



# Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance<sup>1</sup>

This standard is issued under the fixed designation D7897; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 Practice D7897 applies to simulation of the effects of field exposure on the solar reflectance and thermal emittance of roof surface materials including but not limited to field-applied coatings, factory-applied coatings, single-ply membranes, modified bitumen products, shingles, tiles, and metal products. The solar reflectance and thermal emittance of roof surface materials can be changed by exposure to the outdoor environment. These changes are caused by three factors: deposition and retention of airborne pollutants; microbiological growth; and changes in physical or chemical properties. This practice applies to simulation of changes in solar reflectance and thermal emittance induced by deposition and retention of airborne pollutants and, to a limited extent, changes caused by microbiological growth.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

**C1549** Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer

**E691** Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

**G151** Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

**G154** Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.20 on Roofing Membrane Systems.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

### 2.2 Other Standards:

**ANSI/CRRC S100** Standard Test Methods for Determining Radiative Properties of Materials<sup>3</sup>

## 3. Terminology

### 3.1 Definitions:

3.1.1 *solar energy*—the radiant energy originating from the sun.

3.1.1.1 *Discussion*—Approximately 99 % of terrestrial solar radiation lies between the wavelengths of 0.3 and 2.5  $\mu\text{m}$ , with peak radiation near 0.5  $\mu\text{m}$ . This spectrum includes ultraviolet, visible, and near-infrared radiation.

3.1.2 *solar reflectance*—the fraction of incident solar flux reflected by a surface.

3.1.3 *thermal emittance*—efficiency with which a surface emits thermal radiation, measured on a scale from 0 to 1, where a value of 1 indicates perfect emission (that is, equal to that of a black body).

3.1.4 *thermal radiation*—the radiant energy originating from a 300 K (about 27°C) black body.

3.1.4.1 *Discussion*—Approximately 99 % of thermal radiation lies between the wavelengths of 4 and 80  $\mu\text{m}$ , with peak radiation near 10  $\mu\text{m}$ .

## 4. Summary of Practice

4.1 This practice presents a rapid laboratory method for weathering and soiling, which simulates natural changes in solar reflectance and thermal emittance of materials in the field. The practice describes a simulated field exposure protocol that consists of spraying an aqueous suspension of soot and other soluble soiling constituents, including salts and organic matter, onto a specimen of roof surfacing materials. The specimen is exposed in a weathering apparatus before soiling, to provide UV conditioning; and after soiling, to simulate the cleaning effect of moisture (1).<sup>4</sup>

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>4</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

## 5. Significance and Use

5.1 The solar reflectance of a building envelope surface affects surface temperature and near-surface ambient air temperature. Surfaces with low solar reflectance absorb a high fraction of the incoming solar energy. Sunlight absorbed by a roof or by other building envelope surfaces can be conducted into the building, increasing cooling load and decreasing heating load in a conditioned building, or raising indoor temperature in an unconditioned building. It can also warm the outside air by convection. Determination of solar reflectance can help designers and consumers choose appropriate materials for their buildings and communities.

5.1.1 The solar reflectance of a new building envelope surface often changes within one to two years through deposition and retention of soot and dust; microbiological growth; exposure to sunlight, precipitation, and dew; and other processes of soiling and weathering. For example, light-colored “cool” envelope surfaces with high initial reflectance can experience substantial reflectance loss as they are covered with dark soiling agents. Current product rating programs require roofing manufacturers to report values of solar reflectance and thermal emittance measured after three years of natural exposure (2, 3). A rapid laboratory process for soiling and weathering that simulates the three-year-aged radiative properties of roof and other building envelope surface materials expedites the development, testing, and introduction to market of such products.

5.2 Thermal emittance describes the efficiency with which a surface exchanges thermal radiation with its environment. High thermal emittance enhances the ability of a surface to stay cool in the sun. The thermal emittance of a bare metal surface is initially low, and often increases as it is soiled or oxidized (4). The thermal emittance of a typical non-metal surface is initially high, and remains high after soiling (5).

5.3 This practice allows measurement of the solar reflectance and thermal emittance of a roofing specimen after the application of the simulated field exposure.

5.4 This practice is intended to be referenced by another standard, such as ANSI/CRRC S100, that specifies practices for specimen selection and methods for radiative measurement.

## 6. Standard Practice Method and Apparatus

6.1 *Soiling Agents*—Atmospheric particles originate from windblown dust, forest and grassland fires, living vegetation, and sea spray, as well as from human activities, such as the burning of fossil and biomass fuels. Most particles either scatter or weakly absorb sunlight. A notable exception is black carbon soot emitted from the burning of fossil and biomass fuels and from fires. Because of its strong mass absorption efficiency, small amounts of black soot appreciably contribute to the soiling of building surfaces. An aqueous mixture of four soiling agents (as described below) is used for the simulated field exposure. The soiling agents and their concentrations were chosen based on their respective contributions to changes in the solar reflectance spectra of soiled surfaces, as determined in the laboratory. These four soiling agents have been shown to accumulate on surfaces exposed in natural outdoor settings (6).

6.1.1 *Soot*—A commercially available self-dispersible carbon black (Aqua-Black 001: Tokai Carbon Co., Ltd<sup>5</sup>), is used as surrogate for soot.  $1.37 \pm 0.05$  g of Aqua-Black 001 aqueous dispersion (19 % m/m carbon black) is diluted into 1 L of distilled water and shaken for three to five minutes to produce a stable soot (carbon black) suspension of  $0.26 \pm 0.01$  g/L.

6.1.2 *Dust*—A mixture of iron oxide ( $\text{Fe}_2\text{O}_3$ ) powder (color: red-brown, particle size  $<5$   $\mu\text{m}$ , purity  $\geq 99$  %, CAS: 1309-37-1; example: SKU 310050 Sigma Aldrich) and two natural clays ((1) montmorillonite K10 powder (color: yellowish-gray, surface area: 220 to 270  $\text{m}^2/\text{g}$ , CAS: 1318-93-0; example: SKU 281522 Sigma Aldrich) and (2) nanoclay, hydrophilic bentonite (particle size  $\leq 25$   $\mu\text{m}$ , CAS: 1302-78-9; example: SKU 682659 Sigma Aldrich)) is used as a surrogate for dust. (Similar chemicals can be procured from other vendors.)

6.1.2.1 A mass of  $0.3 \pm 0.02$  g of  $\text{Fe}_2\text{O}_3$  powder is mixed with  $1.0 \pm 0.05$  g of montmorillonite and  $1.0 \pm 0.05$  g of bentonite. The mixture is transferred into 1 L of distilled water and stirred for about 1 h to prepare a stable dust suspension of  $2.3 \pm 0.1$  g/L. To prevent sedimentation, the suspension is stirred again before use if more than 1 h has elapsed since it was originally stirred.

6.1.3 *Salts*—A solution containing a mixture of inorganic salts is prepared by dissolving  $0.3 \pm 0.03$  g of sodium chloride (NaCl, CAS: 7647-14-5),  $0.3 \pm 0.03$  g of sodium nitrate ( $\text{NaNO}_3$ , CAS: 7632-00-0) and  $0.4 \pm 0.03$  g of calcium sulfate dihydrate ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , CAS: 7778-18-9) into 1 L of distilled water. The solution is stirred to ensure that all salts are dissolved. The total salt concentration of the solution is  $1.0 \pm 0.1$  g/L.

6.1.4 *Particulate Organic Matter (POM)*— $1.4 \pm 0.05$  g of humic acid (CAS: 1415-93-6) is dissolved in 1 L of distilled water to produce a solution of  $1.4 \pm 0.05$  g/L.

6.1.5 *Composition of Soiling Mixture*—A separate solution or suspension is prepared for each soiling agent. Once prepared, the four soiling solutions/suspensions described above are combined in various ratios depending upon the climate to be simulated. Each soiling mixture below has the same total mass concentration of soiling agents.

6.1.5.1 *Composition of soiling mixture for average U.S. conditions (average of three exposure sites: Phoenix, Arizona; Miami, Florida; and Youngstown, Ohio)*—Soiling agent mass is 47 % dust, 20 % salts, 28 % POM, and 5 % soot. This yields 0.58 g/L dust, 0.25 g/L salts, 0.35 g/L POM, and 0.065 g/L soot in the soiling mixture. Note that this soiling mixture is prepared by combining equal volumes of the dust suspension, salt solution, POM solution, and soot suspension defined in 6.1.1 through 6.1.4.

<sup>5</sup> The sole source of supply of the material known to the committee at this time is Tokai Carbon Co., Ltd. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

6.1.5.2 Composition of soiling mixture for hot and dry climates (Phoenix, Arizona)—Soiling agent mass is 79 % dust, 20 % salts, 0 % POM, and 1 % soot. This yields 0.98 g/L dust, 0.25 g/L salts, 0 g/L POM, and 0.012 g/L soot in the soiling mixture.

6.1.5.3 Composition of soiling mixture for hot and humid climates (Miami, Florida)—Soiling agent mass is 16 % dust, 7 % salts, 69 % POM, and 8 % soot. This yields 0.20 g/L dust, 0.087 g/L salts, 0.85 g/L POM, and 0.10 g/L soot in the soiling mixture.

6.1.5.4 Composition of soiling mixture for moderate summer and cold winter climates (Youngstown, Ohio)—Soiling agent mass is 61 % dust, 31 % salts, 0 % POM, and 8 % soot. This yields 0.75 g/L dust, 0.38 g/L salts, 0 g/L POM, and 0.10 g/L soot in the soiling mixture.

6.2 *Soiling Apparatus*—The soiling mixture is placed in an air-pressurized spraying tank, equipped with an air pressure gauge. The tank is connected with tubing to a brass spraying nozzle that includes a strainer to minimize clogging. The nozzle (example: UniJet Fogger Nozzle Assembly, model 1/4TT+SF-2, Spraying Systems Co.) produces a wide-angle (approximately 100 to 110°), hollow-cone fine spray with a delivery rate of 3.5 litres per hour at 138 kPa [20 psi] gauge pressure. The nozzle is oriented vertically to spray downward.

6.3 *Weathering Apparatus*—A laboratory accelerated weathering device is used to simulate outdoor weathering. The weathering device exposes materials to alternating cycles of ultraviolet (UV) light and moisture at controlled, elevated temperatures. It uses fluorescent UVA-340 lamps to simulate the high energy photons in sunlight. Moisture is introduced with condensing humidity or water spray, or both (Practices G151 and G154).

## 7. Test Specimens

7.1 The standard practice described here applies to roofing specimens that are flat (planar).

## 8. Calibration of Soiling

8.1 Calibration of the soiling procedure consists of verifying the wet soiling mass retained by a reference roofing product specimen and the uniformity of soiling pattern on the specimen's surface. The reference specimen should have a light-colored, non-porous, non-fluorinated polymeric surface to facilitate inspection and validation of the soiling pattern, and to minimize variations in retention of wet soiling mass. Recommended reference specimens include white single-ply membranes and white field-applied elastomeric coatings.

8.2 The soiling mixture is agitated for 1 to 2 minutes to re-suspend any settled particles, then placed into the spraying vessel.

8.2.1 The soiling mixture shall be re-agitated hourly if the calibration process takes more than 1 hour. To re-agitate, remove the soiling mixture from the spraying vessel, then repeat 8.2.

8.3 A clean reference specimen (10 by 10 cm, and flat) is weighed before soiling (mass  $m_0$ ). The spraying system is then operated for about 10 to 15 seconds to attain a uniform and

stable spraying mist. Next, while the mist is spraying, the weighed reference specimen is introduced into the soiling chamber, placed 40 to 60 cm below the spraying nozzle, oriented horizontally, and sprayed for about 10 to 30 seconds (Fig. 1). The soiled reference specimen is removed from the soiling chamber, then reweighed (mass  $m_1$ ).

8.4 If the wet soiling mass ( $m_1 - m_0$ ) deposited on the reference specimen is less than 0.7 g (7 mg/cm<sup>2</sup>), the spraying time should be increased. If the wet soiling mass is greater than 0.9 g (9 mg/cm<sup>2</sup>), the spraying time should be decreased. Repeat 8.3 as needed, varying spraying time until the wet soiling mass is  $0.8 \pm 0.1$  g ( $8 \pm 1$  mg/cm<sup>2</sup>). Record the final spraying time as  $\tau$ .

8.4.1 Note that the deposition rate can be adjusted as needed by repositioning the reference coupon within the soiling chamber. Variations in the duration of spraying or the distance between the spraying nozzle and the specimen, or both, are allowed as long as the soiling pattern remains uniform and the wet mass deposition is  $0.8 \pm 0.1$  g ( $8 \pm 1$  mg/cm<sup>2</sup>).

8.5 After the spraying duration  $\tau$  and specimen position have been determined, the calibration experiment should be repeated at least two more times to verify that the wet soiling mass retained by the 10 by 10 cm reference specimen does not differ from 0.8 g by more than 0.1 g. After spraying and weighing, each specimen is heated with an infrared lamp to evaporate the water. To protect the specimen, its surface temperature should not be allowed to exceed 80°C during the drying process.

8.6 After drying, the surface of reference specimen should be covered with evenly separated and randomly distributed soil spots with diameters ranging between 1.5 and 3.0 mm. The uniformity of the soiling on the dried specimen shall be assessed visually. If the specimen is not uniformly soiled, the calibration process shall be repeated on fresh reference specimens until uniform soiling is attained.

## 9. Procedure

9.1 The specimen is prepared in three stages: (1) weathering-apparatus exposure before soiling, (2) soiling, and (3) weathering-apparatus exposure after soiling (Fig. 2).

9.2 *Weathering-apparatus Exposure Before Soiling*—To provide UV conditioning, the specimen shall undergo 24 h in the weathering apparatus (6.3) according to Practice G154, Cycle 1. Each cycle of weathering shall include 8 h of UV exposure (0.89 W/m<sup>2</sup>/nm). The specimen shall then be removed from the chamber to dry and cool to room temperature (15 to 25°C) before soiling.

9.3 *Soiling*—The conditioned specimen shall be sprayed with the soiling apparatus (6.2) using the spraying conditions (position and orientation of specimen; spray duration  $\tau$ ) established during the calibration process (Section 8). Before spraying, the soiling mixture shall be agitated as described in 8.2. After spraying, the specimen shall be removed from the chamber and dried for 2 to 10 minutes under an infrared heat lamp (250 W) with the specimen surface temperature not exceeding 80°C. The specimen is then cooled to room temperature.

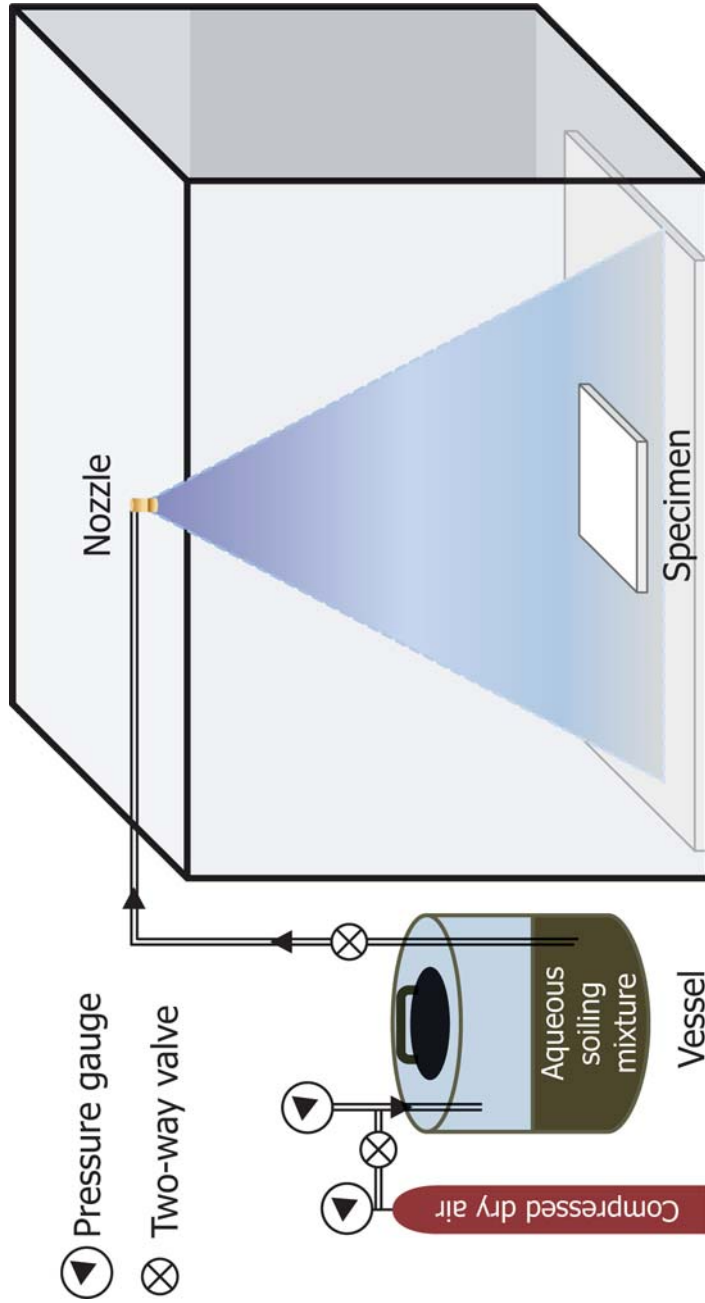


FIG. 1 Apparatus Used for Laboratory Soiling of Roofing Materials



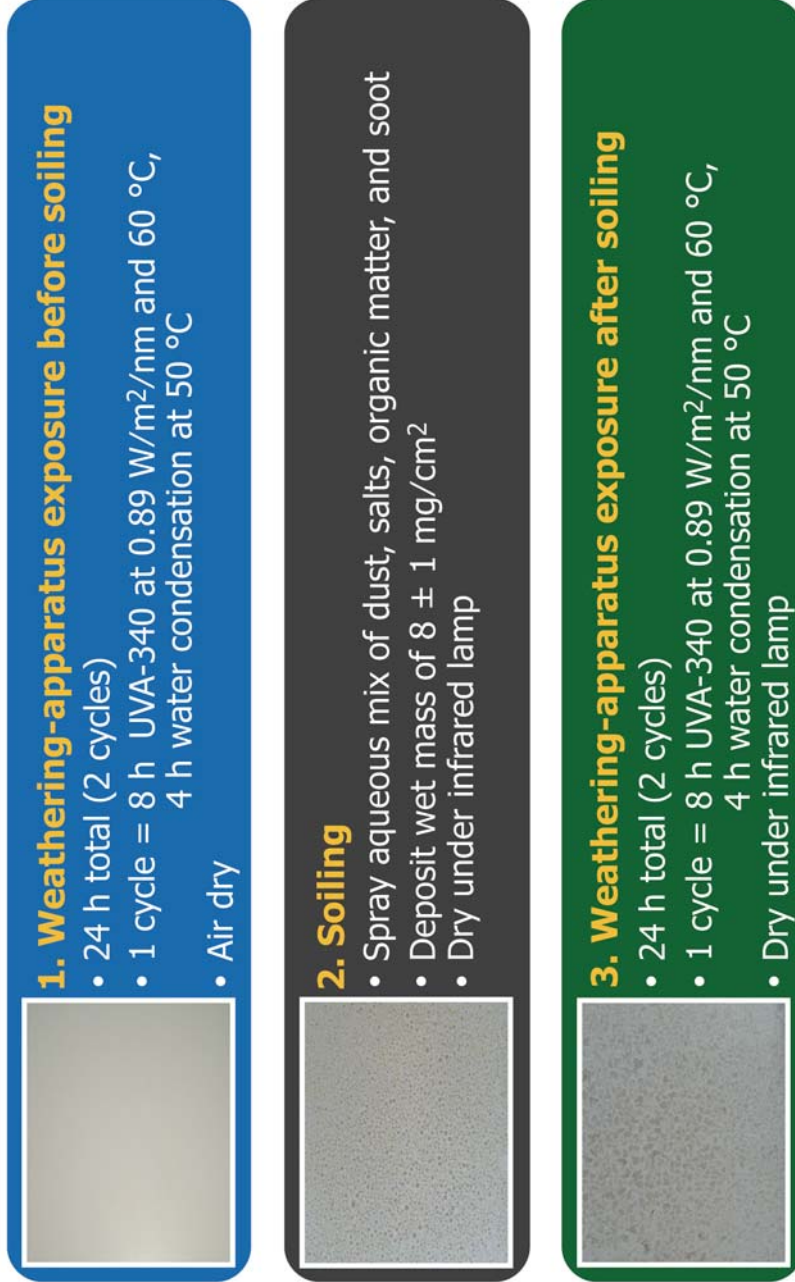


FIG. 2 Summary of the Simulated Field Exposure Method

9.4 *Weathering-apparatus Exposure After Soiling*—To simulate the cleaning effect of moisture, the soiled specimen shall undergo 24 h in the weathering apparatus according to Practice G154, Cycle 1 (same as in 9.2). After weathering-apparatus exposure, the specimen shall be removed from the chamber and dried for 2 to 10 minutes under an infrared heat lamp (250 W) with the specimen surface temperature not exceeding 80°C. The specimen is then cooled to room temperature. Once dry and at room temperature, the specimen is ready for measurement of its radiative properties.

9.5 *Number of Specimens*—Prepare the number of specimens required by the standard that specifies practices for specimen selection and methods for radiative measurement.

10. Report

10.1 The report shall include the following:

10.1.1 The place, date, and operator of the practice.

10.1.2 The description and composition of the soiling mixture.

10.1.3 Photographs of the specimen before and after simulated field exposure.

11. Validation, Precision, and Bias

11.1 *Precision*—The precision of the simulated field exposure described here was determined by conducting an inter-laboratory study according to Practice E691. Seven participant laboratories conducted the practice on a set of twelve roofing products.

11.1.1 *Metrics*—The method precision was evaluated by calculating the repeatability and reproducibility of the effect of the simulated field exposure on solar reflectance of roofing products. Repeatability concerns the variability between independent test results obtained within a single laboratory. The tests performed in each laboratory were conducted by a single operator. Reproducibility refers to the variability between single test results obtained in different laboratories. Two data consistency statistics were evaluated: between-laboratory statistic *h*, and within-laboratory statistic *k*.

11.1.2 *Results*—The inter-laboratory study (see Annex A1) demonstrated that the simulated field exposure practice is consistent with the 0.5 % significance level as defined by

Practice E691 and did not show any bias due to operators, devices, or laboratory equipment. The calculated range of method repeatability and reproducibility for solar reflectance determinations are:

11.1.3 *Repeatability*—2.8 to 7.9 % (mean 5.4 %);  $k \leq 1.6$ .

11.1.4 *Reproducibility*—9.1 to 19.6 % (mean 13.2 %);  $|h| \leq 1.4$ .

11.1.5 The *k* and  $|h|$  did not exceed their corresponding critical values of  $k_{critical} = 1.87$  and  $|h_{critical}| = 2.05$ .

12. Keywords

12.1 dust; laboratory; organic; roofing; salt; simulated field exposure; soiling; solar energy; solar reflectance; soot; thermal emittance; thermal radiation; weathering

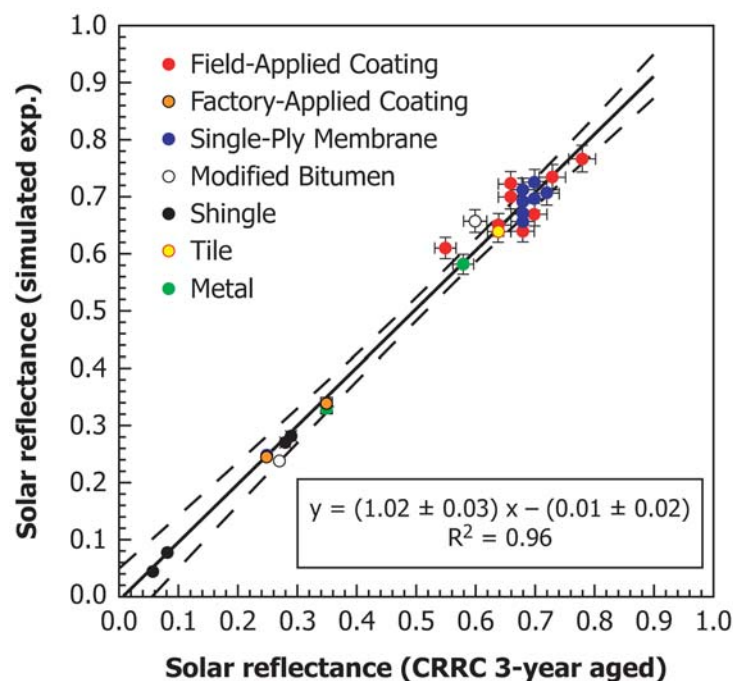


FIG. 3 Correlation of Solar Reflectances of Roofing Products After Simulated Field Exposure to Those After Three Years of Natural Exposure (CRR3 Three-Site Average)

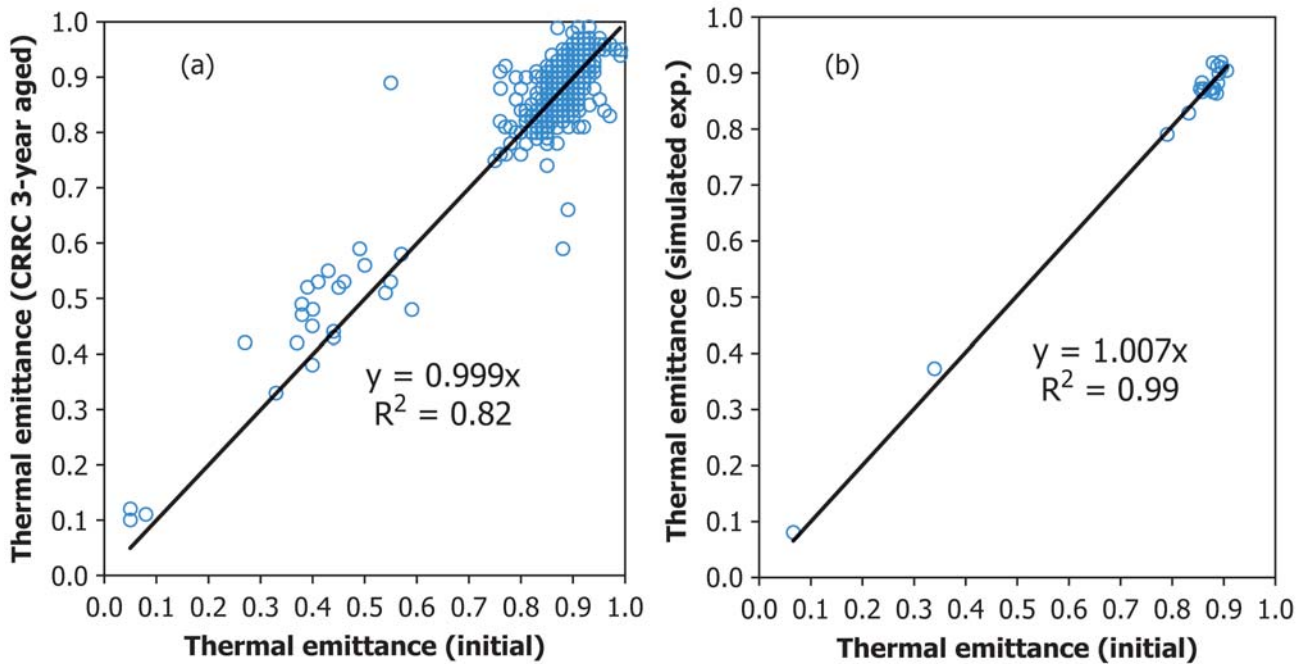


FIG. 4 Aged Versus Initial Thermal Emittances of (a) 4908 Products Rated by CRRC and (b) 25 Products Subjected to Simulated Field Exposure

ANNEX

(Mandatory Information)

A1. INTER-LABORATORY STUDY FOR DETERMINING THE PRECISION OF THE “STANDARD PRACTICE FOR LABORATORY SOILING AND WEATHERING OF ROOFING MATERIALS TO SIMULATE EFFECTS OF NATURAL EXPOSURE ON SOLAR REFLECTANCE AND THERMAL EMITTANCE”

A1.1 To determine the precision of the simulated field exposure described here, an inter-laboratory study was performed following Practice E691. Seven participant laboratories conducted the practice. An experimental protocol was sent to all participants along with four replicates (specimens) of twelve materials (roofing products). The twelve materials included all of the roofing products listed in 1.1 and had initial solar reflectances ranging from 0.26 to 0.91 (Table A1.1). The method precision was evaluated by calculating for each mate-

rial the repeatability, reproducibility, and data consistency of solar reflectance after simulated field exposure, according to Test Method C1549:

A1.1.1 *Repeatability*—Precision under repeatability conditions (within laboratory; same operator, equipments, lab).

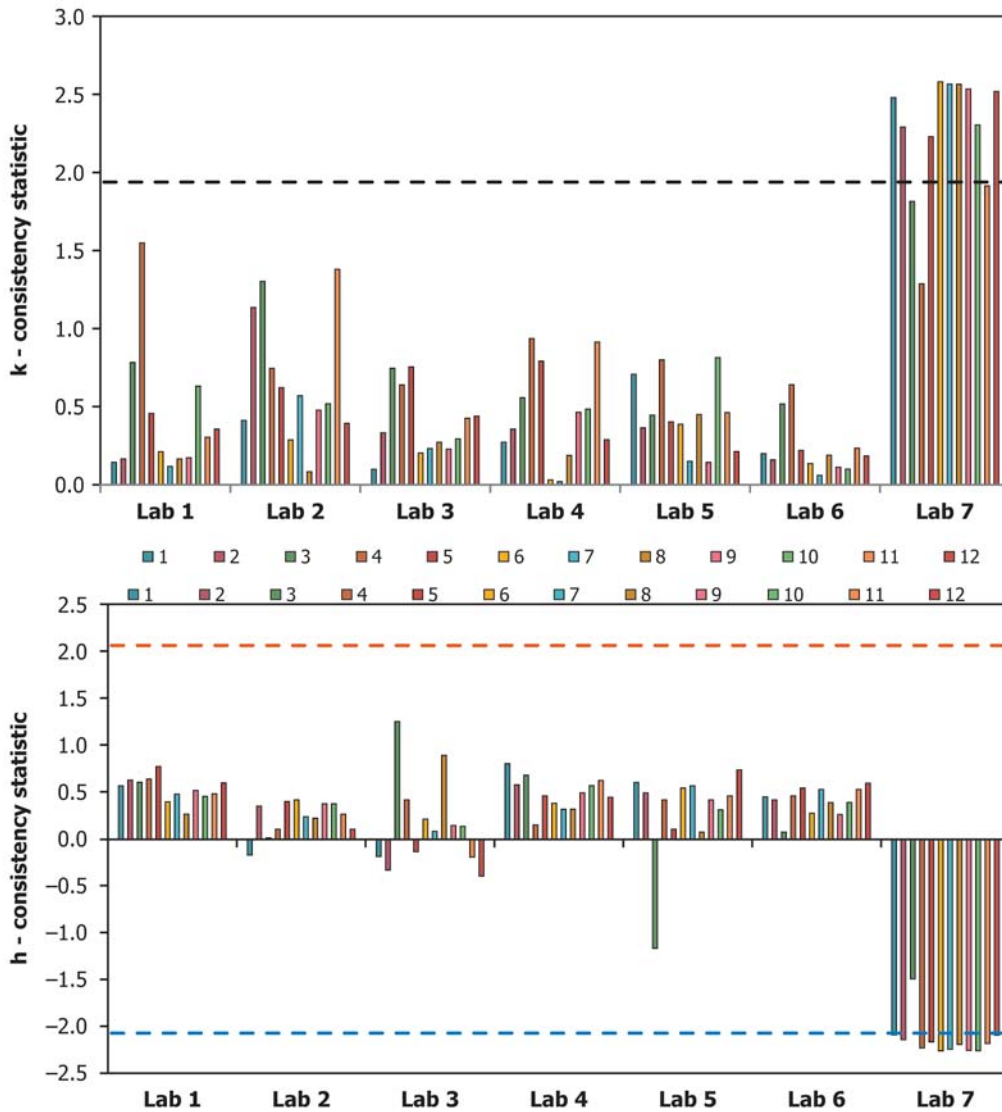
A1.1.2 *Reproducibility*—Precision under reproducibility conditions (between-laboratory: different labs, operators, equipments).

A1.1.3 *Data Consistency*—Between-laboratory consistency. Statistic *h* is an indicator of how one lab’s average compares with the average of the other labs. Within-laboratory consistency statistic *k* is an indicator of how one laboratory’s within-lab variability compares with the variability of all of the laboratories combined. For seven laboratories and four replicates, the critical values of *h* and *k* at the 0.5 % significance level are  $h_{critical} = \pm 2.05$  and  $k_{critical} = 1.87$ .

A1.2 Figs. A1.1 and A1.2 present the results based on the data produced at the seven participant laboratories. Laboratories 1 to 6 yielded *h* and *k* statistics for all twelve materials that were well below  $h_{critical}$  and  $k_{critical}$ ; only Laboratory 7 exceeded these critical values (Fig. A1.1). After investigation,

TABLE A1.1 Roofing Products Used in the Inter-laboratory Study

Product #	Category	Color
1	factory-applied coating	white
2	single-ply membrane	white
3	asphalt shingle	white
4	clay tile	red
5	modified bitumen	white
6	concrete tile	white
7	field-applied coating	white
8	metal	bare
9	field-applied coating	white
10	single-ply membrane	white
11	single-ply membrane	white
12	modified bitumen	white



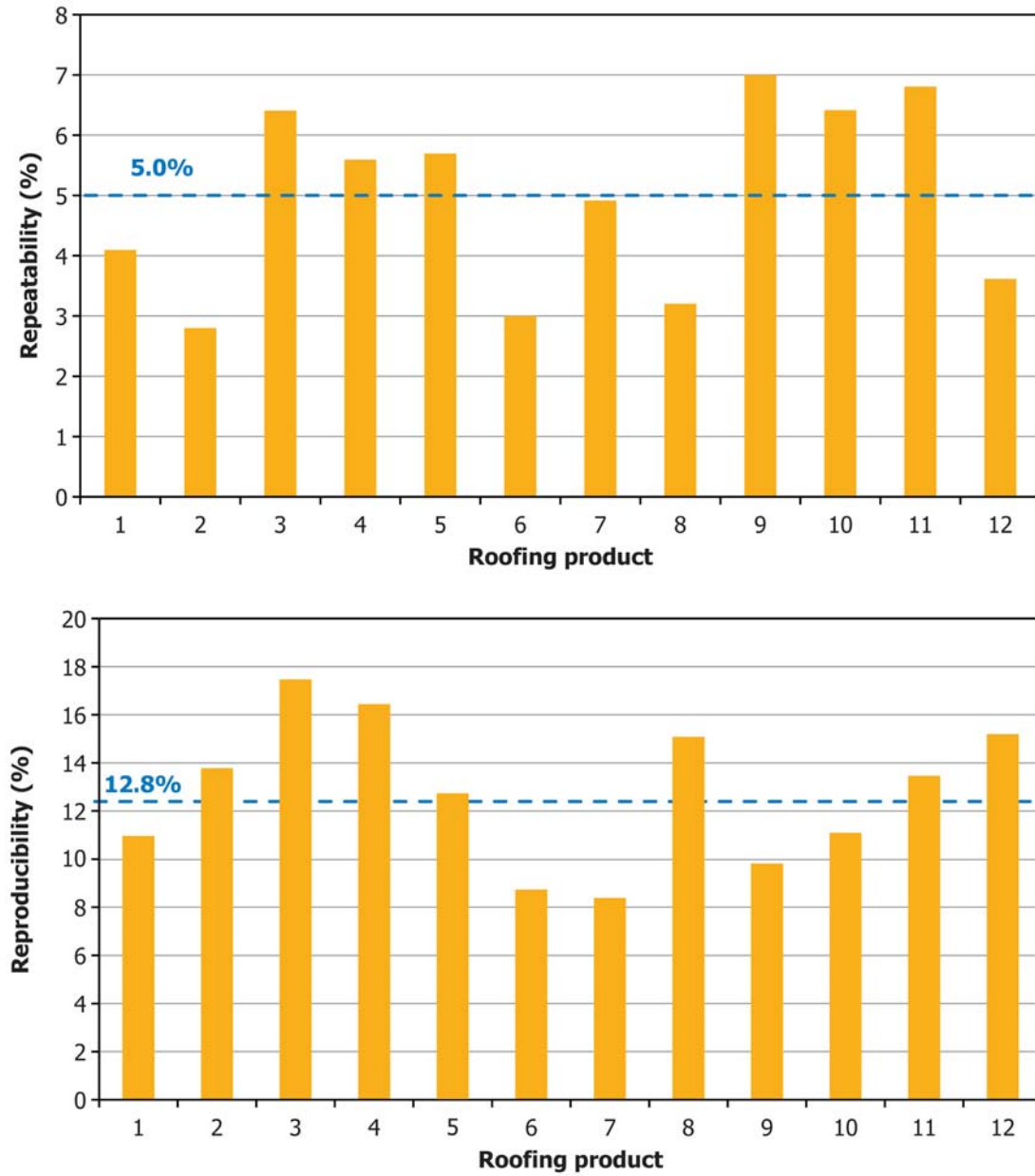
Laboratory 7 was excluded from the calculations of repeatability and reproducibility shown in Fig. A1.2 because it deviated from the experimental protocol.

**FIG. A1.1 Data Consistency Statistics Obtained During the Inter-laboratory Study with Seven Participant Laboratories for Twelve Roofing Products**

Laboratory 7 was excluded from the determination of repeatability and reproducibility because it did not follow the standard practice method. In particular, Laboratory 7 did not adhere to the method’s criteria of applying  $8 \pm 1 \text{ mg/cm}^2$  of wet soiling mass to all specimens. Excluding results from Laboratory 7, these values show that the simulated field

exposure did not exceed the critical values determined by the 0.5 % significance level as defined by Practice E691 and did not show any bias due to operators, devices, or laboratory environment. In addition, excluding results from Laboratory 7, all products had comparable repeatability and comparable reproducibility (Fig. A1.2).





A dashed horizontal line marks the average value of repeatability (5.0 %) in subfigure a, and the average value of reproducibility (12.8 %) in subfigure b.  
**FIG. A1.2 Distribution of the (a) Repeatability and (b) Reproducibility Metrics Obtained During the Inter-laboratory Study by Six Different Laboratories for Twelve Roofing Products**

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