exposure. TPO membranes are highly resistant to mold and algae growth, which can degrade a roof's overall reflectivity and reduce anticipated energy savings. [7]. It is important to note, however, that the reflective membrane is only one component of an energy-efficient roof system. Proper insulation must be used to ensure an energy-efficient building.

Because there was no published track record of the TPO material in the early 2000s, the Western States Roofing Contractors Association (WSRCA), some TPO manufacturers and researchers at the National Research Council Institute for Research in Construction (NRC-IRC) in Canada initiated a research project to study the performance of TPO roof membranes in various climatic zones [8–9]. The project consisted of evaluating physical, mechanical and chemical properties of 1.525-mm- (60-mil-) thick TPO membranes from four manufacturers before and after exposure in Anchorage, Alaska; Las Vegas; Seattle; and San Antonio. These locations represent four different climatic regions in western North America. The unexposed and test cuts collected after one year of exposure were sent to the NRC-IRC laboratory for evaluation. Thereafter, test cuts were collected every two years and sent to NRC-IRC for evaluation. Among the properties evaluated initially are the linear dimensional change, water absorption and reflectivity of the unexposed and exposed samples. Also, the surface characteristic of some of the seven-year samples was investigated. This paper presents the dimensional stability results of the unexposed and seven-year samples, as well as the laboratory reflectivity values for samples exposed up to 10 years.

Experimental

Materials

Forty-eight TPO roof membrane samples (1 m x 1 m each) from four manufacturers (1–4) were retrieved from the sites. From the 48 samples, 16 were unexposed and the other 32 had been exposed up to 10 years in the four locations mentioned in the previous paragraph. A labelling system was developed in the laboratory as follows: The numbers 1-4 were added after the initials of each exposure location to indicate the roof area followed by the years of exposure. For example, LV2e10 refers to a sample from Las Vegas; roof area 2, exposed for 10 years.

Visual inspection showed the weathered surface of the samples was in good condition with neither pinholes nor crazes. Seven- and 10-year Texas samples showed white spots on the surface. The LV2e10 showed a large crack near the seam. The unexposed and exposed samples (except for year 10) were cleaned in the laboratory with a damp cloth and allowed to dry at room temperature for at least a day before conducting any test. According to those who collected field samples, all 10-year samples were cleaned on-site during collection before sending them to NRC-IRC's laboratory.

Sample preparation

Linear Dimensional Change

Because of the limited amount of material, only one specimen (254 mm x 254 mm) was cut from each of the unexposed samples, except LV3, SEA3 and TX2, which were not tested because of the lack of material. Three specimens from each of the seven years' samples were cut. Before conditioning, each specimen was marked and measured at three equally spaced points along each side in the machine (MD) and cross (XD) directions using a digital caliper with an accuracy of 0.01 mm. Then, it was dusted with talc and sandwiched between two pieces of silicone-coated paper secured together with paperclips. The assemblies containing specimens were placed in a convection oven at 70 ± 2 C for six hours for conditioning as specified by ASTM D6878-03 [10]. They were removed from the oven and allowed to cool in the laboratory at 23 ± 2 C and 50 ± 5 percent relative humidity for at least one hour before performing any measurements. The linear dimensional change of each specimen was measured as per ASTM D1204-02 [11]. The linear dimensional change—the change in dimension as a percent of the original dimension—was calculated as follows:

$$\textit{Linear Dimensional Change} = (D_f - D_o)/D_o \times 100\%$$

where:

D_f = final dimension (length or width) of the specimen

D_o = initial dimension (length or width) of the specimen

A positive linear dimensional change indicates expansion while a negative value denotes shrinkage. Please note that because of time limitations, the linear dimensional stability test is reported for up to seven years.

Reflectivity

Unexposed, three-, seven- and 10-year samples from the WSRCA research project were selected for reflectivity measurements. Five specimens 3 cm x 4 cm in size were cut from each of the "as received" (zero three and seven years) samples. Only two specimens from each of the 10 years' samples were cut and tested. The same sample labeling system in subsection 3.1 was used for reflectivity measurements.

A Cary 5E UV-VIS-NIR spectrophotometer equipped with a diffuse reflectance accessory and the Cary WinUV Scan software were used to measure specimens' reflectivity. The top ply surface of the specimen before and after cleaning was measured in the 2500–300 nm range. The specimen surface was cleaned by wiping the surface with a damp cloth and allowed to dry for at least 20 minutes before rescanning. The reflectivity of the top ply surface of specimens was measured.

Please note all samples had been cleaned previously when they were first received. The new and three-year samples had been stored in the laboratory for about four to five years and the seven-year for more than a year. In this work, the reflectivity values before cleaning were obtained from stored and not on "as received" samples, with exception of the 10 years, as this work was decided and carried out almost a year after performing all other analyses on the seven-year samples. Reflectance spectra were collected using the following experimental parameters:

Start wavelength (nm)	2500
End wavelength (nm)	300
Independent NIR	ON
Measurement mode	Auto
UV-Vis scan rate (nm/min)	300
UV-Vis data interval (nm)	0.5
UV-Vis average time (sec)	0.1
UV-Vis SBW	2
NIR scan rate (nm/min)	60
NIR data interval (nm)	1
NIR average time (sec)	1
Slit height	Reduced
Beam mode	Double
Signal-to-noise mode	Off
UV source	On
Vis source	On
Third source	Off
Source changeover (nm)	350

Detector changeover (nm)	800
Grating changeover (nm)	800
Baseline correction	On
Baseline type	Zero/baseline correction

Results and Discussion

Linear Dimensional Change

The average values for the linear dimensional changes of the samples are summarized in Table 1 and represented in Figure 1. Each entry is the average and standard deviation of three individual measurements on each of the three specimens. The linear dimensional change of all samples was within the maximum allowable limit of ±1 percent as specified in ASTM D6878 [10] for new membranes. Some of the linear dimensional changes are quite small and barely visible in the graphs with ±1.0 percent scale, therefore, for clarity, two different scales were used in Figure 1. After the small changes observed in the first year of exposure, the linear dimensional stability in MD and XD remained almost unchanged up to seven years of service in the field.

Table 1 – Summary of average* linear dimensional changes of unexposed and exposed samples

Sample	Exposure time (Yrs.)	Dimensional changes MD (%)	Change** (%)	Dimensional changes XD (%)	Change** (%)
AK1	0 7	–0.10 ± 0.04 –0.04 ± 0.00	– 0.06	–0.09 ± 0.02 –0.03 ± 0.01	– 0.06
AK2	0 7	–0.23 ± 0.04 –0.12 ± 0.01	– 0.11	–0.26 ± 0.06 –0.04 ± 0.01	– 0.22
AK3	0 7	–0.06± 0.06 –0.04 ± 0.02	– 0.02	–0.05 ± 0.05 –0.01 ± 0.01	– 0.04
AK4	0 7	–0.16 ± 0.06 –0.06 ± 0.01	– 0.10	–0.04 ± 0.02 –0.03 ± 0.00	– 0.01
LV1	0 7	0.18 ± 0.01 –0.03 ± 0.01	– –0.21	–0.05 ± 0.02 –0.03 ± 0.01	– 0.02
LV2	0 7	–0.05 ± 0.03 –0.11 ± 0.01	– –0.06	–0.10 ± 0.07 –0.03 ± 0.01	– 0.07
LV3	0 7	NA –0.06 ± 0.02	– –	NA –0.05 ± 0.01	– –
LV4	0 7	–0.12 ± 0.04 –0.04 ± 0.01	– 0.08	–0.03 ± 0.01 –0.02 ± 0.01	– 0.01
SEA1	0 7	–0.06 ± 0.01 –0.06 ± 0.00	– 0.00	–0.12 ± 0.02 –0.06 ± 0.00	– 0.06
SEA2	0 7	–0.36 ± 0.02 –0.22 ± 0.01	– 0.14	–0.22 ± 0.01 –0.14 ± 0.01	– 0.08
SEA3	0 7	NA –0.03 ± 0.00	– –	NA –0.03 ± 0.01	– –
SEA4	0 7	–0.19 ± 0.04 –0.10 ± 0.01	– 0.09	–0.06 ± 0.03 –0.01 ± 0.00	– 0.05
TX1	0 7	0.05 ± 0.02 –0.02 ± 0.00	– –0.07	–0.03 ± 0.04 –0.04 ± 0.01	– –0.01
TX2	0 7	NA –0.08 ± 0.00	– –	NA –0.04 ± 0.01	– –
TX3	0 7	–0.09 ± 0.03 –0.03 ± 0.00	– 0.06	–0.05 ± 0.02 –0.05 ± 0.00	– 0.00
TX4	0 7	–0.13 ± 0.00 –0.05 ± 0.00	– 0.08	–0.09 ± 0.02 –0.03 ± 0.00	– 0.06

*Average of three specimens

**Dimensional change$_{(exposed)}$ – Dimensional change$_{(unexposed)}$

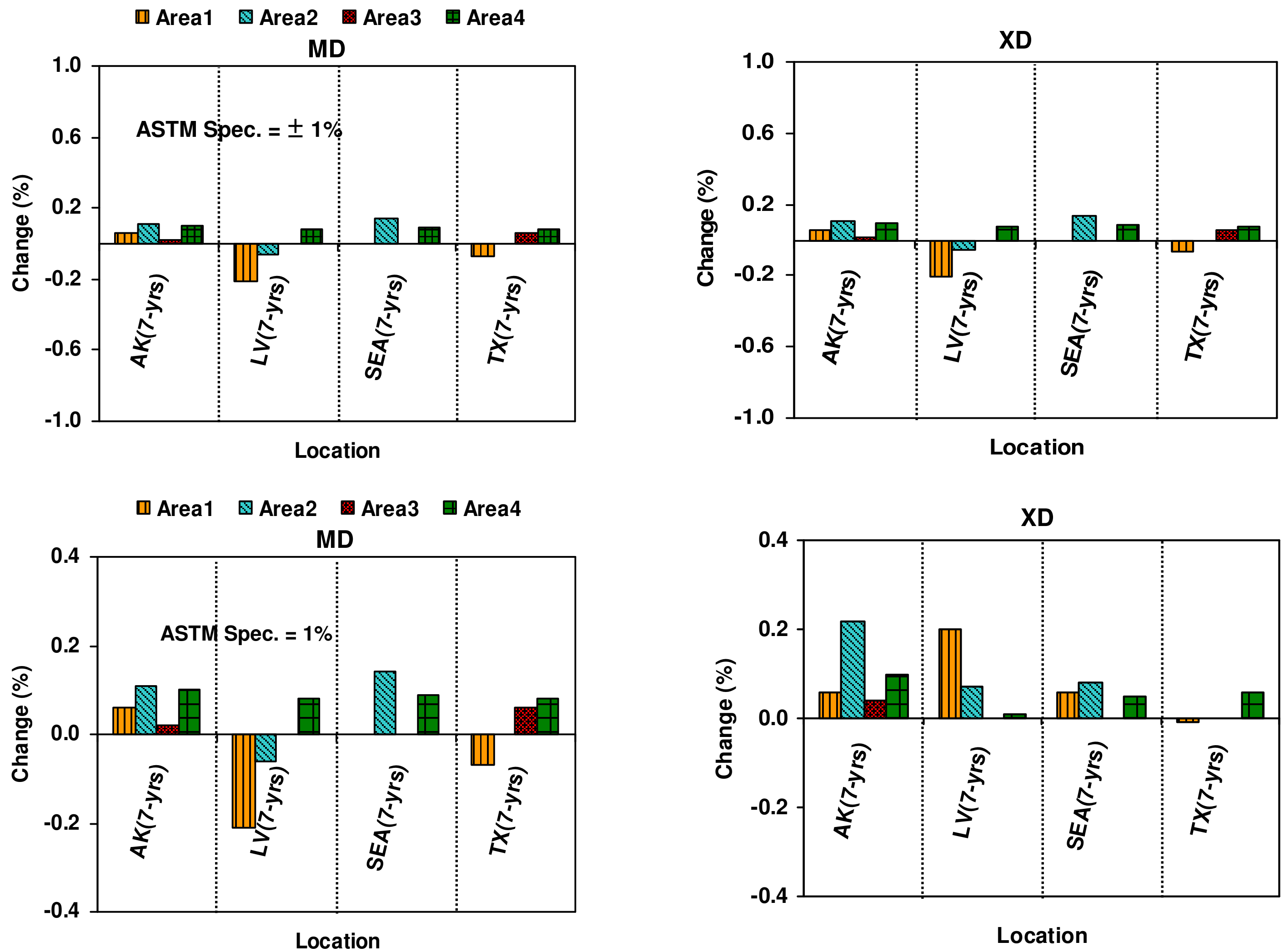

Figure 1 – Linear dimensional changes of seven-year samples in MD and XD (plotted on two different scales). Note: ASTM allowed limit is ±1 percent.

Reflectivity

The E903 Tool Simplified0011 integrator *[12],* which is the newest version of the Spectral Integrator Workshop [13] was used as the calculation tool. The E903 Tool Simplified0011 implements ASTM E903-96 [14], withdrawn in 2005. It weighs spectrometer measurements of near normal-hemispherical solar spectral reflectance with ASTM G173-03 [15] air-mass 1.5 global and direct-normal solar irradiances to compute global-hemispherical and near normal–hemispherical solar (300-2500 nm), UV (300-400 nm), visible (400-700 nm) and near-infrared (700-2500 nm) reflectance. Note the standard specifies only the computation of near normal–hemispherical solar reflectance. Weighting near–hemispherical spectral reflectance with global solar irradiance tends to underestimate true global–hemispherical solar reflectance by as much as 0.01, because the diffuse component of sunlight (about 15 percent) is reflected more strongly than sunlight at near–normal incidence. [12]

The main difference between these two integrators is they use different ASTM International standards to calculate the solar irradiance. The Spectral Integrator Workshop uses the solar irradiance tables from ASTM G159-98 [16], which has been withdrawn. The E903 Tool Simplified0011 employs the solar irradiance tables from ASTM G173-03, [13] where the reference spectra are based on version 2.9.2 of the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) atmospheric transmission code and an air mass of 1.5 as the generating model [15]. One essential outcome of SMARTS as a pivotal calculation tool is that scientists and practicing engineers now are able to select a major North American city and transparently obtain the necessary inputs to SMARTS that correspond to summer design conditions (with respect to solar radiation) for the selected area [16].

The hemispherical tilted spectrum is similar to the hemispherical spectrum in use since 1987 but differs from it because the wavelength range for the current spectrum has been extended deeper into the ultraviolet; uniform wavelength intervals now are used; more representative atmospheric conditions are represented; and SMARTS version 2.9.2 has been used as the generating model [13].

The E903 Tool Simplified0011 integrator allows calculation of the Hemispherical Tilt reflectance (H:Sol) and the Direct + Circumsolar reflectance (D:Sol), respectively, as well as the fraction values for UV, VIS and NIR. Because of the amount of data, only the Hemispherical Tilt reflectance (H:Sol) reported in Table 4 will be discussed. Average values reported are from measurements performed on two to five specimens.

The average Hemispherical solar (H:Sol), called reflectivity, of the unexposed and exposed specimens (Table 4) are represented in Figure 3. The reflectivity values for specimens before cleaning (bc in Figure 3) range from 0.61 to 0.87 and from 0.69 to 0.88 after cleaning (c in Figure 3) with a damp cloth with measurement errors ranging from 0 to 0.05. As expected, the surface displayed a higher reflectivity value after cleaning. However, only a slight increase is observed in the laboratory reflectivity values after cleaning. This may be explained by the fact that surfaces have been cleaned previously when received. It is important to note that the three-year SEA1 and SEA4 specimens show reflectivity values lower than those of the seven- and ten-year specimens. Most specimens have reflectivity values at or above the EPA ENERGY STAR specification of 65 percent [4].

Table 4 – Summary of average* reflectivity of TPO samples

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity	Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity
AK1	0	Dirty	0.87 ± 0.01	AK2	0	Dirty	0.76 ± 0.01
		Clean	0.88 ± 0.01			Clean	0.78 ± 0.00
	3	Dirty	0.75 ± 0.01		3	Dirty	0.62 ± 0.01
		Clean	0.75 ± 0.01			Clean	0.73 ± 0.01
	7	Dirty	0.74 ± 0.02		7	Dirty	0.68 ± 0.01
		Clean	0.74 ± 0.01			Clean	0.70 ± 0.01
	10	Dirty	0.79 ± 0.01		10	Dirty	0.71 ± 0.00
		Clean	0.79 ±0.02			Clean	0.71 ± 0.02
AK3	0	Dirty	0.77 ± 0.01	AK4	0	Dirty	0.81 ± 0.01
		Clean	0.78 ± 0.01			Clean	0.82 ± 0.00
	3	Dirty	0.61 ± 0.01		3	Dirty	0.71 ± 0.02
		Clean	0.71 ± 0.01			Clean	0.76 ± 0.01
	7	Dirty	0.70 ± 0.01		7	Dirty	0.72 ± 0.01
		Clean	0.73 ± 0.01			Clean	0.73 ± 0.01
	10	Dirty	0.69 ± 0.05		10	Dirty	0.73 ± 0.01
		Clean	0.75 ± 0.01			Clean	0.75 ± 0.02
LV1	0	Dirty	0.80 ± 0.01	LV2	0	Dirty	0.77 ± 0.02
		Clean	0.80 ± 0.01			Clean	0.78 ± 0.02
	3	Dirty	0.74 ± 0.02		3	Dirty	0.74 ± 0.02
		Clean	0.76 ± 0.02			Clean	0.76 ± 0.01
	7	Dirty	0.76 ± 0.00		7	Dirty	0.76 ± 0.02
		Clean	0.78 ± 0.01			Clean	0.78 ± 0.00
	10	Dirty	0.78 ± 0.00		10	Dirty	0.78 ± 0.01
		Clean	0.79 ± 0.01			Clean	0.78 ± 0.01

*Average of two to five specimens

Table 4 – Summary of average* reflectivity of TPO samples – *Continued*

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity	Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity
LV3	0	Dirty	0.76 ± 0.01	LV4	0	Dirty	0.80 ± 0.02
		Clean	0.77 ± 0.00			Clean	0.83 ± 0.01
	3	Dirty	0.71 ± 0.02		3	Dirty	0.77 ± 0.01
		Clean	0.75 ± 0.02			Clean	0.79 ± 0.01
	7	Dirty	0.76 ± 0.02		7	Dirty	0.78 ± 0.01
		Clean	0.78 ± 0.01			Clean	0.78 ± 0.00
	10	Dirty	0.77 ± 0.01		10	Dirty	0.77± 0.00
		Clean	0.78 ± 0.01			Clean	0.77 ± 0.01
SEA1	0	Dirty	0.86 ± 0.01	SEA2	0	Dirty	0.74 ± 0.03
		Clean	0.86 ± 0.00			Clean	0.76 ± 0.01
	3	Dirty	0.69 ± 0.02		3	Dirty	0.61 ± 0.02
		Clean	0.69 ± 0.01			Clean	0.69 ± 0.03
	7	Dirty	0.77 ± 0.01		7	Dirty	0.65 ± 0.02
		Clean	0.78 ± 0.01			Clean	0.70 ± 0.01
	10	Dirty	0.81 ±0.01		10	Dirty	0.67 ± 0.04
		Clean	0.82 ±0.01			Clean	0.69 ± 0.04
SEA3	0	Dirty	0.73 ± 0.03	SEA4	0	Dirty	0.81 ± 0.01
		Clean	0.75 ± 0.02			Clean	0.82 ± 0.00
	3	Dirty	0.62 ± 0.01		3	Dirty	0.64 ± 0.01
		Clean	0.69 ± 0.02			Clean	0.71 ± 0.01
	7	Dirty	0.67 ± 0.02		7	Dirty	0.75 ± 0.01
		Clean	0.70 ± 0.02			Clean	0.77 ± 0.01
	10	Dirty	0.70 ± 0.03		10	Dirty	0.78 ± 0.01
		Clean	0.71 ± 0.03			Clean	0.78 ± 0.01

*Average of two to five specimens

Table 3 – Summary of average* reflectivity – *Continued*

Sample ID	Exposure time Yrs.)	Surface condition	Reflectivity	Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity
TX1	0	Dirty	0.77 ± 0.01	TX2	0	Dirty	0.77 ± 0.00
		Clean	0.78 ± 0.01			Clean	0.78 ± 0.00
	3	Dirty	0.70 ± 0.03		3	Dirty	0.68 ± 0.02
		Clean	0.74 ± 0.00			Clean	0.70 ± 0.01
	7	Dirty	0.71 ± 0.02		7	Dirty	0.67 ± 0.02
		Clean	0.75 ± 0.01			Clean	0.70 ± 0.02
	10	Dirty	0.79 ± 0.01		10	Dirty	0.69 ± 0.02
		Clean	0.79 ± 0.01			Clean	0.69 ± 0.01
TX3	0	Dirty	0.78 ± 0.02	TX4	0	Dirty	0.82 ± 0.01
		Clean	0.80 ± 0.01			Clean	0.83 ± 0.01
	3	Dirty	0.68 ± 0.02		3	Dirty	0.73 ± 0.02
		Clean	0.72 ± 0.03			Clean	0.77 ± 0.01
	7	Dirty	0.68 ± 0.05		7	Dirty	0.72 ± 0.02
		Clean	0.73 ± 0.02			Clean	0.75 ± 0.01
	10	Dirty	0.75 ± 0.0o		10	Dirty	0.73 ± 0.01
		Clean	0.75 ± 0.00			Clean	0.75 ± 0.01

**Average of two to five specimens

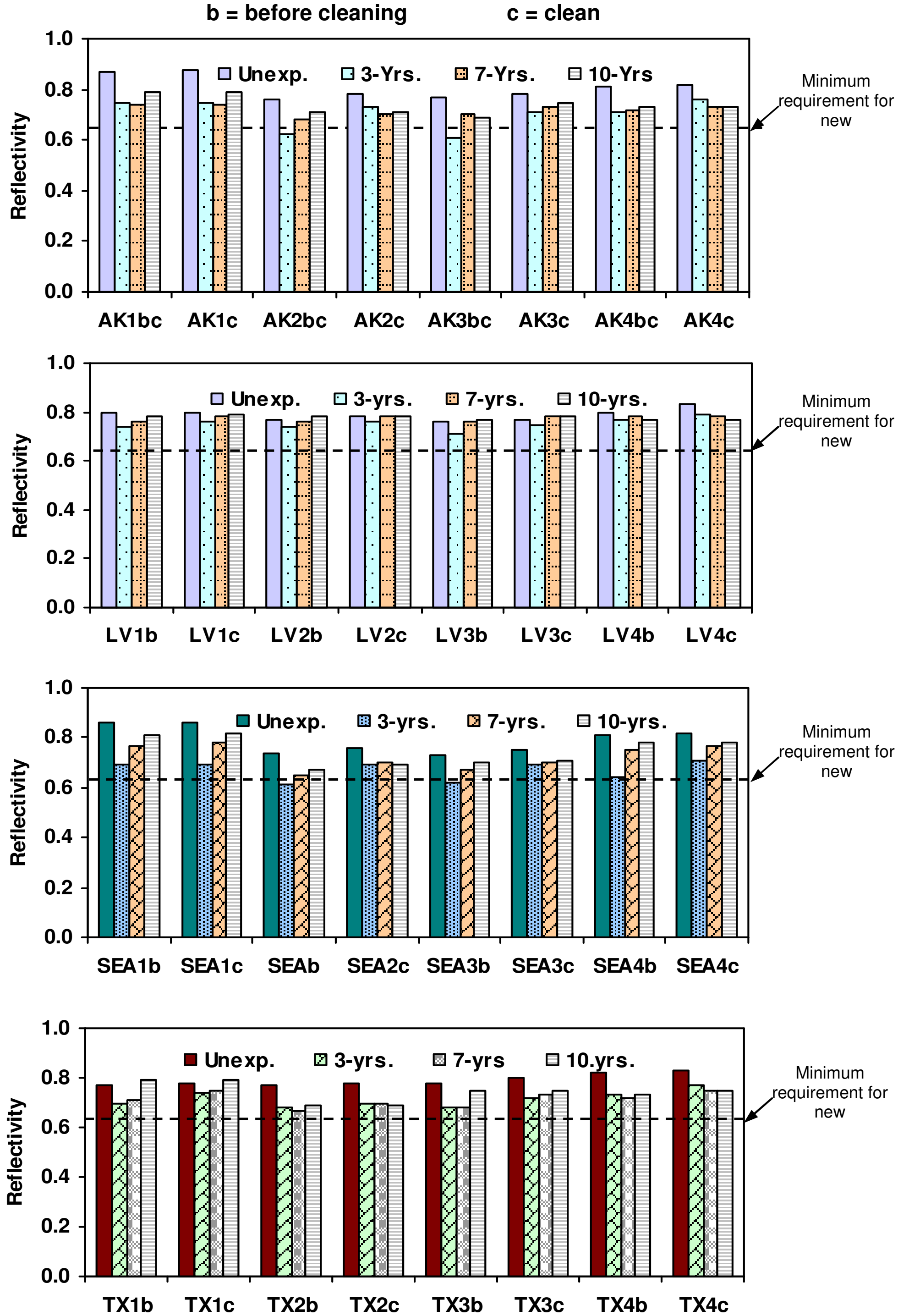

Figure 3 – Reflectivity of unexposed, three-, seven- and 10-year samples. Note that all reflectivity values exceed the 50 percent requirement for 3-year-old membranes even after 10 years.

Figure 4a shows photos of the specimens used for reflectivity measurements. It can be observed from the photo**s** that the surface of the three-year exposed specimens is duller than that of the unexposed and seven-year specimens. This may explain the lower reflectivity values for the SEA1 and SEA4 specimens.

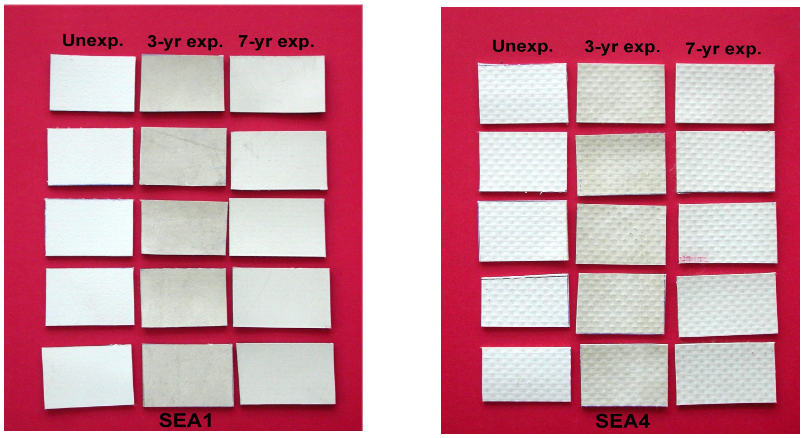

Figure 4a – Photos of unexposed, three- and seven-year SEA1 and SEA2 samples (**five** measurements on each)

Visual inspection of the "as received" three- and seven-year sample showed the latter was cleaner when it arrived at the lab even though it has been exposed in the field for seven years. Based on the information collected from the site, no surface cleaning was performed before collecting the seven-year samples. The surface of ten-year samples was cleaner than the seven-year samples**,** but the former were cleaned during sample collection.

Reflectivity measurements also were performed on the unexposed (new) roof membranes, as well as in the field during the third- and fifth-year inspections before and after cleaning [17] using two cleaning methods. One consisted of wetting and scrubbing the surface with stiff-bristle push brooms or long-handled brushes using mild detergent and water solution, then rinsed, along with a side-by-side comparison of pressure rinsing/washing. The scrubbed areas produced a slightly more reflective surface. The field and laboratory measurements are summarized in Table 5. It is important to mention that field values shown in Table 5 are for three to four and five to six years' exposure while the laboratory values are for three and seven years' exposure. Although laboratory values are not for the exact same age as field values, they roughly are compared because there are no significant changes in the samples' reflectivity after being exposed in the field for three years.

Table 5–Laboratory and field reflectivity values of TPO samples

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity (H:Sol)				Lab vs. field Absolute difference††
			Lab	Change* (%)	Field[17]†	Change* (%)	
AK1	0	Dirty	0.87		0.87		0
		Clean	0.88	1	0.87	0	0
	3	Dirty	0.75		0.72		3
		Clean	0.75	0	0.77	5	2
	7	Dirty	0.74		NA	–	
		Clean	0.74	0			
	10	Dirty	0.79				
		Clean	0.79	0			
AK2	0	Dirty	0.76		0.78		2
		Clean	0.78	2	0.78	0	0
	3	Dirty	0.62		0.60		2
		Clean	0.73	9	0.68	8	5
	7	Dirty	0.68		NA	–	
		Clean	0.70	2			
	10	Dirty	0.71				
		Clean	0.71	0			
AK3	0	Dirty	0.77		0.79		2
		Clean	0.78	1	0.79	0	1
	3	Dirty	0.61		0.60		1
		Clean	0.71	10	0.68	8	3
	7	Dirty	0.70		NA	–	
		Clean	0.73	3			
	10	Dirty	0.69				
		Clean	0.75	6			
AK4	0	Dirty	0.81		0.86		5
		Clean	0.82	2	0.86	0	4
	3	Dirty	0.71		0.63		8
		Clean	0.76	5	0.72	9	4
	7	Dirty	0.72		NA	–	
		Clean	0.73	1			
	10	Dirty	0.73				
		Clean	0.75	2			
LV1	0	Dirty	0.80		0.87		7
		Clean	0.80	0	0.87	0	7
	3	Dirty	0.74		0.69		5
		Clean	0.76	2	0.75	6	1
	7	Dirty	0.76		0.71		5
		Clean	0.78	2	0.78	7	0
	10	Dirty	0.78		NA	–	
		Clean	0.79	1			

*Clean 2nd time–dirty

†Field measurements were performed on three to four- and five to six-year samples

††Lab values–field values

Table 5–Laboratory and field reflectivity values of TPO samples – *Continued*

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity Lab	Change* (%)	Field[17]†	Change* (%)	Lab vs. field Absolute difference††
LV2	0	Dirty	0.77		0.78		1
		Clean	0.78	1	0.78	0	0
	3	Dirty	0.74		0.72		2
		Clean	0.76	2	0.76	4	0
	7	Dirty	0.76		0.74		2
		Clean	0.78	2	0.82		4
	10	Dirty	0.78		NA	–	–
		Clean	0.78	0			
LV3	0	Dirty	0.76		0.79		3
		Clean	0.77	1	0.79	0	2
	3	Dirty	0.71		0.65		6
		Clean	0.75	4	0.74	9	1
	7	Dirty	0.76		0.69		7
		Clean	0.78	2	0.80	11	2
	10	Dirty	0.77		NA	–	–
		Clean	0.78	1			
LV4	0	Dirty	0.80		0.86		6
		Clean	0.83	3	0.86	0	3
	3	Dirty	0.77		0.70		7
		Clean	0.79	2	0.78	8	1
	7	Dirty	0.78		0.74		4
		Clean	0.78	0	0.83	9	5
	10	Dirty	0.77		NA	–	–
		Clean	0.77	0			
SEA1	0	Dirty	0.87		0.87		0
		Clean	0.87	0	0.87	0	0
	3	Dirty	0.70		0.68		2
		Clean	0.71	6	0.71	3	0
	7	Dirty	0.78		0.69		9
		Clean	0.80	2	0.78	9	2
	10	Dirty	0.81		NA	–	–
		Clean	0.82	1			
SEA2	0	Dirty	0.75		0.78		3
		Clean	0.77	2	0.78	0	1
	3	Dirty	0.61		0.61		0
		Clean	0.70	9	0.63	2	7
	7	Dirty	0.66		0.61		5
		Clean	0.71	5	0.69	8	2
	10	Dirty	0.67		NA	–	–
		Clean	0.69	2			

*Clean 2nd time–dirty
†Field measurements were performed on three to four- and five to six-year samples
††Lab values–field values

Table 5–Laboratory and field reflectivity values of TPO samples – *Continued*

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity				Lab vs. field Absolute difference††
			Lab	Change* (%)	Field[17]†	Change* (%)	
SEA3	0	Dirty	0.74		0.79		5
		Clean	0.76	2	0.79	0	3
	3	Dirty	0.63		0.62		1
		Clean	0.70	7	0.67	5	3
	7	Dirty	0.67		0.65		2
		Clean	0.70	3	0.69	4	1
	10	Dirty	0.70		NA	–	–
		Clean	0.71	1			
SEA4	0	Dirty	0.82		0.86		4
		Clean	0.83	1	0.86	0	3
	3	Dirty	0.65		0.66		1
		Clean	0.72	7	0.73	7	1
	7	Dirty	0.76		0.70		6
	10	Dirty	0.78		NA	–	–
		Clean	0.78	0			
TX1	0	Dirty	0.78		0.87		2
		Clean	0.79	1	0.87	0	8
	3	Dirty	0.70		0.59		11
		Clean	0.74	4	0.73	14	1
	7	Dirty	0.72		0.57		15
		Clean	0.75	3	0.71	14	4
	10	Dirty	0.79		NA	–	–
		Clean	0.79	0			
TX2	0	Dirty	0.78		0.78		0
		Clean	0.78	0	0.78	0	0
	3	Dirty	0.69		0.63		6
		Clean	0.71	2	0.69	6	2
	7	Dirty	0.68		0.58		10
		Clean	0.71	3	0.71	13	0
	10	Dirty	0.69		NA	–	–
		Clean	0.69	0			

*Clean –dirty

†Field measurements were performed on three to four- and five to six-year samples

††Lab values–Field values

Table 5–Laboratory and field reflectivity values of TPO samples – *Continued*

Sample ID	Exposure time (Yrs.)	Surface condition	Reflectivity Lab	Change* (%)	Field[17]†	Change* (%)	Lab vs. Field Absolute difference††
TX3	0	Dirty	0.79		0.79		0
		Clean	0.81	2	0.79	0	2
	3	Dirty	0.69		0.54		15
		Clean	0.72	3	0.69	16	3
	7	Dirty	0.69		0.55		14
		Clean	0.74	5	0.70	15	4
	10	Dirty	0.75		NA	–	–
		Clean	0.75	0			
TX4	0	Dirty	0.83		0.86		3
		Clean	0.83	0	0.86	0	3
	3	Dirty	0.74		0.60		14
		Clean	0.78	4	0.72	8	6
	7	Dirty	0.73		0.58		15
		Clean	0.76	3	0.71	13	5
	10	Dirty	0.73		NA	–	–
		Clean	0.75	2			

*Clean–dirty

†Field measurements were performed on three to four- and five to six-year samples

††Lab values–Field values

Results indicate that, in general, the reflectivity of the roof membranes increased by less than 10 percent after cleaning, regardless of the cleaning method, with the exception of the Texas field values, which show an increase up to 16 percent after cleaning. Such an increase is not significant and may not justify cleaning expenses (including use of resources such as water). It is important to mention that both cleaning methods used in the field were quite harsh. They could cause erosion of the surface because of scrubbing with the end result of an increase in surface porosity. Therefore, cleaning is not recommended unless specified by the manufacturer.

As can be observed from values in Table 5, reflectivity values for the new samples measured in the laboratory are, in general, similar to those measured in the field. However, values for exposed samples show larger differences. For samples exposed in

Alaska and Las Vegas, the difference between lab and field values range from 0 to 8 percent and increase to 15 percent for the Texas samples. Such differences may be explained by the fact that measurements are not taken on the same roof area. For example, lab specimens were taken from different areas of each test cut sample (1 m x 1 m). Reflectivity values reported are the average of individual measurements on each specimen (2–5). Field measurements were taken more or less randomly and on much larger areas. In spite of this, it is clear the NIR-UV-Vis technique shows comparable results.

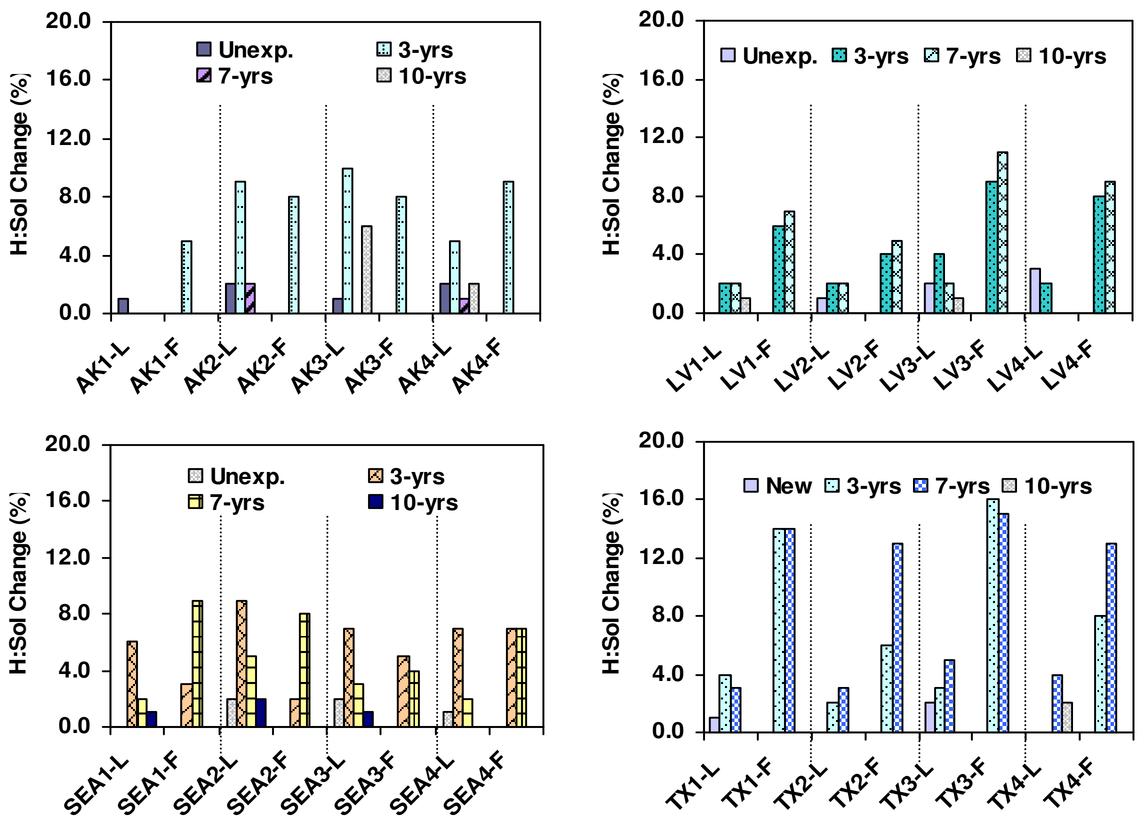

Figure 4b – Changes in reflectivity of the roof samples after cleaning (2nd time) in the laboratory (L) and field (F)

Changes in reflectivity after cleaning in the laboratory (L) a second time and field (F) of the specimens are represented in Figure 4b. No seven-year field reflectivity data from the Alaska site and 10-year sample is available. The figure indicates the change or increase in reflectivity after cleaning in the field for the seven-year specimens generally is slightly larger than the laboratory, especially for specimens from the Texas exposure site. This is because of the fact that specimens measured in the lab (except for the ten-year samples) were cleaned a few years before conducting reflectivity measurements.

Conclusions

1. The linear dimensional change of all seven-year samples was within the maximum allowable limit of ±1 percent as specified in ASTM D6878 [10] for new membranes. After the small changes observed in the first year of exposure, the linear dimensional stability in MD and XD remained almost unchanged for up to seven years of service in the field.
2. The reflectivity values (lab and field) for the three- and seven-year samples before cleaning (2nd time) range from 0.61 to 0.87 and from 0.69 to 0.88 after cleaning with a damp cloth. As expected, the surface displayed a higher reflectivity value after cleaning. Values after cleaning are above the 50 percent ENERGY STAR specified limit for exposed membranes.
3. The laboratory reflectivity values for the three-year specimens from AK2, AK3, SEA2, and SEA3 before cleaning a second time were slightly below the 0.65 limit (0.61-0.63). Similar values were obtained in the field for these samples before cleaning. However, the field measurements indicate the three AK4e3 and all three-

and seven-year samples from the Texas location display reflectivity values (before cleaning 2nd time), ranging from 0.53 –0.61.

4. Although there are some differences between the laboratory and field values, in general, both follow a similar trend.

Acknowledgments

Authors are very thankful to Mrs. Helen Yew and Mrs. Sladana Bundalo-Perc for performing analyses of the samples (0, 3 and 7).

References

1. National Roofing Contractors Association, *NRCA Roofing Materials Guide,* Vol. 11, August 1987, p. 92.

2. T.R. Simmons, R.M. Paroli, KY Liu, A.H. Delgado, J.D. Irwin, "Evaluation of in-service thermoplastic olefin (TPO) roofing membranes", Roofing Research and Standards Development:: 4th Volume (Nashville, TN., U.S.A., 1998) pp. 19-42, (ASTM Special Technical Publication Vol. 1349) (ASTM-STP-1349)

3. A. Synnefa, M. Santamouris, K Apostolakis, Solar Energy 81 (2007) pp. 488–497

4. Energy Star Reflective Roof Products http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_emissivity

5. http://cyberparent.com/green-building/roofing-roofs-reflective.htm

6. Hashem Akbari, Ronnen Levinson, Stephanie Stern. Procedure for measuring the solar reflectance of flat or curved roofing assemblies. *Solar Energy* 82 (2008) pp. 648-655

7. Randy Ober, Paul Oliveira, "TPO Roofing Membranes", ASTM Standardization News, August 2003 (http://www.astm.org/SNEWS/AUGUST_2003/obeoli_aug03.html)

8. Carlson, J., Delgado, A.H., Rosenow, E., Barnhardt, K.C., Paroli, R.M., "Performance evaluation of unexposed and field-exposed thermoplastic polyolefin TPO roof membranes," Proceedings of the: RCI A International Convention "Seeking Adventure...Advancing Knowledge" (Phoenix, Arizona, March 23, 2006), pp. 1-18

9. Tom Bradford, K.C. Barnhardt, J. Carlson, Ana H. Delgado, Ralph M. Paroli, Ernie Rosenow, Randy Ober, Jim Jannasch, Steve Moskowitz and Mike Hubbard, TPO Weathering Farm, WSRCA TPO Weathering Farm Project: Fourth Year Results, *Western Roofing Magazine*, April/March 2006, pp. 20-27.

10. ASTM D6878-03 Standard Specification for Thermoplastic Polyolefin Based Sheet Roofing

11. ASTM D1204-02 Standard Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature

12. E903 Solar Reflectance, Coded by Ronnen Levinson, Lawrence Berkeley Laboratory. Revised 2008-03-02 to remove display of direct-normal ("collimated") solar reflectance

13. Courtesy of Dr. Hashemn Akbari and Dr. Ronnen Levinson, Heat Island Group, Lawrence Berkeley National Laboratory, USA

14. ASTM E903-96 Standard Method for Solar Absorptance, Reflectance and Transmittance of Materials using Integrating Spheres

15. ASTM G173–03 *Standard Tables for Reference Solar Spectral Irradiances: Director Normal and Hemispherical on 37 ° tilted surface*

16. ASTM G159–98: Standard Tables for References Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface (Withdrawn 2005). In *Annual Book of ASTM Standards, Vol. 14.04*. Philadelphia, PA: American Society for Testing and Materials.

17. Solar Consulting Services, Reference Spectra, SMARTS, www.solarconsultingservices.com/referemcespectra.php

18. Seven–Year TPO Report, *Western Roofing, Insulation and Siding* magazine – May/June 2010, pp 55–74.